THE INFLUENCE OF THE ADITIONAL 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 connductive 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 curent 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 where a metallic earth fault or an earth fault of a very low resistance can really occur are those disposing of good earthing, such as MV switching substations (as described in [3]). It can also occur in an MV/LV distribution transforming substation if there is a sparkover directly to the conductive parts of the substation connected to the earthing system. This is where a real risk of increasing the fault current and therefore the touch and step voltages on the transformer station earthing due to the additional earthing of the affected phase can appear. If the earthing is common with the LV network, the dangerous touch voltage appears on its neutral conductor as well.
To evaluate the above-mentioned risk, a detailed analysis of the situation in an MV/LV distribution transforming substation during the earth fault was performed. It was based on the fault simulations using the mathematical model of the network in PSCAD software. The simulation results were then verified by experiments in selected parts of a real network operated by the E.ON Distribuce company.

ADITIONAL 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_{max1} a P_{max2} 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_{SH}. 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_{load} is divided into two load currents I_{loadA} and I_{loadB} in a ratio corresponding to the ratio of the impedances of the fault loop and the line (1). Current I_{loadA} flows to the load through the affected phase, while current I_{loadB} supplies the load through shunting resistance R_{SH}, earth resistance R_{Gr} and the fault loop with a resistance of R_{fLoop} (composed of the resistance of the 110/22 kV transformer station earthing R_{ES}, fault resistance R_f as well as the total impedance of the LV network represented by earthing resistances R_{EDTS} a R_{EPEN}, transformer winding resistance, phase conductor resistance R_{Ph}, neutral conductor resistance R_{PEN}, load resistance R_{LOAD}). The value of fault current I_f is thus principally influenced by the total fault impedance R_{fLoop} (impedance between the affected phase and earth) and by the load of the closest distribution stations I_{load}. It can be calculated as follows:

$$I_f = I_{loadB} = I_{load} \cdot \frac{R_{L1}}{R_{SH} + R_{Gr} + R_{fLoop} + R_{L1}} . \qquad (1)$$

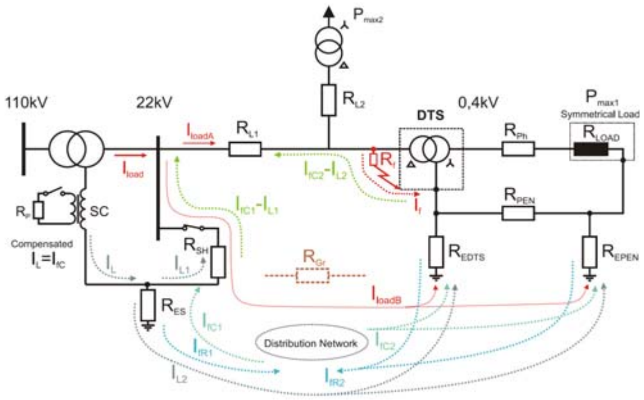

Fig. 1. Network diagram showing the negative influence of the additional earthing of the affected phase (I_L – compensating current, I_{fC} – network capacitive current, I_{fR} – residual earth current)

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_{SH} (green), load in the affected phase I_{loadA} (blue) during the earth fault before and after the additional earthing of the affected phase through shunting resistance R_{SH} = 10 Ω. The redistribution of current I_{load} is indicated by the dashed violet curve representing the sum of currents $I_{SH} + I_{loadA}$. The situation before the additional earthing corresponds to $I_{SH} = 0$, therefore $I_{load} = I_{loadA}$. At time $t = 2$ s after the additional earthing, the sum $I_{SH} + I_{loadA}$ represents the original load current $I_{load} = I_{loadA} + I_{loadB}$ (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_{SH} from 10 Ω to 50 Ω. Also, the simulation results show that increasing the shunting resistance leads to a phase shift between the fault and shunting currents.

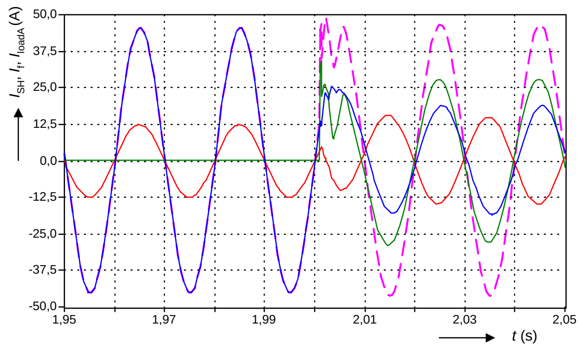

Fig. 2. Results of the simulations in PSCAD – shunting resistance R_{SH} = 10 Ω

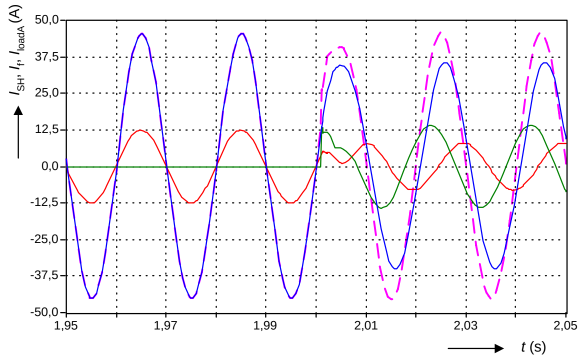

Fig. 3. Results of the simulations in PSCAD – shunting resistance R_{SH} = 50 Ω

The explication 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_{SH} = 10 Ω) 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 Ω) leads to the redistribution of the residual earth current to $I_{fR} = I_{fR1} + I_{fR2}$, where

$$I_{fR2} = I_{fR} \frac{R_{ES} + R_{SH}}{R_{ES} + R_{SH} + R_{fLoop} + R_{L1}} , \qquad (2)$$

the compensating current to $I_L = I_{L1} + I_{L2}$, where

$$I_{L2} = I_L \cdot \frac{R_{SH}}{R_{ES} + R_{SH} + R_{Gr} + R_{fLoop} + R_{L1}} , \qquad (3)$$

as well as the network capacitive current to $I_{fC} = I_{fC1} + I_{fC2}$, where

$$I_{fC2} = I_{fC} \cdot \frac{R_{ES} + R_{SH}}{R_{ES} + R_{SH} + R_{fLoop} + R_{L1}} . \qquad (4)$$

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

$$\bar{I}_{\mathrm{f}} = \left(I_{\mathrm{fR2}} - I_{\mathrm{napB}}\right) + \mathrm{j}\left(I_{\mathrm{L2}} - I_{\mathrm{fC2}}\right) \quad (5)$$

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}.

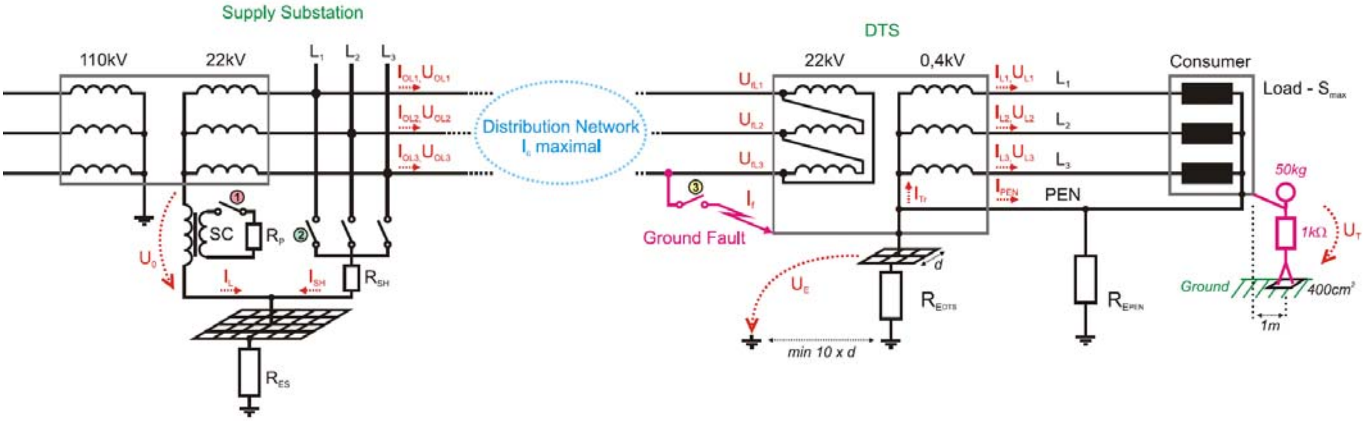

Fig. 4. Network diagram for the verification of the influence of the additional earthing of the affected phase on contact voltage

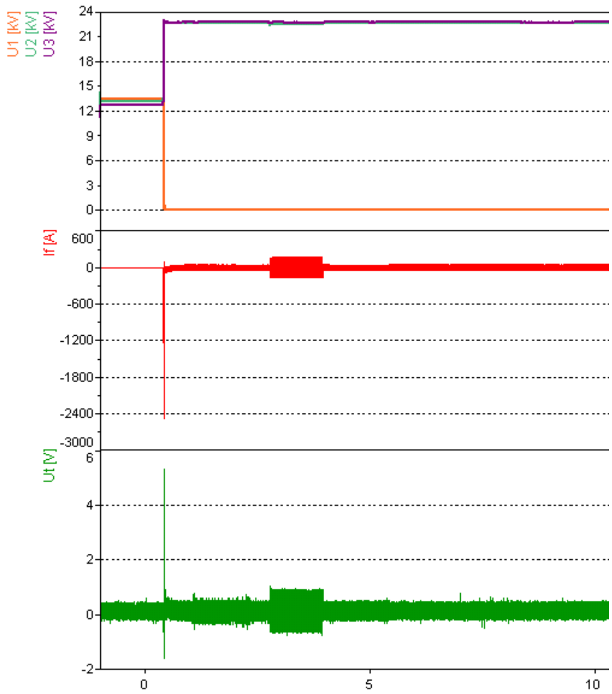

Fig. 5. RMS values of phase voltages (orange, cyan, dark green), fault current (red) and increase of the potential (green)

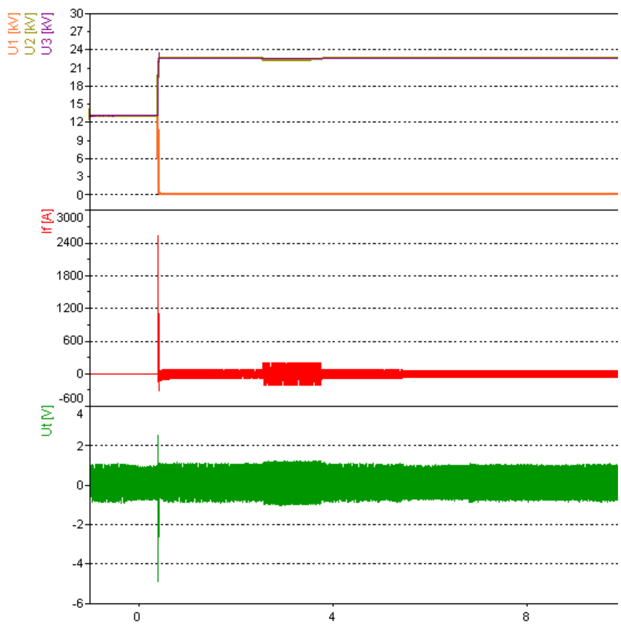

Fig. 6. RMS values of phase voltages (orange, cyan, dark green), fault current (red) and increase of the potential (green)

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.

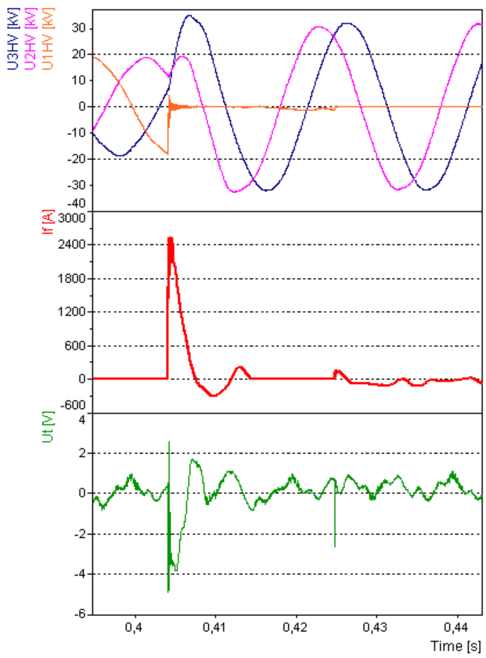

Fig. 7. Phase voltages (orange, cyan, dark green), fault current (red) and increase of the potential (green) – detail of fault rise

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.

Acknowledgments

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