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Determination of network impedance at the place of single-phase load connection

***Abstract**. The article deals with asymmetry in three phase systems and its relations to single-phase load and short circuit power. A ratio is derived between the coefficient of the voltage asymmetry ρ_u, the single-phase load S_{1f} and the three-phase short circuit power. Further is shown an idea to investigate short circuit power from measured values of ρ_u and S_{1f}. The results of verification measurement which was carried out in a traction transformer substation of electric railways 25 kV; 50 Hz of the Czech railways are mentioned in the article too.*

***Streszczenie.** Analizowano asymetrię sieci trójfazowej i jej związek z obciążeniem jednofazowym i mocą zwarciową. Określono relację między współczynnikiem asymetrii i obciążeniem jednofazowym. (**Określenie impedancji sieci w miejscu obciążenia jednofazowego**)*

Keywords: asymmetry, short circuit power, traction.
Słowa kluczowe: asymetria sieci trójfazowej, moc zwarciowa.

Introduction

Fortescue´s method is used to solve asymmetrical when solving unsymmetrical systems in electrical power engineering. This method makes it possible to decompose n-phase asymmetrical system to (n-1) symmetrical systems creating rotating field and one non-rotating field (does not create rotating magnetic field). It means that we can decompose the three-phase asymmetrical system of the voltage ($\underline{U}_A$, $\underline{U}_B$, $\underline{U}_C$) according to Fortescue´s method on the positive sequence which creates basic rotating magnetic field ($\underline{U}_{A+}$, $\underline{U}_{B+}$, $\underline{U}_{C+}$),negative (reverse rotating in comparison with positive one) sequence which creates negative rotating magnetic field ($\underline{U}_{A-}$, $\underline{U}_{B-}$, $\underline{U}_{C-}$) and zero sequence (non-rotating) which does not create rotating magnetic field($\underline{U}_{A0}$, $\underline{U}_{B0}$, $\underline{U}_{C0}$). Relations between voltage and current asymmetrical system and particular sequences show equations (1), (2), (3) and (4):

(1) $$\begin{pmatrix} \underline{U}_A \\ \underline{U}_B \\ \underline{U}_C \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix} . \begin{pmatrix} \underline{U}_0 \\ \underline{U}_+ \\ \underline{U}_- \end{pmatrix}$$

(2) $$\begin{pmatrix} \underline{U}_0 \\ \underline{U}_+ \\ \underline{U}_- \end{pmatrix} = \frac{1}{3} . \begin{pmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{pmatrix} . \begin{pmatrix} \underline{U}_A \\ \underline{U}_B \\ \underline{U}_C \end{pmatrix}$$

where $\underline{U}_A$, $\underline{U}_B$, $\underline{U}_C$ are phasors of phase voltages of the asymmetrical system, $\underline{U}_0$, $\underline{U}_+$, $\underline{U}_-$ are the phasors of voltages of the symmetrical sequence components, $a = e^{j120^\circ}$ is operator.

Similar equations can be written also for currents.

Calculation of the voltage asymmetry from the short-circuit ratios in the network at the place of connection of the single-phase load.

For the single-phase load (Fig. 1) the phase currents will be as follows:

(3) $$\underline{I}_A = \underline{I}_{AB}\ ;\quad \underline{I}_B = -\underline{I}_{AB}\ ;\quad \underline{I}_C = 0$$

with improvement of the (4) we can calculate current of the negative sequence component:

(4) $$\underline{I}_- = \frac{\underline{I}_A + a^2 . \underline{I}_B + a . \underline{I}_C}{3} = \frac{\underline{I}_{AB} . \left(1 - a^2\right)}{3}$$

by substitution to the relation for voltage asymmetry we get:

(6) $$\rho_u = \frac{U_-}{U_+} . 100 = \frac{I_- . Z_-}{U_+} . 100 = \frac{I_{AB} . Z_-}{\sqrt{3} . U_+^2} . 100$$

and after arrangement:

(7) $$\rho_u = \frac{I_{AB}}{\sqrt{3}} . \frac{\sqrt{3}}{\sqrt{3}} . \frac{U_+}{U_+} . \frac{Z_-}{U_+} . 100 = \\ = I_{AB} . \sqrt{3} . U_+ . \frac{Z_-}{3 . U_+^2} . 100$$

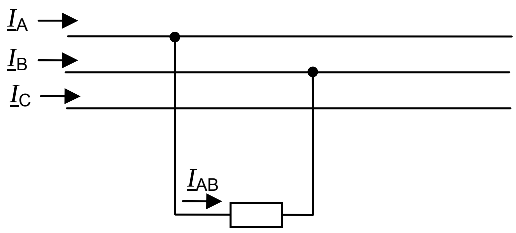

Fig. 1 Connection of the single-phase load to the three-phase network

If we know that single-phase load:

(8) $$S_{1f} = U_{AB} . I_{AB} \cong \sqrt{3} . U_+ . I_{AB}$$

and three-phase short circuit power S''_{k3} we calculate according to [3]:

(9) $$S''_{k3} = \frac{c . U_v^2}{Z_k} \cong \frac{1 . \left(\sqrt{3} . U_+\right)^2}{Z_-} \quad \text{(MV.A; 1,kV,}\Omega\text{)}$$

with these simplifications:
- value of coefficient c equals 1,
- base voltage U_v equals to voltage of positive sequence component $\sqrt{3} . U_+$,
- for total impedance Z_k between the place of connection of the single-phase load and generators of a supply system in which are mostly turboalternators stands approximately: $Z_k \cong Z_-$.

Then from (8), with consideration of (8) and (9), we get the approximate relation for the coefficient of voltage asymmetry:

(10) $$\rho_u \cong \frac{S_{1f}}{S''_{k3}} . 100 \ (\%)$$

After arrangement of the (10) we get relation for calculation of three phase short-circuit power S''_{k3}:

(11) $$S_{k3}^{"} \cong \frac{S_{1f}}{\rho_u} \cdot 100$$

And impedance Z_k we calculate from the relation (9):

(12) $$Z_k = \frac{c.U_v^2}{S_{k3}^{''}}$$

Verification measurement

Single-phase electric railways 25 kV; 50 Hz are typical examples of the single-phase load of the electric power system and because of this it belongs to the biggest origins of the asymmetry. Schematically is the connection of the electric railways 25 kV; 50 Hz shown on Fig. 2. From this we can see that in the Czech railways are the electric railways 25 kV; 50 Hz supplied from high voltage network 110 kV. Typical show of time - single-phase load S_{1f}- characteristic is on the Fig. 3.

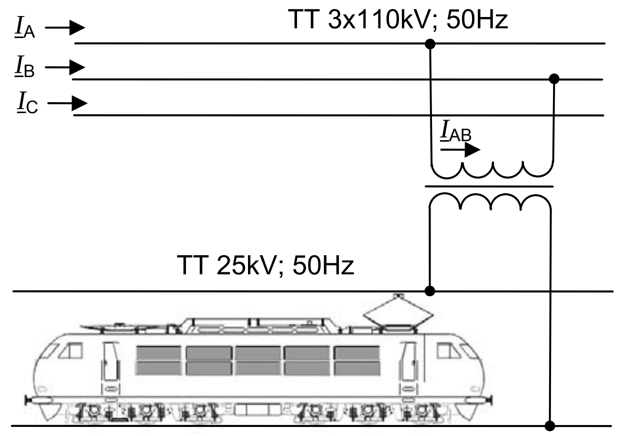

Fig. 2 Connection of the electric railways 25 kV; 50 Hz to the 110 kV network

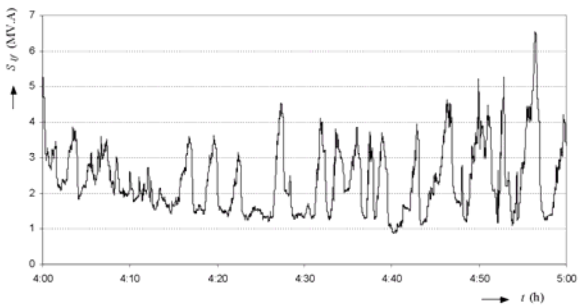

Fig. 3 Time – load of traction substation of railways 25 kV; 50 Hz characteristic

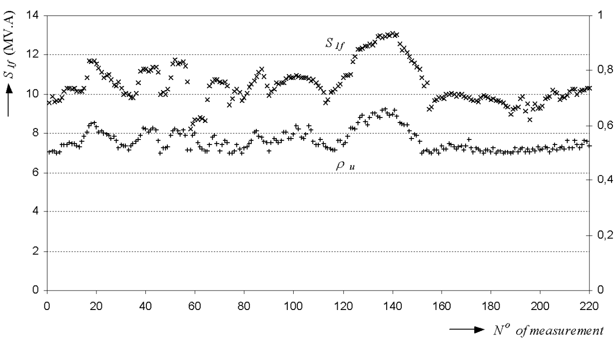

Fig. 4 Graphical figuration of the measured values ρ_U and S_{1f}

To verify of this idea we chose measurements which $\rho_u \geq 0{,}5\%$, to minimize measurement error.

Measured values of the ρ_u & S_{1f} are in Fig. 4. In Fig. 5 are the values of a short circuit power $S_{k3}^{"}$ calculated according in relation (11) to the values of the voltage asymmetry ρu and single-phase load S_{1f}.

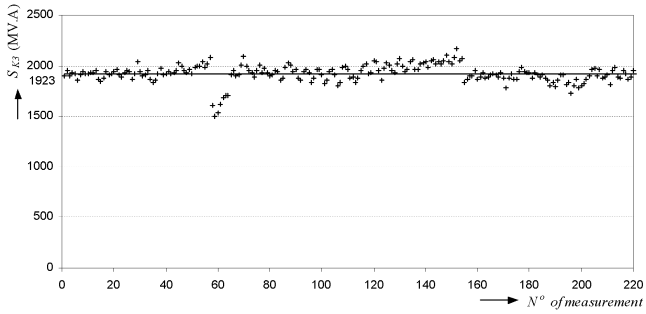

Fig 5 Calculated values of the short circuit power $S_{k3}^{"}$

Conclusion

In the place of the connection of the traction transformer substation is calculated three-phase short circuit power according to [3] $S_{k3}^{"}$=1780 MV.A. Average power from measurements calculated according to the relation (13) is 1923 MV.A. This approves correctness of all the relations and steps which were mentioned in the article.

Impedance of network 110 kV:

$$Z_k = \frac{c.U_v^2}{S_{k3}^{''}} = \frac{1 \cdot 110{,}450^2}{1923} = 6{,}34\ \Omega \cdot$$

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