Vol. V No 2 September 1999

SUPPLY NETWORK CURRENT SYMMETRIZATION—A GRAPHICAL APPROACH

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Summary: **The three methods of selecting elements for symmetrising network currents and at the same time compensating the reactive power are presented. To select the symmetrising elements, it is necessary to measure the phase voltages U_{fi} (i = 1, 2, 3) of the network, line currents I_i, phase active power P_i and reactive power Q_i of the network.**

1. INTRODUCTION

High power loads such as arc furnaces in steel-making often absorb asymmetrical currents from the network. Too large asymmetry of the currents is unfavorable. In such cases, the necessity of equalizing the currents where the industrial plant absorbs its power could arise.

Unequal currents can be symmetrised by connecting to the network the branch with the relevant electrical elements.

A load generating asymmetrical currents in a network can be replaced with two equivalent loads: a symmetrical three-phase and single-phase loads which can be symmetrised by means of reactors and capacitors to equalize the currents within the supply network.

Also, it can be assumed that the current asymmetry of the supply network is a result of three, delta-connected, single-phase loads of different impedances. After the symmetrisation each of them, by means of reactors and capacitors, the current equalization of the supply network will be completed.

The network current can also be symmetrised by connecting to the network three delta-connected capacitors of different capacitances.

The above-mentioned methods of current network symmetrisation resulting in the simultaneous equalization of active and reactive phase powers of the network are analysed below. The problem of current symmetrisation is strictly connected with the problem of compensation of the network reactive power, so both these problems will be discussed together. The following assumption have been made:

- there is no neutral wire in the three-phase network;
- the network load is of a resistive-inductive character;
- the phase-to-phase voltages $\underline{U}_{pi}$ and phase voltages $\underline{U}_{fi}$ of the network are symmetrical;
- the angles j$_i$ between the respective network currents $\underline{I}_i$ and phase voltages $\underline{U}_{fi}$ (i = 1, 2, 3) are known. The angles j$_i$ can be calculated using the measured voltages U_{fi}, currents I_i and phase powers P_{fi} of the network.

2. DETERMINATION OF THE SINGLE-PHASE CURRENT EQUALIZING THE NETWORK CURRENTS

A method of symmetrising the unequal network currents: $I_1 \neq I_2 \neq I_3$ by means of the single-phase system of adequate elements which generates the required symmetrising current, is presented in Fig. 1. Symmetric currents of the supply network: $\underline{I}_1$, $\underline{I}_{21} = a^2\underline{I}_1$, $\underline{I}_{31} = a\,\underline{I}_1$ ($a = -0.5 + j\sqrt{3}/2$) occur when a system generating the current $\underline{I}_{d2}$ and satisfying the equation $\underline{I}_2 + \underline{I}_{d2} = \underline{I}_{21}$ is connected to the voltage $\underline{U}_{p2}$.

The current $\underline{I}_{d2}$ increasing the current $\underline{I}_3$ to the value of $\underline{I}_{31}$ will occur in the third phase.

This results from the equation: $\underline{I}_1 + \underline{I}_2 + \underline{I}_{d2} + \underline{I}_3 - \underline{I}_{d2} = 0$ and $\underline{I}_1 + \underline{I}_2 + \underline{I}_3 = 0$. The current $\underline{I}_{d2}$ which symmetrizes the network currents, is delayed by a small angle relative to the voltage $\underline{U}_{p2}$. To generate such a current, it is necessary to connect to the voltage $\underline{U}_{p2}$ the branch with the resistance R_{d2} and a relatively small reactance X_{d2}. An additional power loss: $R_{d2}\, I^2_{d2}$ will occur in this branch.

Another symmetry of network currents $\underline{I}_2$, $\underline{I}_{32} = a^2\,\underline{I}_2$, $\underline{I}_{12} = a\,\underline{I}_2$ will occur after connecting to the voltage $\underline{U}_{p3}$ the branch where the current $\underline{I}_{d3}$ satisfying the equation $\underline{I}_3 + \underline{I}_{d3} = \underline{I}_{32}$ will occur. The current $\underline{I}_{d3}$ is delayed by an angle greater than 120° relative to the voltage $\underline{U}_{p1}$. Such a current will occur in the branch with the negative resistance, i.e. a power source, and the inductive reactance.

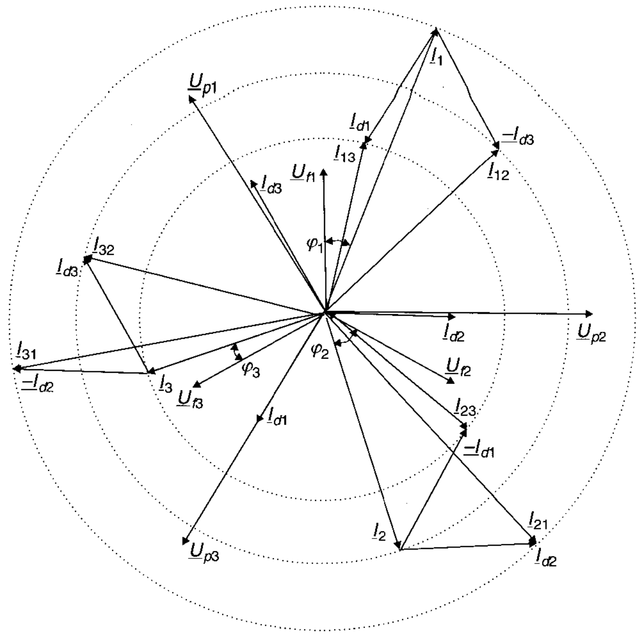

Fig. 1. Graphical determination of the symmetrising currents $\underline{I}_{di}$

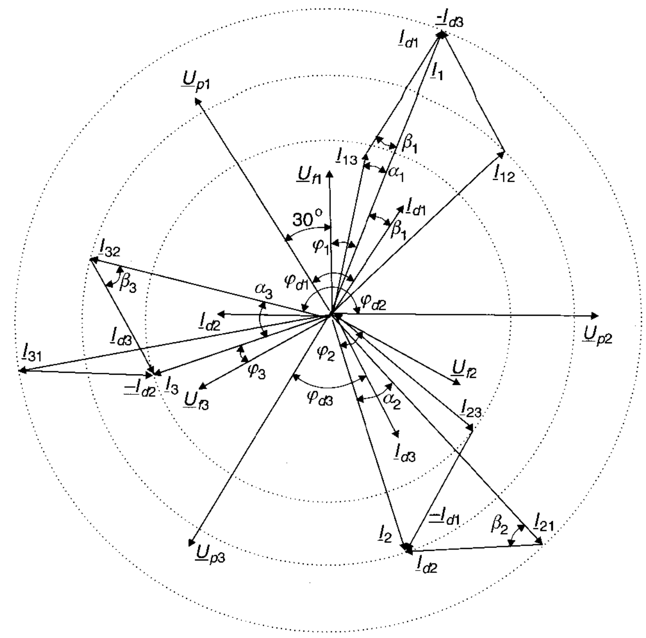

Fig. 2. Vector diagram of the currents and voltages described by equations (1)

Another symmetry of the network currents $\underline{I}_3$, $\underline{I}_{13} = a^2\underline{I}_3$, $\underline{I}_{23} = a\underline{I}_3$ can be obtained by means of the branch connected to the voltage $\underline{U}_{p1}$ where the current $\underline{I}_{d1} = \underline{I}_{13} - \underline{I}_1$ with the phase angle of almost 120° ahead of the phase voltage $\underline{U}_{p1}$ will flow. The branch should therefore include an adequate power source and capacitors.

The three different systems presented of current symmetrisation that can be made of branches with the adequate symmetrising elements are unsuitable for industrial use for economic and technical reasons (due to greater power loss or sometimes the power source required).

3. THE SINGLE-PHASE LOAD SYMMETRISATION SYSTEM

The loads charging the network with asymmetrical currents can be replaced by an equivalent system consisting of a symmetrical three-phase load and the branch with adequate elements. This is explained in Fig. 2 which differs from Fig. 1 in the opposite senses of currents $\underline{I}_{di}$.

According to the following equations, the system of asymmetrical network currents $I_1 \neq I_2 \neq I_3$ can be replaced by one of the three different symmetrical currents and a single-phase current:

$$\begin{aligned}\left[\underline{I}_1\ \underline{I}_2\ \underline{I}_3\right] &= \left[a^2\underline{I}_3+\underline{I}_{d1}\quad a\underline{I}_3-\underline{I}_{d1}\quad \underline{I}_3\right]\\ &= \left[a\underline{I}_2-\underline{I}_{d3}\quad \underline{I}_2\quad a^2\underline{I}_2+\underline{I}_{d3}\right]\\ &= \left[\underline{I}_1\quad a^2\underline{I}_1+\underline{I}_{d2}\quad a\underline{I}_1-\underline{I}_{d2}\right]\end{aligned} \tag{1}$$

It can be assumed for the first of the above-mentioned equations, that two loads: namely three-phase and single-phase are connected to the network. The three-phase load absorbs equal currents from the network: $I_{13} = I_{23} = I_3$. The active and reactive powers of this load are:

$$P_3 = 3U_f I_3 \cos\varphi_3; \qquad Q_3 = 3U_f I_3 \sin\varphi_3 \tag{2}$$

The single-phase load connected to the voltage $\underline{U}_{p1}$ absorbs the current $\underline{I}_{d1}$ which can be determined by the equation:

$$I_{d1} = \sqrt{I_1^2 + I_{13}^2 - 2I_1 I_{13}\cos\alpha_1}; \quad \alpha_1 = \varphi_1 - \varphi_3 \tag{3}$$

Compared to the voltage $\underline{U}_{p1}$, this current is delayed by the angle $\varphi_{d1} = 30° + \varphi_1 + \beta_1 < 90°$, where:

$$\sin\beta_1 = \frac{I_{13}}{I_{d1}}\sin\alpha_1 \tag{4}$$

The single-phase load representing asymmetry is a series connection of the resistance R_{d1} and inductive reactance X_{Ld1} equal to:

$$R_{d1} = \frac{U_p}{I_{d1}}\cos\varphi_{d1}; \qquad X_{Ld1} = \frac{U_p}{I_{d1}}\sin\varphi_{d1} \tag{5}$$

In the relevant professional literature, e.g. [2], symmetrisation systems for a single-phase load are described. A resistive-inductive load meeting the condition:

$$\mathrm{tg}\,\varphi_{d1} = \frac{X_{Ld1}}{R_{d1}} < \frac{1}{\sqrt{3}} \tag{6}$$

constitutes a symmetrical system with a capacitor and reactor of reactances:

$$X_{C2} = \frac{R_{d1}^2 + X_{Ld1}^2}{\frac{R_{d1}}{\sqrt{3}} - X_{Ld1}}; \qquad X_{L3} = \frac{R_{d1}^2 + X_{Ld1}^2}{\frac{R_{d1}}{\sqrt{3}} - X_{Ld1}} \tag{7}$$

connected to the voltages U_{p1} and U_{p2}, respectively (Fig. 3). Replacing the phases of the networks connected to either capacitors or a reactor results in the desymmetrisation of the system.

For a load for which the equation $X_{Ld1} = R_{d1} / \sqrt{3}$ holds, a symmetrising element is a reactor only of the reactance $X'_{L3} = 2X_{Ld1}$ ($X_{C2} \to \infty$). If the inequality $\mathrm{tg}\,\varphi_{d1} = X_{d1} / R_{d1} > 1/\sqrt{3}$ holds, then instead of the capacitor C_2 in the system as in Fig. 3, a second reactor of the reactance:

$$X'_{L2} = \frac{R_{d1}^2 + X_{d1}^2}{X_{d1} - \frac{R_{d1}}{\sqrt{3}}} \tag{8}$$

should be used to obtain the symmetry of the line currents.

Symmetrisation of single-phase load currents can be also achieved in such a way that the whole reactive power ($Q_{d1} = X_{Ld1} I_{d1}^2$) of the load is first compensated for by a capacitor (connected parallel to the load) of reactance:

$$X_{CK} = \frac{R_{d1}^2 + X_{Ld1}^2}{X_{Ld1}} \tag{9}$$

and then, according to Fig. 3, a symmetrising capacitor and reactor of the equivalent reactances:

$$X'_{C2} = X'_{L3} = \sqrt{3} R_{Z1} \tag{10}$$

are connected to the load with a capacitor of the equivalent resistance:

$$R_{Z1} = \frac{R_{d1}}{1 - \frac{X_{Ld1}}{X_{CK}}} \tag{11}$$

The symmetric system of a single-phase load with capacitors and reactor absorbs only the active power $P_{d1} = R_{d1} I_{d1}^2$ and loads the network with symmetrical currents $I_{ui} = P_{d1} / (3U_f)$ being in phase with the phase voltages $\underline{U}_{fi} (i = 1, 2, 3)$.

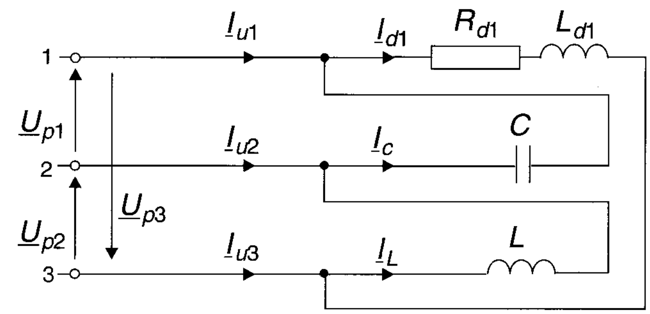

Fig. 3. The symmetrisation system of a single-phase load: $R_{d1} + jX_{d1}$

The network is loaded with the total active power $P_s = P_3 + P_{d1}$ and reactive power Q_3 (eq. 2). If tg $\varphi_s = Q_3/Ps$ is too large, then the reactive power Q_3 may be decreased by such a quantity Q'_3 so that tg $\varphi'_s = (Q_3 - Q'_3/Ps$ would not exceed the level at which the fee for the reactive power is charged. The reactive power will decrease by Q'_3 when identical capacitors of reactance $X'_{CK} = 3U_p^2 / Q'_3$ are connected to each network phase-to-phase voltage. As a consequence of the current symmetrisation and the compensation of the reactive power, two capacitive reactances X_{CK} (eq. 9) and X'_{CK} that correspond with the two capacitances C_K and C'_K are connected to the voltage U_{p1}, so the equivalent capacity of the two group of capacitors is $C_{Z1} = C_K + C'_K$. Two capacitors with a capacity of $C_{Z2} = C'_2 + C'_K$ are connected to the voltage U_{p2} where C'_2 results from the symmetrisation reactance X'_{C2}.

The inductive reactance X'_{L3} (11) and capacitive reactance X'_{CK} are connected to the voltage U_{p3}. Instead of these reactances, the equivalent reactance X_{Z3} determined from the relationship $(X_{Z3})^{-1} = (X'_{CK})^{-1} - (X'_{L3})^{-1}$ should be connected. If $(1/X_{Z3}) > 0$ then the capacitors of capacity $C_{Z3} = 1/(\omega X_{Z3})$ are the equivalent reactance; if $(1/X_{Z3}) < 0$ then X_{Z3} is the reactor reactance.

The second equality (1) means that the given unequal network current I_i will occur when we connect to the network both: a three-phase symmetric load with the currents $I_{12} = I_2 = I_{32}$, the powers $P_2 = 3U_f I_2 \cos\varphi_2$ and $Q_2 = 3U_f I_2 \sin\varphi_2$, and an additional single-phase symmetric load connected to the voltage $\underline{U}_{p3}$ absorbing the current $\underline{I}_{d3}$ shifted ahead of the voltage by the angle of $\varphi_{d3} = 150^\circ - \alpha_3 - \beta_3 - \varphi_3 < 90^\circ$. The load is of resistive-capacitive character.

The current I_{d3}, angles a$_3$ and b$_3$ (Fig.2), the resistance R_{d3} and the capacitive reactance X_{Cd3} of the single-phase load can be calculated using relationships similar to (3-5). The active power of the load is $P_{d3} = R_{d3} I_{d3}^2$ and the capacitive reactive power $Q_{Cd3} = X_{Cd3} I_{d3}^2$. If $X_{Cd3} < R_{d3} / \sqrt{3}$ then the capacitor and reactor of reactances:

$$X_{C1} = \frac{R_{d3}^2 + X_{Cd3}^2}{\frac{R_{d3}}{\sqrt{3}} + X_{Cd3}}; \qquad X_{L2} = \frac{R_{d3}^2 + X_{Cd3}^2}{\frac{R_{d3}}{\sqrt{3}} - X_{Cd3}} \tag{12}$$

are the symmetrising elements, where the capacitor should be connected to the voltage U_{p1} and the reactor to the voltage U_{p2}, as in Fig. 3. If $X_{Cd3} = R_{d3} / \sqrt{3}$ then the only sym-

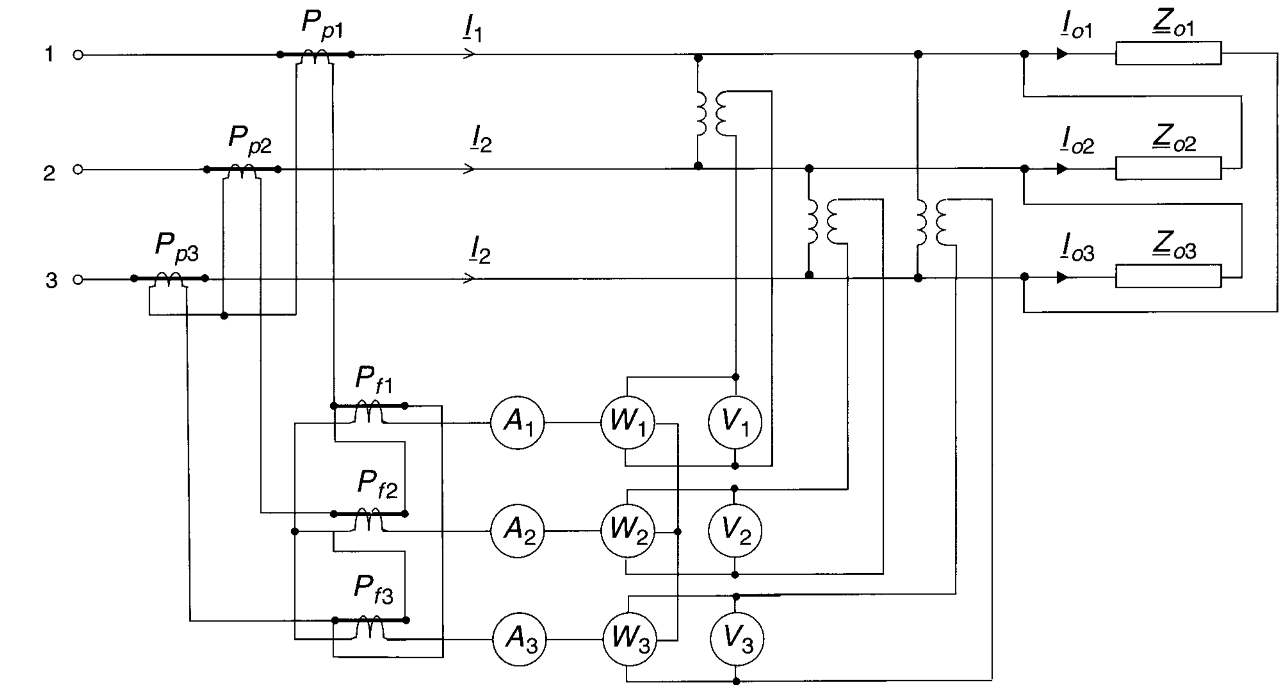

Fig. 4. System for measuring voltages, currents and phase powers of the delta-connected load Z_{0i}.

metrising elements are the capacitors of reactance $X_{C1} = 2X_{Cd3}$ ($X_L \to \infty$), and when the inequality $X_{Cd3} > R_{d3} / \sqrt{3}$ holds then, instead of the reactor L_2, a capacitor of reactance $X_{C2} = -X_{L2}$ should be connected.

After the compensation of the single-phase load reactive power Q_{Cd3} by a parallel connection to the load of a reactor of reactance:

$$X_{LK} = \frac{R_{d3}^2 + X_{Cd3}^2}{X_{Cd3}} = \frac{U_p^2}{Q_{Cd3}} \qquad (13)$$

then the required reactances of the symmetrising elements are:

$$X'_{C1} = X'_{L2} = \sqrt{3}\frac{R_{d3}}{1 - \dfrac{X_{Cd3}}{X_{LK}}} = \sqrt{3}\frac{U_p^2}{P_{d3}} \qquad (14)$$

In such a case the total active power of the three-phase and single-phase load is: $P_S = P_2 + P_{d3}$ and the reactive power is Q_2. If we want to decrease the power Q_2 by a value Q'_2, then the identical capacitors Q'_K of reactances $X'_{CK} = 3U_p^2 / Q'_2$ should be connected to each voltage U_{pi} within the supply network.

The capacitive reactances X'_{C1} and X'_{CK} of the aquivalent capacitance $C_{Z1} = C'_1 + C'_K$ are connected to the voltage U_{p1}. The reactances: inductive X'_{L2} and capacitive X'_{CK} are connected to the voltage U_{p2}. The equivalent reactance X_{Z2} is calculated from the relationship $(X_{Z2})^{-1} = (X'_{CK})^{-1} - (X'_{L2})^{-1}$. A similar relationship is used to calculate the equivalent reactance X_{Z3} of the two reactances X_{LK} (eq. 13) and X'_{CK} connected to the voltage U_{p3}. The equivalent reactances X_{Z2} and X_{Z3} can be the reactances of the reactor or capacitors like the equivalent reactance X_{Z3} in the previous example.

If the reactive powers absorbed from the network are equal in both the analysed examples of symmetrisation concerning the first and the second equation in (1), then the equivalent reactances X_{Z1}, X_{Z2}, X_{Z3} calculated in the first example should be equal to the respective reactances calculated in the second example.

For the third equation in (1) it can be assumed that the three-phase load absorbs the symmetrical currents $I_1 = I_{21} = I_{31}$ (Fig. 2) from the network and the current I_{d2} in the single-phase element connected to the voltage U_{p2} is shifted by the angle $\varphi_{d2} \approx 180^o$ versus U_{p2}. This element is of a negative resistance, i.e. it is a power source. Such an element cannot be symmetrised with the capacitors and reactor.

3. SYMMETRISATION OF THREE SINGLE-PHASE LOADS

It can be assumed that the asymmetrical currents of a supply network are caused by connecting three delta-connected resistive-inductive loads of different impedances: $Z_{0i} = R_{0i} + jX_{0i}$ to the network. These impedances can be determined by means of a system illustrated in Fig. 4.

The primary windings of current transformers P_{fi} are delta-connected and fed from current transformers P_{pi} measuring the network currents. Secondary currents i_{0i} of current transformers P_{fi} are therefore proportional to the currents $I_{0i} = \vartheta_p \vartheta_f i_{0i}$ of the loads, where ϑ_p, ϑ_f are the transformation ratios of the transformers P_{pi} and P_{fi}. The measurement of the voltage U_p, currents I_{0i} and power P_{0i} enables the current transformers to determine their resistances R_{0i} and reactances X_{0i}. The reactive power $Q_0 = X_{0i} I_{0i}^2$ of each load can be compensated for by the capacitors connected in parallel to the loads with reactances:

$$X_{CKi} = \frac{U_p^2}{Q_{0i}} = \frac{R_{0i}^2 + X_{0i}^2}{X_{0i}} \tag{15}$$

where the equivalent resistance R_{Zi} of a load with the capacitor is:

$$R_{Zi} = \frac{R_{0i}}{1 - \dfrac{X_{0i}}{X_{CKi}}} \tag{16}$$

The resistances R_{Zi} together with the capacitive resistances X_{CSi} and inductive X_{LSi} which satisfy the equations:

$$X_{CS2} = X_{LS3} = \sqrt{3} R_{Z1}; \; X_{CS3} = X_{LS1} = \sqrt{3} R_{Z2}; \\ X_{CS1} = X_{LS2} = \sqrt{3} R_{Z3} \tag{17}$$

and are connected to the respective voltages U_i of the network, constitute symmetrical systems. The subscripts of the reactances detail which line voltages they are to be connected to. Thus the reactances $X_{CK1}, X_{CS1}, X_{LS1}$ are connected to the voltage U_{p1} and their equivalent value X_{Z1} can be described by the expression: $\dfrac{1}{X_{Z12}} = \dfrac{1}{X_{CK1}} + \dfrac{1}{X_{CS1}} - \dfrac{1}{X_{LS1}}$. Taking into account the equality of $X_{LS1} = X_{CS3}$, this expression can be written as:

$$\frac{1}{X_{Z1}} = \omega C_{Z1} = \omega (C_{K1} + C_{S1} - C_{S3}) \tag{18a}$$

The equivalent reactances X_{Z2} and X_{Z3} are connected to the voltages U_{p2} and U_{p3} where the inversions of the reactances are:

$$\frac{1}{X_{Z2}} = \omega C_{Z2} = \omega (C_{K2} + C_{S2} - C_{S1}) \tag{18b}$$

$$\frac{1}{X_{Z3}} = \omega C_{Z3} = \omega (C_{K3} + C_{S3} - C_{S2}) \tag{18c}$$

Connecting the capacitors of capacitance C_{Z1}, C_{Z2}, C_{Z3} into the network results in symmetrical currents being in phase with the respective phase voltages U_{f1}.

The network power factor can be reduced (to $\cos \varphi_s < 1$) by disconnecting a part of the capacitors with identical capacitances from each voltage.

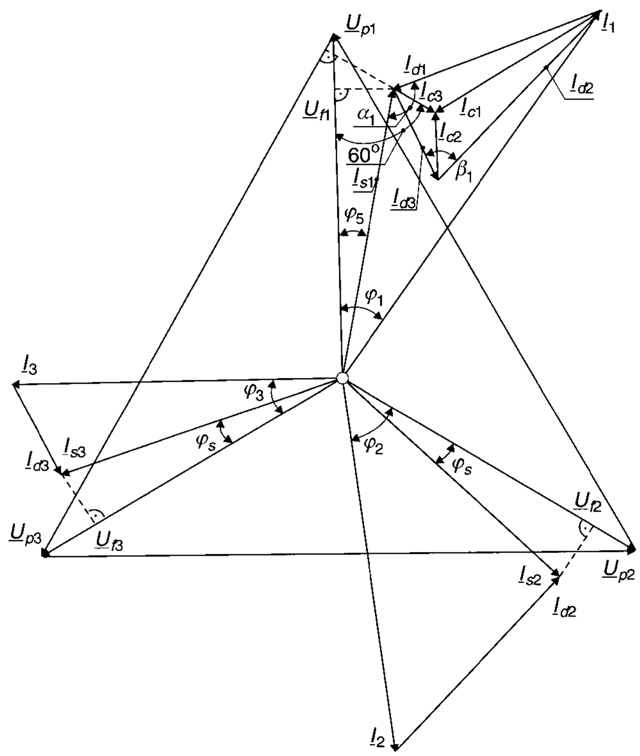

Fig. 5. Graphical determination of currents I_{d3}, I_{C2}, I_{C3} of the symmetrising capacitors

4. DELTA SYSTEM OF SYMMETRISATION CAPACITORS

A detailed analysis of a system symmetrising the network load is included in [1]. A graphical method for determination of the currents of the delta-connected capacitors is presented in Fig. 5, where they both equalize the network currents and maintain the preset value of the power factor.

The active and reactive powers, P and Q of an asymmetrical load are respectively:

$$P = U_f \, (I_1 \cos\varphi_1 + I_2 \cos\varphi_2 + I_3 \cos\varphi_3) \\ Q = U_f \, (I_1 \sin\varphi_1 + I_2 \sin\varphi_2 + I_3 \sin\varphi_3) \tag{19}$$

Identical active power $P_S = P$ occur at symmetrical currents I_S whose active components satisfy the equation:

$$I_S \cos\varphi_3 = \frac{1}{3}(I_1 \cos\varphi_1 + I_2 \cos\varphi_2 + I_3 \cos\varphi_3) \tag{20}$$

Such a value of $\mathrm{tg}\varphi_S = Q_S / P_S < Q / P$ can be adopted so that no fee is charged for the reactive power. The reactive power Q_S occurring at symmetrical currents I_{Si} is equal: $Q_S = 3 U_f \, I_S \sin \varphi_S$.

To obtain the symmetrical currents $\underline{I}_{Si}$, additional currents $\underline{I}_{di}$ should be added to the currents $\underline{I}_i$. The current I_{d1} is determined by the relationship:

$$I_{d1} = \sqrt{I_1^2 + I_{S1}^2 - 2I_1 I_{S1}\cos(\varphi_1 - \varphi_S)} \qquad (21)$$

The currents I_{d2} and I_{d3} can be calculated using similar relationships.

Because $\underline{I}_1 + \underline{I}_2 + \underline{I}_3 = 0$, then the sum of the currents $\underline{I}_{d1} + \underline{I}_2 + \underline{I}_3 = 0$. In consequence the line currents $\underline{I}_{di}$ form a delta (Fig. 5). The angle β_1 of this delta-form opposite to the side I_{d1} can be calculated using the relationship:

$$\mathrm{tg}\frac{\beta_1}{2} = \sqrt{\frac{(p - I_{d2})(p - I_{d3})}{p(p - I_{d1})}} \qquad \text{where}$$

$$p = \frac{1}{2}(I_{d1} + I_{d2} + I_{d3}) \qquad (22)$$

Likewise the angle β_2 opposite to the side I_{d2} and the angle β_3 opposite to the side I_{d3} can be calculated.

The currents $\underline{I}_{Ci}$ are added to the delta of line currents in such a way that $\underline{I}_{C1} \perp \underline{U}_{p1}$, $\underline{I}_{C2} \perp \underline{U}_{p2}$, $\underline{I}_{C3} \perp \underline{U}_{p3}$, i.e. the angles between these currents are 120°. The line currents constitute the differences of the respective phase currents: $\underline{I}_{d1} = \underline{I}_{C1} - \underline{I}_{C3}$, $\underline{I}_{d2} = \underline{I}_{C2} - \underline{I}_{C1}$, $\underline{I}_{d3} = \underline{I}_{C3} - \underline{I}_{C2}$. The currents I_{C1} and I_{C3} can be calculated from the current delta: I_{C1}, I_{C3}, I_{d1}. In this delta the angle $\gamma_1 = \measuredangle(I_{d1}, I_{C3}) = \alpha_1 + \varphi_S - 60°$ and the angle $\gamma_3 = \measuredangle(I_{d1}, I_{C1}) = 60° - \gamma_1$. The currents I_{C1}, I_{C3} can be determined knowing the current I_{d1} and the angles γ_1 and γ_3. A knowledge of the currents I_{d3} and I_{C3} and the angle $\gamma_2 = \measuredangle(I_{d3}, I_{C3}) = \beta_2 - \gamma_3$ ($\beta_2 = \measuredangle(I_{d1}, I_{d3})$) enables the current I_{C2} to be calculated.

In order to have symmetrical currents in the network, of I_s and, at the same time, shifted in phase by the angle φ_S vs the respective phase voltages $\underline{U}_{fi}$ of the network, a capacitor of reactance $X_{C1} = U_p / I_{C1}$ should be connected to the voltage $\underline{U}_{p1}$, a capacitor of reactance $X_{C2} = U_p / I_{C2}$ should be connected to the voltage $\underline{U}_{p2}$, and a capacitor of reactance $X_{C3} = U_p / I_{C3}$ should be connected to the voltage $\underline{U}_{p3}$. After symmetrisation of the currents in the network to I_S, the reactive power Q_S will be less than the power Q (eq. 19). The difference of these powers is equal to the power of the symmetrisation capacitors of reactances X_{Ci}, i.e.:

$$Q - Q_S = U_p^2\left(\frac{1}{X_{C1}} + \frac{1}{X_{C2}} + \frac{1}{X_{C3}}\right) \qquad (23)$$

5. CONCLUSIONS

The method of symmetrisation of network currents, given as the first, is not suitable for practical purposes due to the large additional loss of active power.

The three subsequent methods of selecting elements for symmetrising network currents and at the same time compensating the reactive power are equivalent because the elements calculated by each of these methods enables the same network load level to be achieved.

To select the symmetrising elements, it is necessary to measure the symmetrical voltages U_{fi} (i=1, 2, 3), line currents I_i, phase active power P_i and reactive power Q_i of the network.

When the calculations given in Section 3 are employed, an additional system for measuring the phase currents I_{fi} (Fig. 4) is needed. The measurement results enables the symmetrisation currents and, based on this, the symmetrising elements to be calculated.

6. REFERENCES

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