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A METHOD FOR DETERMINING THE INSULATION PARAMETERS OF THREE-PHASE NETWORKS WITH VOLTAGE UP TO 1000 V WITH INSULATED STAR CENTRE OF THE TRANSFORMATOR

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ABSTRACT
A method is proposed for determining the insulation parameters by connecting an additional conductance to one of the phases and measuring the voltage of the other two phases. The method proposed has the following advantages: it is easily realizable, and it is based only on the voltage measurement, whereas the necessary accuracy and safety of the measuring are achieved.

In order to ensure the necessary electrical safety conditions, it is very important to know the insulation parameters (with respect to the ground) of networks for voltage up to 1000 V, with insulated star centre of the transformator. Different methods are known for these parameters determination. Measurement of running-light current and short-circuit current is the most often used method (Sichev, Zapenko 1979). The necessity to measure short-circuit current that aggravates the electrical safety during the measurement can be outlined as disadvantage of this method. Use of phase-sensitive equipment represents other measuring method (Zapenko, 1972) Disadvantage of this method is the necessity to measure the current phase in addition to the measurement of the current size. This complicates the measurement process and decreases its accuracy. A graphical-analytical method exists also (Sichev ,Zapenko, 1979). Its disadvantage is the necessity to carry out heavy calculations.

A method is proposed here for determining the insulation parameters by connecting an additional conductance to one of the phases and measuring the voltage of the other two phases. The method proposed has the following advantages: it is easily realizable, and it is based only on the voltage measurement, whereas the necessary accuracy and safety of the measuring are achieved. The method is elucidated and realized by the scheme shown in Fig. 1, where: $U_{\Phi A}$, $U_{\Phi B}$, $U_{\Phi C}$ are the complex phase voltages of the source and these voltages form asymmetric three-phase system; U_A, U_B, U_C – complex voltages (with respect to the ground) of the individual phases of the network; U_N - complex biased voltage of the grounded neutral;
r_A, r_B, r_C – active insulation resistance between the ground and phases;
C_A, C_B, C_C – conductors capacity (with respect to the ground);
R_D – additional resistance that is connected during the measurements.

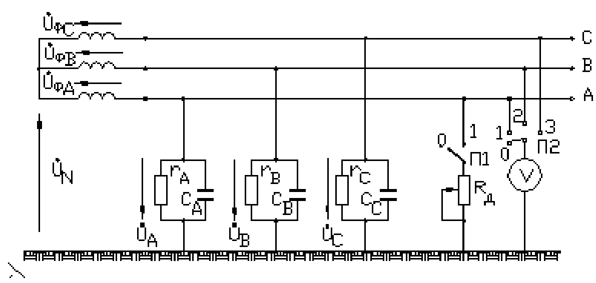

Figure 1

A diagram shown in Fig. 2 can represent each state of the network described above, at predetermined directions of the voltage vectors. In order to determine the coordinates (x, y) of the point N it is necessary at first to find the analytical expression for determining U_A, U_B and U_C voltages using the data read in the voltmeter. To solve the tack, equations are worked out for circumferences with centers in points A, B and C and radiuses U_A, U_B and U_C.

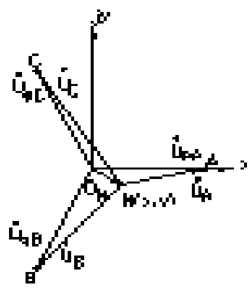

Figure 2

To solve the tack, equations are worked out for circumferences with centers in points A, B and C and radiuses U_A, U_B and U_C.

Coordinates of points A, B and C are determined in the following way:

$$A(\frac{U_Л}{\sqrt{3}},0),\ B(-\frac{U_Л}{2\sqrt{3}},-\frac{U_Л}{2} \quad и \quad C(-\frac{U_Л}{2\sqrt{3}},\frac{U_Л}{2})$$

The equation of a circumference with a radius R is represented in the following way:

$(x – a)^2 + (y – в)^2 = R^2$.

Consequently:

$$(x-\frac{U_Л}{\sqrt{3}})^2+y^2=U_A^2;$$

$$(x+\frac{U_Л}{2\sqrt{3}})^2+(y+\frac{U_Л}{2})^2=U_B^2;$$

$$(x+\frac{U_Л}{2\sqrt{2}})^2+(y-\frac{U_Л}{2})^2=U_C^2\cdot$$

After finding the quadrate, it is obtained:

$$x^2+y^2-\frac{2U_Л}{\sqrt{3}}.x+\frac{U_Л^2}{3}=U_Л^2; \qquad (1)$$

$$x^2+y^2+\frac{U_Л}{\sqrt{3}}.x+U_Л.y+\frac{U_Л^2}{3}=U_B^{2;} \qquad (2)$$

$$x^2+y^2+\frac{U_Л}{\sqrt{3}}.x-U_Л.y+\frac{U_Л^2}{3}=U_C^2\cdot \qquad (3)$$

Coordinates of U_N are determined using the equations of circumferences with a center in point B and radius U_B and with a center in point C and radius U_C. Using equation (2) and (3), it is obtained:

$$x^2+y^2+U_Ф.x+U_Л.y+U_Ф^2=U_B^2 \qquad (4)$$

$$x^2+y^2+U_Ф.x+U_Л.y+U_ô^2=U_C^2 \qquad (5)$$

After processing equation (4) and (5), it is obtained:

$$y=\frac{U_B^2-U_C^2}{2U_Л}=\frac{U_B^2-U_C^2}{2\sqrt{3}.U_ф}, \qquad (6)$$

$$x=\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}.U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}-\frac{U_Ф}{2}, \qquad (7)$$

where $U_Ф$ is the phase voltage.

Then:

$$U_N=\left[\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}-\frac{U_Ф}{2}\right]+j(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф})\cdot \qquad (8)$$

Knowing that:

$U_A = U_{ФA} - U_N = U_Ф – U_N$,

$U_B = a^2 . U_A = (-\frac{1}{2}-j\frac{\sqrt{3}}{2}).U_Ф - U_N$, (9)

$U_C = aU_A = (-\frac{1}{2}+j\frac{\sqrt{3}}{2}).U_Ф - U_N$

and laying out

$$U_i=a_i+jd_i, \qquad (10)$$

where i = A,B, C, it is obtained:

$$U_A=\frac{3}{2}U_Ф-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}+j(\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}), \qquad (11)$$

$$U_B=\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}+j(-\frac{\sqrt{3}}{2}U_Ф+\frac{\sqrt{3}}{2}U_Ф+\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}), \qquad (12)$$

$$U_C=\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2}+j(\frac{\sqrt{3}}{2}U_Ф+\frac{U_C^2}{2\sqrt{3}U_Ф}) \qquad (13)$$

It is laid out in equations (11), (12), and (13)

$$\left.\begin{aligned}a_A&=\frac{3}{2}U_Ф-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2};\\ d_A&=\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф};\end{aligned}\right\} \qquad (14)$$

$$\left.\begin{aligned}a_B&=-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2};\\ d_B&=\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф;\end{aligned}\right\} \qquad (15)$$

$$\left.\begin{aligned}a_C&=-\sqrt{U_C^2-(\frac{U_B^2-U_C^2}{2\sqrt{3}U_Ф}-\frac{\sqrt{3}}{2}U_Ф)^2};\\ d_C&=\frac{U_C^2-U_B^2}{2\sqrt{3}U_Ф}+\frac{\sqrt{3}}{2}U_Ф.\end{aligned}\right\} \qquad (16)$$

By use of the equation of a circumference with center in point A and radius U_A, it is obtained:

$$(x-U_A)^2+y^2=U_A^2. \qquad (17)$$

Taking into consideration (6) and (7), it is found:

$$U_A = \sqrt{\frac{1}{2}\left[U_B^2 + U_C^2 + 3U_\Phi^2 - \sqrt{9U_\Phi^2(2U_B^2 + 2U_C^2 - 3U_\Phi^2) - 3(U_B^2 - U_C^2)^2}\right]} \quad (18)$$

As it can be seen from equation (18), the measurement of only two voltages U_B and U_C is enough, because the U_A voltage can be found analytically.

It is important to note that the system of equations describing the circumferences has two solutions symmetric with respect to the straight line connecting centers of those circumferences. Calculations presented are for solution situated to the right of the line BC.

The electric circuit shown in Fig. 1 can be described by two complex independent equations, in conformity with the first law of Kirchhoff.

$U_A.Y_A + U_B Y_B + U_C Y_C = 0$

$U_A' Y_A + U_B' Y_B + U_C' Y_C = -U_A' Y_d$ (19)

The first equation of the system (19) reflects the initial state of the circuit (the switch П1is in position 0). The second equation reflects the state when to one of the phases (phase A) is connected and additional resistance r_d (the switch П1 is in position 1).

The system (19) of complex equations is transformed into a system of algebraic equations, while equation (10) is taken into account, as it follows:

$$\left.\begin{array}{l}(a_A + jd_A)Y_A + (a_B + jd_B)Y_B + (a_C + jd_C)Y_C = 0;\\ (a_A' + jd_A')Y_A + (a_B' jd_B')Y_B + (a_C' + jd_C')Y_C = -(a_A' + jd_A')\dfrac{1}{r_d}.\end{array}\right\}$$

Taking into consideration that:

$Y_A = g_A + jb_A,\ Y_B = g_в + jb_B$ и $Y_C = g_C + jb_C$,

it is obtained:

$$\left.\begin{array}{l}a_A g_A + a_B g_B + a_C g_C - d_A b_A - d_B b_B - d_C b_C = 0;\\ d_A g_A + d_B g_B + d_C g_C + a_A b_A + a_B b_B + a_C b_C = 0;\\ a_A' g_A + a_B' g_B + a_C' g_C - d_A' b_A - d_B' b_B - d_C' b_C = -\dfrac{a_A'}{r_д}\\ d_A' g_A + d_B' g_B + d_C' g_C + a_A' b_A + a_B' b_B + a_C' b_C = -\dfrac{d_A'}{r_д}\end{array}\right\} \quad (20)$$

It is known that the network with a voltage up to 1000V is characterized with insignificant asymmetry of the capacitive conductance of the phase insulation with respect to the ground. That is why it is considered in practice that $C_A=C_B=C_C$. At the same time, the asymmetry of the active conductance of the phase insulation with respect to the ground is well pronounced and can vary in broad range.

For the conditions pointed out, the system (20) of equations can be represented in the following form:

$$\left.\begin{array}{l}a_A g_A + a_B g_B + a_C g_C - (d_A + d_B + d_C)b = 0;\\ d_A g_A + d_B g_B + d_C g_C + (a_A + a_B + a_C)b = 0;\\ a_A' g_A + a_B' g_B + a_C' g_C - (d_A' + d_B' + d_C')b = -\dfrac{a_A'}{r_д}\\ d_A' g_A + d_B' g_B + d_C' g_C + (a_A' + a_B' + a_C')b = -\dfrac{d_A'}{r_д}\end{array}\right\} \quad (21)$$

From the system (21) of equations it can be found:

$r_A = 1/g_A$, $r_B = 1/g_B$, $r_C = 1/g_C$ и $C = b/\omega$ (22)

In this way, the insulation parameters can be determined by measuring with a voltmeter the *voltages* U_B, U_C, U_B' *u* U_C', These voltages are introduced as coefficients in specially created program for a calculator able to be programmed.

Having in mind the above mentioned, the following conclusions could be drawn:

1. A method is proposed for determining the insulation parameters by connecting an additional conductance to one of the phases and measuring only four voltages.
2. The method proposed does not require a measurement of the current of directly grounded connection. This ensures electrical safety conditions of measurement.
3. Investigation of the accuracy of the method proposed in dependence of the change of the linear voltage, size of the additional resistance connected, and of the voltmeter internal resistance can be pointed out as future tack.

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