THE ANALYSIS OF EFFICIENCY OF SHUNT RESISTOR DURING A SINGLE-PHASE EARTH FAULT USING THE TWO-PORT NETWORK THEORY

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ABSTRACT

A simple and cheap reduction method to reduce a high residual current of the single-phase earth fault is to earth the affected phase in the transformer station. This paper describes a theoretical verification of efficiency of this method. The two-port network theory, used for the analysis of shunting method is explained, so that it could be applied to the resonant earthed neutral system.

The assembled equivalent circuit and the mathematical description determine the conditions under which the method is possible to use. Parameters of elements of the equivalent circuit which influence the size of the faulty current in the fault point with the connected shunt in the substation were tested. The obtained diagrams show e.g. a dependence of a faulty current flows in the substation and a faulty current in the fault point, on the size of the network capacitive current, size of the fault resistance, size of the shunting resistance and etc. The paper deals with the steady state calculations.

INTRODUCTION

This paper deals with one of the present problems of middle voltage networks. It focuses on the middle voltage cable networks and their safe operating. The high residual current during a single-phase earth fault causes the main problem. A simple and cheap reduction method to lower high residual current is to earth the affected phase in the transformer station. This is known as the shunting method and it is shown in the following Figure 1.

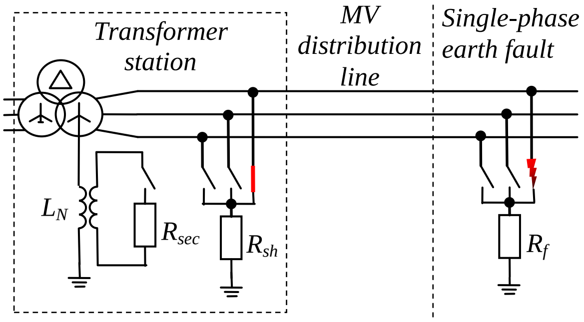

Figure 1: Shunting method.

A theoretical verification of efficiency of this method will be described. The connection of a shunt resistance to the earth can be compared to a follow-up fault in a network with a single-phase earth fault. To describe this situation, it is necessary to deal with unbalanced simultaneous faults, although these belong to the most complicated faulty processes. However, the application of a two-port network theory provides a transparent solution of simultaneous faults and the result is their mathematical description.

THEORETICAL DESCRIPTION

Applied two-port network theory is based on [5], where it is described in detail. In this report we will focus on its practical application.

In this paper the focus will be only on the double single-phase earth faults. The series connection of sequence component systems applies to both of these faults. This means that the resulting interconnection input and output terminals of sequence two-ports will be serial analogously. The two-port network theory is known that, the serial interconnection is interpreted by the z-parameters matrix. In this case, z-parameters are summed and finally we obtain the resulting equivalent circuit. It is important to note that the used two-ports follow connection of radial network in Figure 1. Other lines from the transformer station are not useful to include into the scheme.

Equivalent circuit

Next Figure 2 shows the equivalent circuit for positive-phase sequence (PPS), negative-phase sequence (NPS) and zero-phase sequence (ZPS). The left part of the scheme corresponds to the conditions in the transformer station and the right part to the fault. Shunt elements apply to both places of single-phase earth fault.

In case of PPS and NPS the situation is not difficult and impedances to fault point are given by Thévenin equivalents, i.e. input and output impedance.

ZPS is more difficult because the resonant-earthed neutral point system is solved there. We come out from the knowledge of the simple single-phase earth fault and we also know that the capacitive current is parameter of whole MV network. The capacitive current is represented by one capacity and the arc suppression coil creates a parallel resonant circuit with this capacity. This is common to both fault locations. Another common parameter to both faults in the ZPS two-port equivalent circuit is the resistance of earthing system at transformer station. In contrast, separate parameters in each fault location are fault impedance and shunt resistance. The shunt capacitance of unbalance occupies a special part as it affects both fault locations equally and therefore has no effect on the results of the analysis of the shunting method efficiency.

It should be noted that a resistor in series with the inductance of arc suppression coil adds real component to the single-phase earth fault current and therefore represents the resistance of this coil, leakage current and zero-sequence resistance of the supply transformer. Zero-sequence reactance of supply transformer is apparently included in the size of reactance of arc suppression coil for simplification.

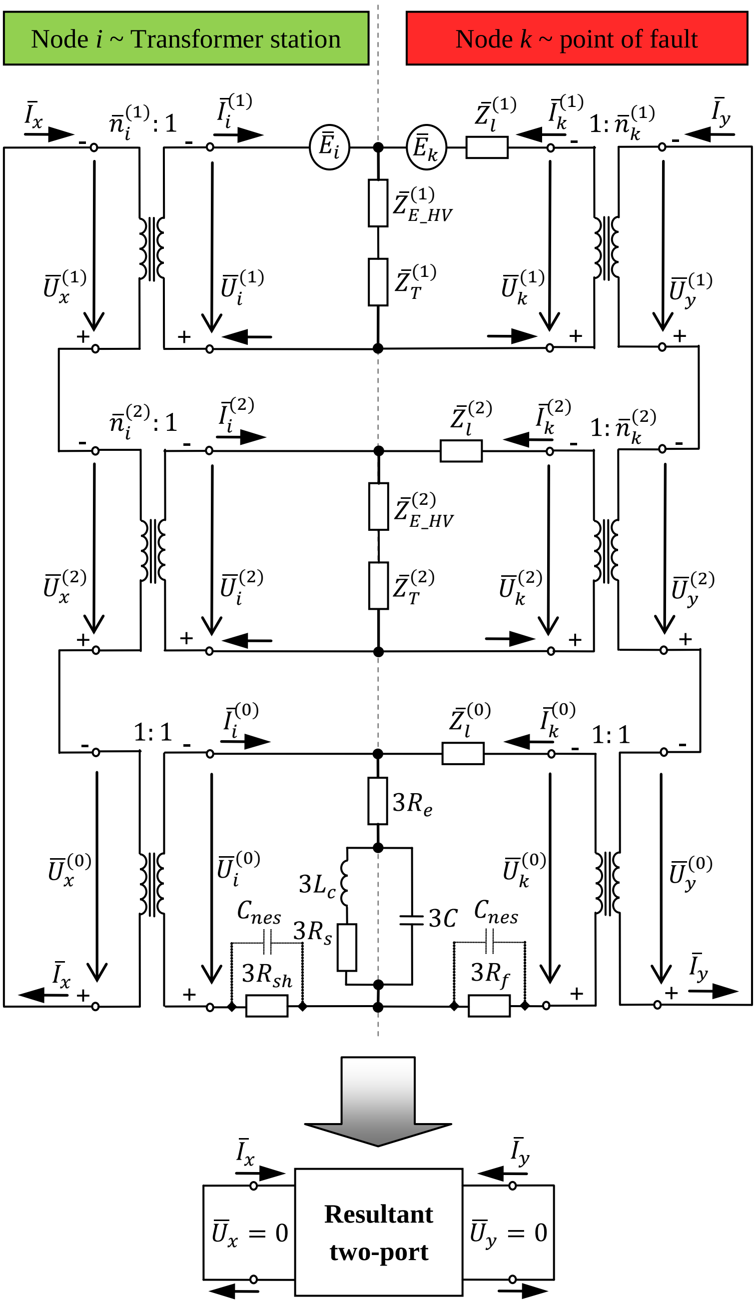

Figure 2: Equivalent circuit.

Mathematical solution

It has been already shortly mentioned that the serial connection of two-ports is interpreted by the z-parameters matrix. For each sequence two-ports (PPS, NPS and ZPS), a system of two equations with four variables can be built, i.e. the input and output sequence currents and voltages. Then twelve variables and only six equations are obtained in total. Adding all the sequence ports results in one equivalent circuit whose input and output terminals are short-circuited. This equivalent circuit can be described by a system of two equations with two variables and thus can be solved. All remaining variables are obtained by substitution into the system of equations of sequence two-ports. Finally, the sequence components system (Fortescue) is transformed to get voltages and currents in the transformer station and point of fault. All important equations refer to the [1] or [5].

RESULTS OF SIMULATION

In the following chapters, changes in the size of the resulting equivalent circuit parameters are simulated to verify the efficiency of the shunting method at different operating conditions. The aim is to obtain diagrams of currents and voltages in both places of single-phase earth fault.

Parameters of the tested model

The network subjected to the calculation of two simultaneous single-phase earth faults has the following default parameters:

Supply E-HV node:

$\bar{Z}_{E\_HV}^{(1)} = \bar{Z}_{E\_HV}^{(2)} = 0.0278 + 0.278 * \mathrm{j}$ (at MV side, corresponds to $\bar{I}''_{k\,3f\,110\,kV} = 10\ kA$);

Transformer 110/22 kV:

$\bar{Z}_T^{(1)} = \bar{Z}_T^{(2)} = 0{,}138 + 2{,}324 * \mathrm{j}$

MV line:

$R_1 = 0{,}245\ \Omega/km$; $R_0 = 0{,}525\ \Omega/km$;

$L_1 = 0{,}92\ mH/km$; $L_0 = 5{,}34\ mH/km$;

Capacitive current (by C): *670 A;*

Earthing resistance of supply transformer:

$R_e = 0{,}005\ \Omega$;

Resistance of shunt equipment $R_{sh} = 11\ \Omega$;

Fault resistance $R_f = 200\ \Omega$;

Arc suppression coil resistance is given by:

$R_s = 1\ \Omega$;

Distance from supply transformer to fault: *20 km*

Some of these parameters are changed in the next chapters. Further, we assume the arc suppression coil is undercompensated by 2 %.

Default fault parameters

In Figure 3 phasor diagrams show voltage and current phasors during two simultaneous single-phase earth faults. Voltages to earth at both places have phase to phase value. Currets are divided in the ratio of 35 A/1,9 A and have approximately real character. The effect of undercompensation is higher in the fault place. This test proves that earthing of the affected phase in the transformer station have a positive effect.

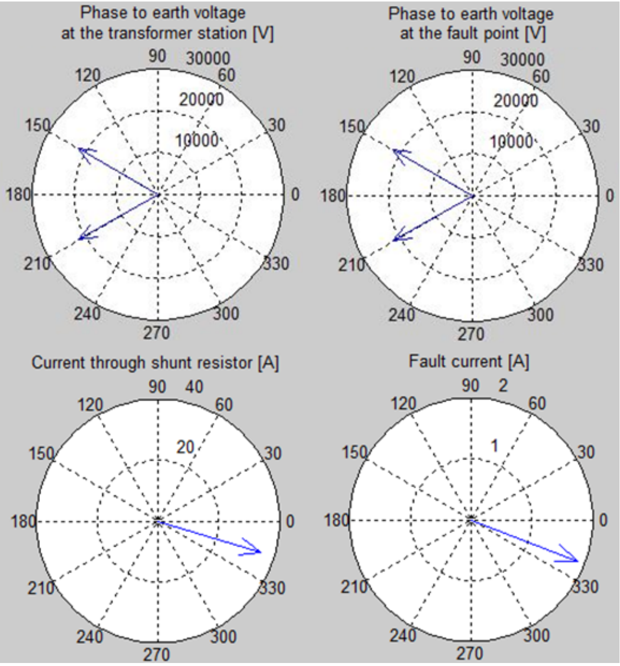

Figure 3: Default fault.

Dependence on fault distance from the supply transformer station

Furthermore, diagrams of fault currents can be drawn depending on the line length. For this test, a low-impedance fault ($R_f = 1\ \Omega$) has been chosen as the worst fault condition due to the efficiency of the shunting method.

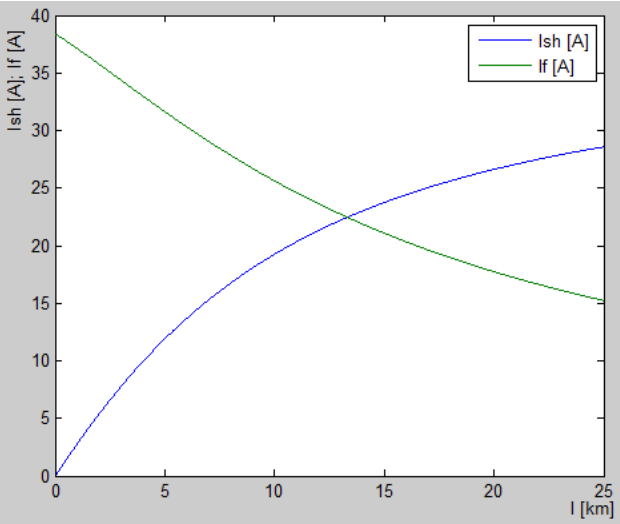

Figure 4: Dependence on fault distance.

The figure 4 shows the reduction of fault current (I_f) at single-phase earth faults with increasing distance from the supply transformer station. According to this, the shunt resistor current (I_{sh}) increases with the distance. Note that characteristics are almost independent of the fault distance when fault resistance is more than 30 Ω.

Fault resistance significantly affects the distribution of fault currents and therefore the following 3D diagrams depend on these parameters.

Test of shunt resistor size

We have considered shunt resistance 11 Ω as the value of equipment of German producer mat - Dr. Becker GmbH. Now we will verify the suitability of this value depending on the resistance of fault. The following diagram shows the size of fault current while the shunt resistance changes from 0 to 100 Ω with the fault resistance ranging from 0 to 2000 Ω. The fault distance from the supply transformer station is 1 kilometre as the worst condition.

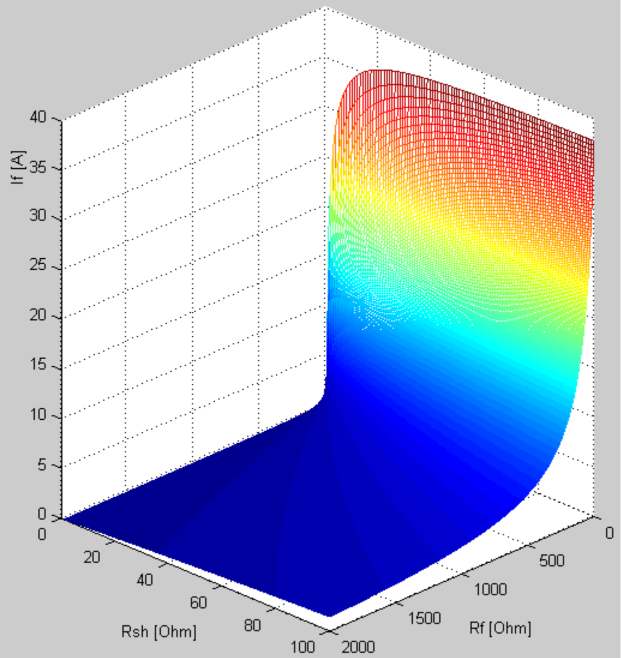

Figure 5: Fault current in dependence on size of shunt resistor and fault resistance.

The positive effect of shunting method decreases with low-impedance faults. Generally, the worst fault condition is zero resistance of fault while high resistance of shunt and the fault is near the supply transformer station.

However, the fault current is reliably conducted into the circuit of shunt when the shunt resistance is around 10 Ω and also for low-impedance faults at the distance 1 kilometre. This can be seen as a very positive result.

Dependence on the size of the capacitive current

In this test, we change the extent of capacitive current in the range of 50 to 850 A and we follow the size of the fault current at the earth fault. The earth fault is now located 1 km from the transformer station and again fault resistance should be also changed.

The resulting Figure 6 shows the positive effect of shunting method even for a very large capacity network.

When low-impedance fault occurs, the fault current at earth fault can rise extremely with the extent of capacitive current. In this case, almost no current flows through the circuit of shunt resistor.

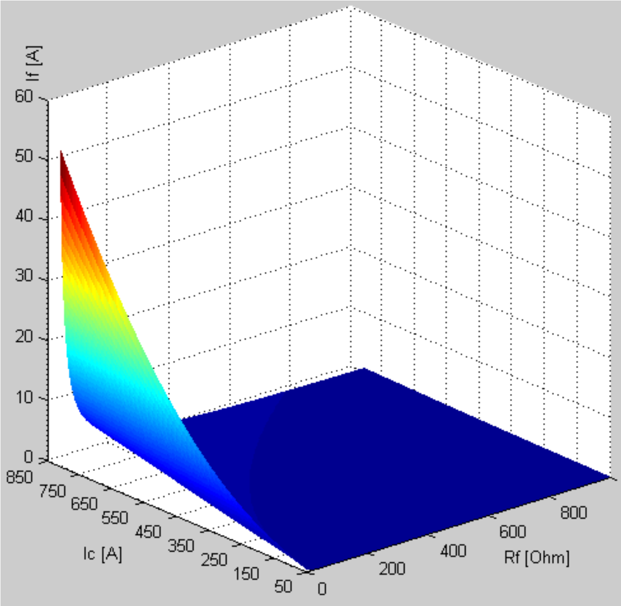

Figure 6: Fault current in dependence on the extent of capacitive current and fault resistance.

The method significantly reduces the residual current in the whole range of simulated capacitive network with fault resistance 100 Ω or more.

CONSLUSION

Low-impedance fault in the vicinity of the transformer station is the most unfavourable condition. In this case, which is less probable, the shunting method has no effect on reducing the size of fault current at the earth fault point. Generally, the method has 50 % efficiency with 20 Ω of fault resistance and 20 km of fault distance. Fault currents are almost independent of the fault distance from the supply transformer station when fault resistance is higher than 30 Ω. The size of power shunt resistor 11 Ω (for mat Becker equipment) was proved appropriate because it provides reduction of fault current even with low-impedance faults. The shunting method proved also positive for very large capacity network. The method of earthing of affected phase was verified by experimental measurements [7] and their results support the theoretical calculations in this paper.

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