THE INFLUENCE OF THE ADDITIONAL EARTHING OF THE AFFECTED PHASE DURING EARTH FAULT ON SAFETY OF DISTRIBUTION NETWORKS

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ABSTRACT

As the most dangerous fault from the touch voltage point of view the earth fault in the common earthing of distribution transformer station (MV/LV) was evaluated. One possibility for decreasing of the fault current and the touch voltage during the fault is additional connecting of the affected phase to the earthing system of supply substation (shunting method). The paper describes the simulations and the experiments which were realized in real network. The simulations were made by software PSCAD and the experiments were done in 22kV compensated network operated by E.ON Distribuce company.

INTRODUCTION

Dealing with an earth fault in a compensated network by means of the additional earthing of the affected phase in a 22 kV substation has become one of the frequently used means to increase the safety of such networks. Creating a conductive path for the residual current of the earth fault directly to the earthing system of a 110/22 kV substation leads to decreasing the value of the fault current at the point of the earth fault and therefore to minimizing the risks related to dangerous contact voltage for most of those faults in MV networks. The detailed description of the method of the additional earthing of the affected phase (also known as shunting) can be found in [1] and [2]. There is no doubt that the method yields positive results in case of resistive earth faults that represent a vast majority of all earth faults in MV distribution networks. The additional earthing of the affected phase leads in this case to the redistribution of the fault current to two parallel paths where the resistance of the artificially created conductive path in the MV substation is always much smaller than the resistance of the fault. On the contrary, a fault that could be described as a metallic earth fault leads to increasing the fault current at the point of the earth fault (see [3], [4]) and thus to increasing the touch and step voltages at the point of the fault. Nevertheless, practical experience shows that the number of points in a MV network where a metallic earth fault can appear is rather limited and that the negative influence of the additional earthing of the affected phase on the situation at the point of the fault is quite rare. It can be concluded from the technical conditions of the operation of a MV distribution network that the only points

ADDITIONAL EARTHING - THEORY

Fig. 1 shows the negative influence of the additional earthing of the affected phase on the value of the current flowing through the point of the fault in a simplified network. It is a compensated 22 kV network supplying two distribution transformers of real loads $P_{\text{max},1}$ and $P_{\text{max},2}$ from a 110/22 kV transformer. The earth fault is caused by the connection between the affected phase and the conductive parts of the distribution transforming substation connected to the earthing system of the transforming station and the earthing of the neutral conductor of the LV network. During the earth fault, the affected phase is in addition earthed in the 22 kV substation through resistance $R_{\text{stg}}$. To simplify the diagram, the lines are represented only by their resistances, which – taking into account the nature of the fault – does not influence the described principle.

The additional earthing of the affected phase results in most cases (resistive earth faults) in “transferring” the fault current from the point of the fault to the substation where the additional earthing is established. However, this does not apply to the situation where the impedance of the fault loop is comparable to the impedance of the impedance of the affected line up to the point of the fault. In such case, the total load current $I_{\text{load}}$ is divided into two load currents $I_{\text{loadA}}$ and $I_{\text{loadB}}$ in a ratio corresponding to the ratio of the
impedances of the fault loop and the line (1). Current $I_{\text{loadA}}$ flows to the load through the affected phase, while current $I_{\text{loadB}}$ supplies the load through shunting resistance $R_{\text{SH}}$, earth resistance $R_{\text{E}}$, and the fault loop with a resistance of $R_{\text{Loop}}$ (composed of the resistance of the 110/22 kV transformer station earthing $R_{\text{EDTS}}$, fault resistance $R_f$ as well as the total impedance of the LV network represented by earthing resistances $R_{\text{DDTS}}$ a $R_{\text{DPEN}}$, transformer winding resistance, phase conductor resistance $R_{\text{Ph}}$, neutral conductor resistance $R_{\text{PEN}}$, load resistance $R_{\text{LOAD}}$). The value of fault current $I_f$ is thus principally influenced by the total fault impedance $R_{\text{FLoop}}$ (impedance between the affected phase and earth) and by the load of the closest distribution stations $I_{\text{load}}$. It can be calculated as follows:

$$I_f = I_{\text{loadB}} = I_{\text{load}} \cdot \frac{R_{\text{LL}}}{R_{\text{SH}} + R_{\text{Gr}} + R_{\text{FLoop}} + R_{\text{L}1}}.$$  (1)

![Network diagram showing the negative influence of the additional earthing of the affected phase](image)

Fig. 1. Network diagram showing the negative influence of the additional earthing of the affected phase ($I_c$ – compensating current, $I_R$ – network capacitive current, $I_{\text{res}}$ – residual earth current)

The results of the simulations performed in PSCAD software prove this clearly. The curves of the following currents are shown in Fig. 2: current flowing through the point of the fault $I_f$ (red) and through the point of shunting $I_{\text{loadB}}$ (blue) during the earth fault before and after the additional earthing of the affected phase through shunting resistance $R_{\text{SH}} = 10 \ \Omega$. The redistribution of current $I_{\text{load}}$ is indicated by the dashed violet curve representing the sum of currents $I_{\text{res}} + I_{\text{loadB}}$. The situation before the additional earthing corresponds to $I_{\text{SH}} = 0$, therefore $I_{\text{load}} = I_{\text{loadA}}$. At time $t = 2 \ \text{s}$ after the additional earthing, the sum $I_{\text{SH}} + I_{\text{loadA}}$ represents the original load current $I_{\text{load}} = I_{\text{loadA}} + I_{\text{loadB}}$ (see Fig. 1). The negative influence of the additional earthing, through which a part of the load flows, results in increasing fault current $I_f$.

It can be assumed that increasing the shunting resistance will be able to limit this negative influence of load. It is clear from Fig. 3 (in comparison with the results in Fig. 2) that the current flowing through the point of the earth fault decreases with increasing shunting resistance $R_{\text{SH}}$ from 10 $\Omega$ to 50 $\Omega$. Also, the simulation results show that increasing the shunting resistance leads to a phase shift between the fault and shunting currents.

![Results of the simulations in PSCAD – shunting resistance $R_{\text{SH}} = 10 \ \Omega$](image)

Fig. 2. Results of the simulations in PSCAD – shunting resistance $R_{\text{SH}} = 10 \ \Omega$

![Results of the simulations in PSCAD – shunting resistance $R_{\text{SH}} = 50 \ \Omega$](image)

Fig. 3. Results of the simulations in PSCAD – shunting resistance $R_{\text{SH}} = 50 \ \Omega$

The explanation of this phenomenon lies in the redistribution of the residual earth current, total network capacitive current and compensating current between the point of the earth fault and the point of the additional earthing (Fig. 1). In the first case, the low resistance of the additional earthing ($I_{\text{SH}} = 10 \ \Omega$) led to the “transfer” of a big part of the fault current to that point, which means that there are not any capacitive and inductive currents flowing through the point of the fault or the point of the additional earthing. There are only the residual current and part of the load current there, both active. In the second case, increasing the shunting resistance ($50 \ \Omega$) leads to the redistribution of the residual earth current to $I_{\text{IR}} = I_{\text{R1}} + I_{\text{R2}}$, where

$$I_{\text{IR2}} = I_{\text{IR}} \cdot \frac{R_{\text{ES}} + R_{\text{SH}}}{R_{\text{ES}} + R_{\text{SH}} + R_{\text{FLoop}} + R_{\text{L}1}},$$  (2)

the compensating current to $I_{\text{IC}} = I_{\text{C1}} + I_{\text{C2}}$, where

$$I_{\text{C2}} = I_{\text{C}} \cdot \frac{R_{\text{ES}} + R_{\text{SH}}}{R_{\text{ES}} + R_{\text{SH}} + R_{\text{FLoop}} + R_{\text{L}1}},$$  (3)

as well as the network capacitive current to $I_{\text{IC}} = I_{\text{C1}} + I_{\text{C2}}$, where

$$I_{\text{IR2}} = I_{\text{IR}} \cdot \frac{R_{\text{ES}} + R_{\text{SH}}}{R_{\text{ES}} + R_{\text{SH}} + R_{\text{FLoop}} + R_{\text{L}1}}.$$  (4)
The resulting current flowing through the point of the fault is equal to the sum of the currents calculated according to (1), (2), (3) and (4); it can be expressed as

\[ I_z = (I_{m2} - I_{aw2}) + j(I_{i2} - I_{aw2}) \] (5)

**EXPERIMENTS**

To verify the above-mentioned theoretical conclusions, measurements in a real network were performed. The aim was to indicate dangerous touch voltages concerning final customers during the fault on the primary side of a distribution transformer. The touch voltage was monitored during an artificially created earth fault in a compensated MV network equipped with an automatic system for the additional earthing of the affected phase.

Three distribution transforming substations with the earthing system interconnected with the earthing of the neutral conductor of the LV network (0.4 kV) and maximum load were chosen, as shown in Fig. 4. These stations were supplied by a 110/22 kV transformer equipped with arc-suppression coil SC that had a resistor connected to its auxiliary power winding for a short-time increase of the active part of fault current \( R_p \). A three-phase circuit breaker of the automatic system for the additional earthing of the affected phase (through resistance \( R_{SH} \) to the earthing system of the supply substation) was connected to the substation busbar.

In order to estimate preliminary the fault current, earthing resistances of the earthing systems of the supply substation \( R_{ES} \) and distribution transforming substation \( R_{EDTS} \) were measured as well as the resistance of the earthing of the PEN conductors in the line leaving the transforming station \( R_{EPEN} \).

Measuring instruments recording current in the arc-suppression coil \( I_L \), its voltage \( U_0 \), current flowing through...
the point of shunting $I_{sh}$, phase voltages $U_{OL1}$, $U_{OL2}$, $U_{OL3}$ and load currents of the affected line $I_{OL1}$, $I_{OL2}$, $I_{OL3}$ were installed in the supply substation.

The quantities recorded in the distribution transforming substation were phase voltages on the primary side of the distribution transformer $U_{fL1}$, $U_{fL2}$, $U_{fL3}$, phase voltages on the secondary side of the distribution transformer $U_{L1}$, $U_{L2}$, $U_{L3}$, load currents on the secondary side of the distribution transformer $I_{L1}$, $I_{L2}$, $I_{L3}$, current flowing through the PEN conductor $I_{PEN}$, current flowing to the transformer neutral $I_{Tr}$ and fault current $I_f$. Also recorded were the increase of the potential of the earthing system of the distribution transforming substation $U_E$, with the earthing electrode at the distance of at least ten times the diameter of the earthing system of the distribution transforming substation.

The touch voltage was measured at the supply point according the standard.

The first results of the experiment are shown at Fig.5, 6 and 7. Fig 5 shows low-ohmic fault in network with capacitive current 302A and for no-loaded DTS. Fig. 6 and Fig. 7 show low-ohmic fault in network with capacitive current 812A and for loaded DTS (180A at low voltage side).

**CONCLUSION**

The first results at first view don’t clearly confirm the theory shown at first part of the paper. The difference between the theory and the experiment is caused by very low earthing resistance of DTS. Directly measured value was 0.02Ω. For similar values there are the increase of the potential of the earthing system of the DTS and the touch voltage neglectable even if the fault current is relatively high.

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