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BALANCING OF CURRENTS AND VOTTAGES OF ELECTRIC NETWORKS NODES USING COMPENSATING PLANTS AT UNSYMMETRICAL POWER SOURCE

The paper consider the currents and voltage balancing in the network nodes; there has been suggested the balancing criterion in condition of cencymmetrical power supply and controlling law, answering it.

Keywords: *balancing, source unsymmetry.*

Essence of problem

Providing electric power quality on sufficient level is one of main tasks of Ukraine power industry. Among the indexes of quality an important place occupies the level of unsymmetry of electric networks voltages. Unsymmetry of voltages negatively influences users operation, as causes the reduction of reliability and economy of work (asynchronous motors, systems of illumination, condenser devices, automatic systems and other), results in the increase of power losses in the electro-transmission lines and transformers and reduction of their carrying capacity [1].

The criterion used for the loadings symmetry at the symmetric voltage source is

$$\underline{Y}_{21} = 0 \tag{1}$$

where $\underline{Y}_{12} = -\left(\underline{Y}_{BC} + a^2\underline{Y}_{CA} + a\underline{Y}_{AB}\right)$ is complex loading reverse sequence conductivity; $\underline{Y}_{BC}$, $\underline{Y}_{CA}$, $\underline{Y}_{AB}$ are complex loading phases conductivities; $a = e^{j120°}$ is operator of turn of the three-phase system. In this case the reverse sequence voltage and current in the loading node will be equal to zero ($U_2 = 0$, $I_2 = 0$).

At asymmetrical source of EMF in the case of application of criterion (1) the incomplete symmetry occurs and the permanent reverse sequence voltage and current in the node of load connection will be, accordingly

$$\dot{U}_2 = \frac{\dot{E}_2}{1 + \underline{Y}_{22}\underline{Z}}; \quad \dot{I}_2 = \dot{U}_2\underline{Y}_{22},$$

where $\dot{E}_2$ is reverse sequence source EMF; $\underline{Z}$ is complex electro-transmission line resistance; $\underline{Y}_{22} = k_{21}(\underline{Y}_{BC} + \underline{Y}_{CA} + \underline{Y}_{AB})$ is complex reverse sequence conductivity of loading; k_{21} is coefficient, that characterizes the relationship of reverse and direct sequence conductivities.

The voltage balancing criterion using of compensative balancing plants (BP) at asymmetrical power source is obtained in [2]

$$\underline{Y}_{21} = \frac{\dot{E}_2}{\dot{E}_1}\left(\underline{Y}_{11} + \frac{1}{\underline{Z}}\right),$$

where $\dot{E}_1$ is direct sequence EMF of source; $\underline{Y}_{11} = \underline{Y}_{BC} + \underline{Y}_{CA} + \underline{Y}_{AB}$ is complex direct sequence conductivity of loading.

The drawback of using this criterion is initiation of considerable additional active-power losses in the transmission line, which are predefined by the increase of reverse sequence current as a result of voltage balancing.

The purpose of this work is the analysis of possibility of application of balancing criteria for control of compensation balancing plants in case of asymmetrical power source.

Substantiation of results

Reduction of losses in transmission lines after voltage balancing using compensation BP is possible applying a criterion

$$\underline{Y}_{21} = k\frac{\dot{E}_2}{\dot{E}_1}\left(\underline{Y}_{11} + \frac{1}{\underline{Z}}\right) \quad (2)$$

where k actual factor the value of which is set depending on the available voltages nonsymmetry level before regulation and acceptable voltages nonsymmetry level after regulation. Coefficient k is determined according to condition

$$k = 1 - \frac{\dot{U}_{2\text{доп}}}{\dot{E}_2} \quad (3)$$

where $\dot{U}_{2\text{доп}}$ acceptable value of reverse sequence voltage in the electric network node.

After substitution (2) in expressions for reverse sequence voltage and current in the node of asymmetrical loading connection [3]

$$\dot{U}_2 = \frac{\dot{E}_2[1+\underline{Y}_{11}\underline{Z}] - \dot{E}_1\underline{Y}_{21}\underline{Z}}{[1+\underline{Y}_{22}\underline{Z}][1+\underline{Y}_{11}\underline{Z}] - \underline{Z}^2\underline{Y}_{21}\underline{Y}_{12}};$$

$$\dot{I}_2 = \frac{\dot{E}_1\underline{Y}_{21} + \dot{E}_2\underline{Y}_{22} + \dot{E}_2\underline{Z}(\underline{Y}_{22}\underline{Y}_{11} - \underline{Y}_{12}\underline{Y}_{21})}{[1+\underline{Y}_{22}\underline{Z}][1+\underline{Y}_{11}\underline{Z}] - \underline{Z}^2\underline{Y}_{21}\underline{Y}_{12}},$$

where $\underline{Y}_{21}$, $\underline{Y}_{12}$, $\underline{Y}_{22}$ conductivities of the asymmetrical loading, it is possible to get formulas for determination of reverse sequence voltage and current, that emerge as a result of symmetrization according to criterion (2), in the form:

$$\dot{U}_2 = \frac{\dot{E}_2(1-k)}{1+\underline{Y}_{22}\underline{Z} - \underline{Y}_{12}\underline{Z}}; \quad \dot{I}_2 = k\frac{\dot{E}_2}{\underline{Z}} + \dot{U}_2\underline{Y}_{22}.$$

The reverse sequence current causes the additional power losses in transmission lines, which are caused by load nonsymmetry.

During regulation it is necessary to set coefficient k for the selection of which the algorithm taking into account (3) is offered to apply:

$$k = \begin{cases} 0 \quad at\ k_{2E} < 2\%; \\ 1 - \dfrac{U_{2\text{доп}}}{E_2}\ at\ k_{2E} \geq 2\%, \end{cases}$$

where k_{2E} is reverse sequence voltage coefficient of supply source. At the reverse sequence voltage coefficient of supply source $k_{2E} \leq 4\%$ and necessity to provide admissible value of reverse sequence voltage in the load node (2% of direct sequence voltage), coefficient k is necessary to accept equal 0,5.

The compensation BP control law, that corresponds to criterion (1), has the form [1]

$$b_{BC} = \frac{1}{3}[b_{11} - b_{вх} - 2b_{21}];$$

$$b_{CA} = \frac{1}{3}\left[b_{11} - b_{вх} + b_{21} + \sqrt{3}g_{21}\right]; \quad (4)$$

$$b_{AB} = \frac{1}{3}\left[b_{11} - b_{вх} + b_{21} - \sqrt{3}g_{21}\right].$$

The compensation BP control law, that corresponds to criterion (2), has the form [4]

$$b_{BC} = \frac{1}{3}\left[(b_{11} - b_{вх})(1 - 2k \cdot k'_{2E}) - 2b_{21} + \right.$$

$$\left. + 2k \cdot k'_{2E}(b_{11} + b_{л}) + 2k \cdot k''_{2E}(g_{11} + g_{л})\right];$$

$$b_{CA} = \frac{1}{3}\left[(b_{11} - b_{вх})\left(1 + k \cdot k'_{2E} - \sqrt{3}k \cdot k''_{2E}\right) + b_{21} + \sqrt{3}g_{21} - \right. \qquad (5)$$

$$\left. - k\left(k'_{2E} - \sqrt{3}k''_{2E}\right)(b_{11} + b_{л}) - k\left(k''_{2E} + \sqrt{3}k'_{2E}\right)(g_{11} + g_{л})\right];$$

$$b_{AB} = \frac{1}{3}\left[(b_{11} - b_{вх})\left(1 + k \cdot k'_{2E} + \sqrt{3}k \cdot k''_{2E}\right) + b_{21} - \sqrt{3}g_{21} - \right.$$

$$\left. - k\left(k'_{2E} + \sqrt{3}k''_{2E}\right)(b_{11} + b_{л}) - k\left(k''_{2E} - \sqrt{3}k'_{2E}\right)(g_{11} + g_{л})\right],$$

where $k'_{2E} = \mathrm{Re}\left(\frac{\dot{E}_2}{\dot{E}_1}\right)$, $k''_{2E} = \mathrm{Im}\left(\frac{\dot{E}_2}{\dot{E}_1}\right)$ actual and imaginary constituents of reverse sequence voltage coefficient correspondingly; $g_{л} = \mathrm{Re}\left(\underline{Z}^{-1}\right)$, $b_{л} = \mathrm{Im}\left(\underline{Z}^{-1}\right)$ is an actual and imaginary constituents of transmission line complete conductivity correspondingly.

The results of load balancing modeling using laws (4) and (5), where as information parameters instead of $\underline{Y}_{11}$, $\underline{Y}_{21}$ actual and imaginary components of conductivities $\underline{Y}_1 = \frac{\dot{I}_1}{\dot{U}_1}$ and $\underline{Y}_2 = \frac{\dot{I}_2}{\dot{U}_1}$ are used, accordingly g_1, b_1 and g_2, b_2 are shown in the Fig. 1, that simplifies measuring process and does not result in substantial increase of balancing errors.

The modeling was conducted at asymmetrical phase loading: $S_{AB} = 100$ кVA, $S_{BC} = 1100$ кVA, $S_{CA} = 1100$ кVA; load power-factor cosφ=0,8; supply network voltage is 10 кV; the transmission line has the length of 1 km and is characterized by complex resistance $\underline{Z} = 0.428 + j0.354$ Ohm.

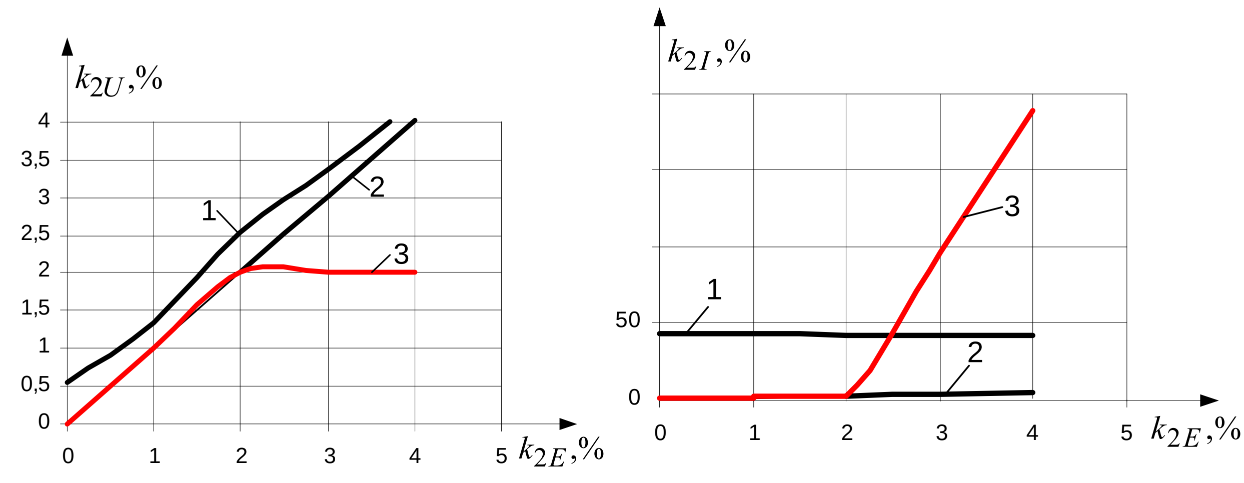

Fig. 1. Dependences of reverse sequence voltage and current coefficient on the voltage source reverse sequence coefficient

Dependences represented in Fig. 2 characterize such modes: 1 is uncontrollable mode; 2 is balancing mode using law (4); 3 balancing mode using law (5).

The character of dependences 1 and 2 (Fig. 1a) enables to assert that the absence of regulation and use of control law (4) results in impermissible reverse sequence voltage coefficient values. The dependence 3 (Fig. 1b) shows, that when using the control law (5) the transmission line active-power losses increase sharply at increase source voltage nonsymmetry.

Let us the dependence of cost of additional electric energy losses in transmission lines (Fig. 2), which are determined by currents nonsymmetry. The case, when the currents nonsymmetry is observed during three thousand hours a year, that corresponds to double-shift work of the enterprise, and electric energy cost amounts to 0,3 grn./kW·hour is considered (dependences of cost of annual losses are constructed for presented for the example given above).

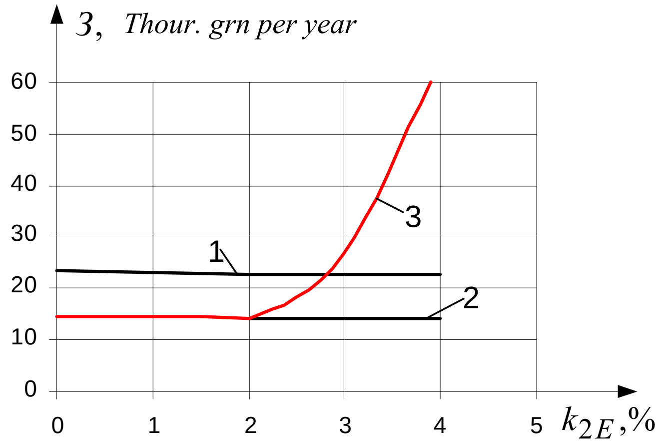

Fig. 2. Dependences of cost of transmission line active energy annual losses on the source reverse sequence voltage coefficient

As it is shown in Fig. 2, in case of asymmetrical source, the coefficient of reverse sequence voltage of which does not exceed admissible value, for the load balancing it is expedient to use control law (4), as it has more simple realization as compared with the law (5). In case of nonsymmetrical source voltage, that exceeds 2%, when the use of only balancing law (5) is possible, the cost of active power losses grows and considerably exceeds the cost of losses at the uncontrollable mode and at the balancing mode using law (4). However the last modes at voltage nonsymmetry, that exceeds State Standard 13109-97 norm (2%), result in considerable damage due to reduction of reliability of electro-receivers, in particular electric drives, which can substantially exceed damage from the power losses. That is why in such case the use of control low (5) can be economically more efficient/

Conclusions

In case of asymmetrical source, the value of reverse sequence voltage coefficient of which exceeds the norm (2%) of State Standard 13109-97 it is, more efficient to use a criterion that takes into consideration power supply voltage nonsymmetry. Its usage allows to provide essential decrease of load nonsymmetry in case of nonsymmetrical power supply.

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