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Determination of Insulation Active Component of an Insulated Neutral Electrical Supply Network

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Abstract: During the insulation testing of an electrical supply network having isolated neutral the capacitive component does not allow us to know the state of the cable insulation. On the other hand, it is the testing of the active component that helps in the electrical danger elimination in case there is an insulation failure. The current leak being a function of the active and capacitive component that could cause the disconnection of the electrical network even in the absence of faults. A total compensation of the network capacitive effect gives the possibility to measure the resistive current leak. The experimental electrical circuits built allowed us to define the whole combinations between the leakage resistance (single-phase, double-phase and three-phase) and the different levels of insulation of the network with respect to earth. The obtained results give an insight into the domains sensitivity of the protection circuits of the insulation active component while keeping the leakage current at safe value of 30 mA.

Key words: Electrical faults, leak resistance, harmless current, isolation, protection device

INTRODUCTION

The leak current capacitive component I_l influences the systems sensitivity and activates the protections without the real existence of a fault or an isolation degradation (Chauvin, 2004; Eliane, 2000). The problem is to find a solution that can eliminate the capacities influence and define the isolation system sensitivity domains by taking into account the active component alone. By taking the condition $I_l = I_{hless}$ (Harmless current) we determine the leak resistances set in function of isolation $R_l = f(r)$ defining the isolation level sensitivity domains protection system. This is done during different faults states for extreme network capacitances (Zero microfarads (0 µf) and one microfarad (1 µf)).

MATERIALS AND METHODS

Leak current in function of active and capacitive components: In case of fault condition in phase A as an example in a three phase network, the unbalance voltage could be determined by the expression:

$$U_0 = \frac{(Y_a + Y_l)U_a + Y_bU_b + Y_cU_c}{Y_a + Y_b + Y_c + Y_l} \quad (1)$$

$Y_a = g_a + j\omega c$ or $g_a = 1/r_a$, $Y_b = g_b + j\omega c$ or $g_b = 1/r_b$

$Y_c = g_c + j\omega c$ Or $g_c = 1/r_c$ Where U_a, U_b, U_c single phase voltages.

Y_a, Y_b, Y_c: Phases conductibilities
Y_l : Leak resistance conductibility
By taking into account voltages operators

$$U_a = U, U_b = a^2U, U_c = aU$$

The expression (1) becomes:

$$U_0 = U\frac{Y_a + Y_l + a^2Y_b + aY_c}{Y_a + Y_b + Y_c + Y_l}$$

Knowing the unbalance voltage, the leak current is calculated by: $I_l = (U_a - U_0)Y_l$ Or

$$I_l = UY_l\frac{Y_b(1-a^2) + Y_c(1-a)}{Y_a + Y_b + Y_c + Y_l}$$

And in real value

$$I_l = \sqrt{3}Ug_l\sqrt{\frac{g^2_b + g^2_c + g_bg_c + \sqrt{3}\omega c(g_c - g_b) + 3\omega^2c^2}{(g_a + g_b + g_c + g_l)^2 + 9\omega^2c^2}} \quad (2)$$

By taking the most dangerous case characterised by the equality of phases isolation $r_a = r_b = r_c = r$ (Ney, 2001) and the line capacity C, we will have:

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$Y_a = Y_b = Y_c = Y$ and $g_a = g_b = g_c = g$ And the expression (2) becomes:

$$I_l = \frac{U}{R_l + 1/3Y}$$

And in real value:

$$I_l = \sqrt{3}Ug\sqrt{\frac{3g^2 + 3\omega^2c^2}{(2g + g_l)^2 + 9\omega^2c^2}} \quad (3)$$

The isolation limit values in function of the line capacity $r_{LV} = f(c)$:

By resolving Eq. 3 with respect to

$$g = \frac{1}{r_{LV}}$$

and by taking

$$m = \frac{I_1}{3Ug_1}$$

we obtain the isolation resistance limit values in function of phases capacity with respect to $r_{LV} = f(c)$ earth where the security conditions are respected (Brown, 2006).

$$r_{LV} = \frac{1 - 4m^2}{\frac{2m^2}{R_l} + \sqrt{\frac{m^2}{R^2_l} + \omega^2C^2(13m^2 - 36m^4 - 1)}} \quad (4)$$

Expression (4) shows the existence of a limit value of line capacity corresponding to the limit isolation value for which the inequality $I_1 < I_{hless}$ would not be respected even if there is perfect isolation.

Theoretical characteristics $R_1 = f(r)$ if $r \neq \infty$

Between O_1 and O_2 (Fig. 1) there is the existence of a voltage called operational voltage equals to:

$$U_{op} = \frac{R_2}{R_2 + R_1} U/\sqrt{3}$$

For a determined operational voltage U_{OP} and a perfect isolation where $r = \infty$, the operational I_{OP} is:

$$I_{op} = \frac{U_{op}}{R_D + R_l} \Rightarrow R_l = \frac{U_{op}}{I_{OP}} - R_D$$

R_D : Elements total resistance contained in the protection circuits.

R_1 : Leak resistance if $I_{op} = I_{hless}$

Taking into account the most dangerous case $r_a = r_b = r_c = r$ (Sabot and Michaud, 1997) for a completely compensated capacity and also taking into account

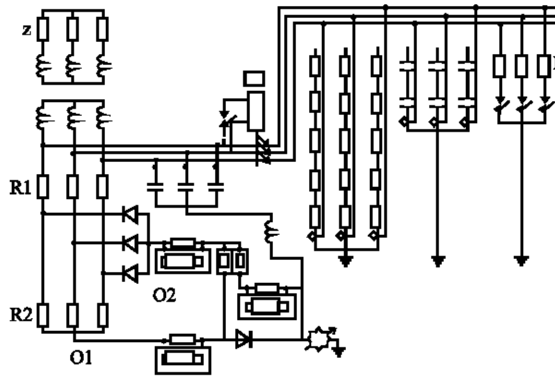

Fig. 1: Testing system and simulation circuits for the electrical network

the parallel connection of resistance (R_D) with the equivalent network resistance, we will have:

- Single phase leak resistance if $r \neq \infty$

$$R_{1s} = \frac{r\left(\frac{U_{op}}{I_{hless}} - R_D\right)}{r - 3\left(\frac{U_{op}}{I_{hless}} - R_D\right)}$$

- Two phase leak resistance if $r \neq \infty$

$$R_{IT} = \frac{2r\left(\frac{U_{op}}{I_{hless}} - R_D\right)}{r - 3\left(\frac{U_{op}}{I_{hless}} - R_D\right)}$$

- Three phase leak resistance if $r \neq \infty$

$$R_{ITH} = \frac{3r\left(\frac{U_{op}}{I_{hless}} - R_D\right)}{r - 3\left(\frac{U_{op}}{I_{hless}} - R_D\right)}$$

It is obvious if the protection trip happens for $r = \infty$ and $R_{ITH} = 3R_1$ it would be the same for $R_{1s} = R_{IT} = R_{ITH}$ ∞ when the isolation decreases to $r = 2R_1 = r_d$.

Physical simulation of an electrical network: This simulation is conceived for a low voltage three phase electrical network. The network is supplied with a transformer having a 380V at the output (Monique and André-luc, 2006). The influence of the line capacity before the transformer is completely eliminated (Chauvin, 1999).

The network isolation is obtained by the installation of resistances and capacitances connected between the phases and the earth manipulated by means of switches.

The electrical faults simulation consists of connecting between the phases and earth real resistances manipulated by a switch.

RESULTS AND DISCUSSION

Experimental testing system: Indirectly we measure the rectified internal current I_r by the use of an oscilloscope, the operational current I_{OP} and the homopolaire current I_O. This experiment is executed for 3 principal isolation fault states and 2 values for the level of isolation (10kΩ and 271kΩ) (Lherm, 1992).

- Symmetrical state
  Test : $r_a = r_b = r_c = \infty$
  Result : I_{OP} : Armature equilibrium
  Test : $r_a = r_b = r_c = 10k\Omega$
  Result : $I_{op}+ I_r \geq I_{hless}$: Armature nonequilibrium

- Single phase faulty state
  Test : $r_a = 271k\Omega$; $r_b = r_c = \infty$
  Result : $I_{op}+ I_r+I_{o+} \leq I_{hless}$: Armature equilibrium
  Test : $r_a = 10k\Omega$; $r_b = r_c = \infty$
  Result : $I_{op}+ I_r+I_{o+} \geq I_{hless}$: Armature nonequilibrium

- Two phase faulty state
  Test : $r_a = r_b = 271k\Omega$; $r_c = \infty$
  Result : $I_{op}+ I_r+I_{o+} \leq I_{hless}$: Armature equilibrium
  Test : $r_a = r_b = 10k\Omega$; $r_c = \infty$
  Result : $I_{op}+ I_r+I_{o+} \geq I_{hless}$: Armature nonequilibrium

Variables determination: The tests are carried out by the variation of isolation simulated values of artificial faults and network capacities. This in order to obtain threshold values of leak resistances and that of leak currents. The combinations obtained $R_l = f(r)$ confirm the theoretical predictions (Fig. 2).

Curve 1: Single phase fault, capacity = 0 and 1 μf; Compensation, capacitance = 0.15 and 0.85 μf.

Curve 2: Two phase fault, capacity = 0 and 1 μf; Compensation, capacitance = 0.15 and 0.85 μf.

Curve 3: Three phase fault, capacity = 0 and 1 μf compensation, capacitance = 0.15 and 0.85 μf.

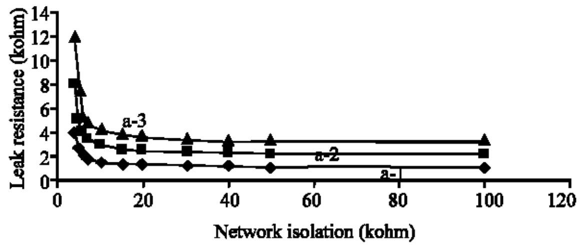

Fig. 2: Fault resistance in function of the network isolation

Every curve represents the mean curve obtained with six successive tests. The mean value of the mean leak resistance that triggers the protection control circuits sensitivity is calculated by the expression:

$$R_{lm} = \frac{R_{l1} + R_{l2} + ... + R_{ln}}{n}$$

Where n = 6 number of tests.

To avoid large errors during the tests results interpretation we have taken into account the typical allowed error. The error found must not be superior to three times the quadratic mean error.

$$R_{l\,max} = 3\delta;\quad \delta = \sqrt{\frac{R^2_{l1} + R^2_{l2} + ... + R^2_{ln}}{n}}$$

$$R_{l1} = R_{l1\,max} - R_{lm};\ R_{l2} = R_{l2\,max} - R_{lm} \text{ and } R_{ln} = R_{ln\,max} - R_{lm}$$

CONCLUSION

The elements which constitute the combinations set $R_l = f(r)$, trigger the protection system sensitivity as long as the leak current I_l is superior to the harmless current. The variables set increases with the network capacity variation from 0-1 μf.

Curve 1 represents the limit value of the combinations set during the single phase fault having a compensation capacitance 0.15-0.85 μf and this would eliminate the leak current capacitive component. These combinations which allow the monitoring of the isolation active component multiplied by two times the number of protection trips during double phase fault (curve 2).

Curve 3 characterises the three phase fault and determine the number of combinations $R_l = f(r)$. More important is the possibility of network exploitation with small isolation parameters values not far from the critical values.

The tests executed have given the possibility to find the combinations that could trigger the protection system sensitivity. This assured an isolation and its capacitive component continuous monitoring.

The direct and alternative leak currents measurements done during the different tests have shown that in any case the values of these currents have not gone beyond the harmless current value.

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