NEW SOLUTION OF IDENTIFICATION OF HIGH-IMPEDANCE EARTH-FAULT IN COMPENSATED MV NETWORK

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ABSTRACT

The identification of high-impedance earth-faults in MV network is a very difficult due to low level of measurement signals for commonly used protections operation scheme. New method of high resistance fault detection based on additional signal injection in neutral point of the network is presented in this paper.

INTRODUCTION

The most of the MV distribution networks in Poland are networks with neutral point grounded by Petersen's coil. Exploitation experience acquired from existing MV networks shows, that a singular earth-fault disturbances where value of a cross-fault resistance is over a dozen kiloohms or even much higher are appeared. In such case the value of zero sequence voltage is below the start-up value of earth-fault protection device and this kind of fault can remain undetected what effects in particular threats. One of a method that allows for identification of such fault, is inclusion of an external diagnostic signal in neutral point of the MV network. Such function is built in Earth-fault Parameters Meter (MPZ) developed in Institute of Electric Power Engineering of the Poznan University of Technology [1,2,3,4]. The existence of stationary MPZ systems allows also for use the forcing modules of these devices to accomplish tasks in a power protection systems.

The authors made an attempt of utilization of the effect resulting from the enforcement an additional asymmetry of zero sequence voltage in neutral point of a network for identification of a high-resistance earth-fault in a MV line. Issues of this type refer to an signal injection methods used for the earth-fault compensation level control and earth-fault identification [5,6]. Large value of the impedance of the short-circuit loop causes lowering of the level of measuring signals, the zero-sequence component of voltage and current (U_0, I_0) used by earth-fault protection. Dependence on the value of transition resistance the value of zero-sequence voltage in compensated 15 kV network (the total value of the capacitive network current equal to 86 A and damping coefficient d_0 equal to 0,04) for different values of the earth-fault compensation coefficient s is shown in Figure 1.

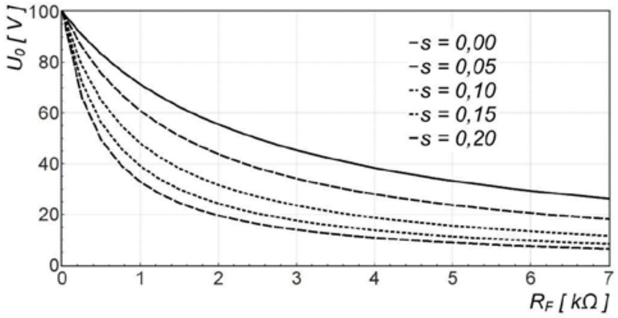

Fig. 1. Influence of resistance R_F on zero sequence voltage U_0 for different compensation coefficients s

Modern earth-fault protection systems used in compensated MV network operate with setting value of U_0 not higher than 0,1 of the rated phase voltage. Using a lower setting value of the zero-sequence voltage U_0 (e.g. equal to 5 V) can cause the detection of earth faults about nearly twice higher the transition resistance. Above-mentioned regularity is shown in Figure 2. Particularly large increment of the detected transition resistance is visible to the network heavily compensated.

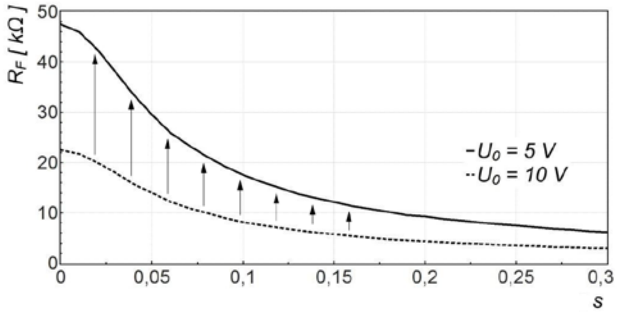

Fig. 2. Dependence on the compensation coefficient s the detectable boundary resistance R_F for different value of zero sequence voltage U_0

The utilization of changes of the earth-fault parameters caused by advent of asymmetry of zero-sequence voltage with value approximately 10% of the phase voltage of the network during operation of the MPZ system offers new opportunities of activation of the earth-fault protection and define an identification criterion of the high-resistance earth-fault in a line.

THEORETICAL ANALYSIS

Comparison of two equivalent circuits (Fig.3) shows that inclusion of additional voltage U_w in neutral point affects on measured values of the zero sequence admittance in a faulted line.

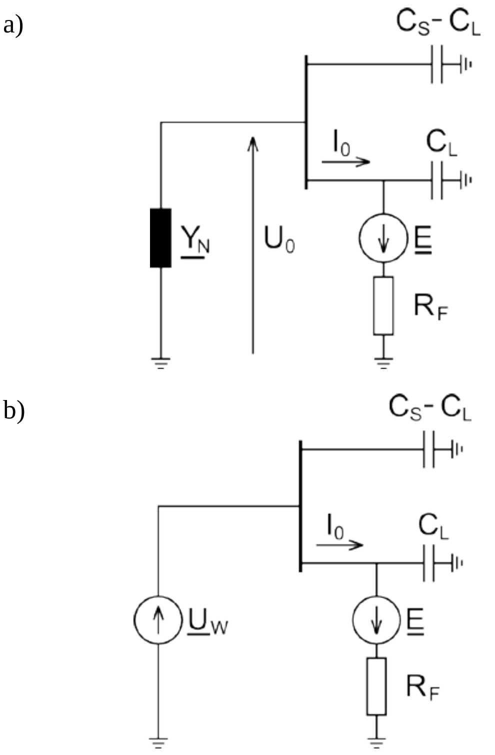

Fig. 3. Equivalent circuit of a MV network before (a) and during an additional zero sequence asymmetry forcing (b)

This dependence is explained in equations below:
- admittance before inclusion of voltage U_w

$$Y_0 = \frac{I_0}{U_0} \approx \omega \cdot C_S \cdot \left[d_{0S} + \mathrm{j}(s-a)\right] \qquad (1)$$

- admittance after inclusion of voltage U_w

$$Y_0 = \frac{I_0}{U_w} \approx \frac{E + U_w}{U_w \cdot R_F} + \mathrm{j}\omega \cdot C_S \cdot a \qquad (2)$$

where:

ω – network pulsation,
C_S – earth-fault capacitance of network,
d_{0S} – damping coefficient of network,
s – earth-fault compensation coefficient,
a – line share coefficient.

Using the scheme shown in Figure 3, components of I_0 current are calculated formulas:

$$I_{cz} = \frac{U_w + E \cdot \cos\varphi}{R_F} \qquad (3)$$

$$I_b = \frac{E \cdot \sin\varphi}{R_F} + \omega \cdot U_w \cdot C_L \qquad (4)$$

where:

I_{cz} – active component of I_0 current,
I_b – reactive component of I_0 current,
U_w – additional voltage connected to neutral point,
E – EMF in grounded phase,
R_F – cross-fault resistance,
ωC_L – zero-sequence susceptance of line,
φ – angle between phasors E and U_w.

Value of coefficient ***d*** is obtained from relation:

$$d = \frac{I_{cz}}{I_b} = \frac{U_w + E \cdot \cos\varphi}{E \cdot \sin\varphi + \omega \cdot R_F \cdot U_w \cdot C_L} \qquad (5)$$

and its absolute value is computed from equation:

$$d = \left|\frac{I_{cz}}{I_b}\right| = \left|\frac{U_w + E \cdot \cos\varphi}{E \cdot \sin\varphi + \omega \cdot R_F \cdot U_w \cdot C_L}\right| \qquad (6)$$

Control system of the additional voltage forcing circuit should have ability to adjust phase shift of voltage U_w to value of phase shift of the voltage in the earthed phase of the faulted line. In Table 1 the values of ***d*** coefficient for different values of angle φ are shown, with assumption that: E= 8660 V, U_W = 10%E, ωC_L= 0,001 S, R_F = 12 kΩ.

Table 1.
Absolute values of ***d*** coefficient in relation to φ angle

Value of φ angle	Absolute values of ***d*** coefficient
[deg]	[-]
0	0,922
30	0,571
60	0,291
90	0,045
120	0,195
150	0,453
180	0,756
210	1,108
240	1,230
270	0,518
300	1,840
330	1,396

It is clear that for the assumed network voltage, capacity of a grounded line and cross-fault resistance, the biggest value of ***d*** coefficient falls on angle in the range from π to 2 π. This is due to the negative value of this component $E \cdot \sin\varphi$ for those angles and reducing the value of the denominator in the Eq. 6. This effect is more pronounced for smaller R_F resistance or lower capacity of a faulty line.

A changes in measured admittance of damaged line after inclusion of voltage U_w can be observed using various parameters characterizing earth fault circuits. For example, it may be the ***d*** coefficient, defined as in Equation 5. To confirm described capabilities, simulation studies were carried out using EMTP applications as well as the research on the physical model of the MV network.

TEST RESULTS

To confirm the validity of the conclusions of the theoretical analysis, laboratory tests were run. To this end, a series of the computer simulations and experiments on the physical model of the MV network were made. Using the PSCAD software the model of the compensated MV network with parameters listed in Table 2 was created. The system of forcing additional voltage U_w, module simulating the natural asymmetry of the network and system for modeling earth faults in selected phase with the declared value of transition resistance were also created and included into the network model. In addition, it was possible to determine the shift angle between a selected phase voltage and forcing voltage U_w.

Table 2.
Selected parameters of 15 kV network modeled with PSCAD application

Total earth-fault capacitive current of the network I_{CS}	100 A
Earth-fault capacitive current of faulty line I_{CL1}	30 A
Damping coefficient of network d_0	0,03
Current of Petersen's coil I_L	115 A
Earth-fault compensation coefficient s	0,15

The studies looked at the value of ***d*** coefficient of faulted line with value of the fault resistance equal to 20 kΩ in the state before and after the inclusion of the voltage asymmetry. In all examined fault cases before inclusion of the additional voltage source, the value of the ***d*** coefficient was about 0,03. After forcing the asymmetry the value of ***d*** coefficient grew up from few to several times. The highest values were observed at shift angle φ close to zero or π.
An important finding of the simulation studies is appearance of explicit changes in the value of the coefficient ***d*** in faulted line at the moment of the additional voltage inclusion during an earth-fault occurrence while in healthy line the value of coefficient ***d*** is small and its change is inconsiderable.

Subsequent studies was carried out on a physical model of the MV network with the following parameters:

- rated network voltage – 400 V,
- power transformer – 5 kVA, 400 V/400 V, winding connection Yd,
- grounding transformer – 5 kVA, 400 V/400 V, winding connection Zy11,
- Petersen's coil – 5 kVA, 230 V, I = 12 ÷ 25 A, tap controlled with 12 taps,
- line 1 – earth-fault capacitive current I_{CL} equal to 12 ÷ 14 A, Ferranti CT 100/1,
- line 2 – I_{CL} = 6 ÷ 8 A, Holmgreen CT 20/5,
- line 3 – I_{CL} = 2 ÷ 3 A, Rogowski coil.

The research included the following tasks:

- phase to ground fault was made in line 2 by the the resistance value chosen so that the value of U_0 voltage is at level of 8 percent of network phase voltage,
- Petersen's coil was tuned exact to the level of compensation,
- in neutral point additional source with voltage at level of 12 percent of network phase voltage with ability to change phase shift angle was connected,
- recordings of transient waveforms of the zero sequence voltage U_0 of network and the zero sequence current of faulted line I_0,
- computer analysis was made on recorded waveforms with removed the higher order harmonics for both U_0 and I_0 signals, basing on these signals the value of ***d*** coefficient was calculated.

Selected results for the healthy and damaged lines during occurrence of the earth fault and inclusion of additional source with different values of phase angle of the voltage U_w are presented in tables below. In Table 3 is shown the values of the coefficient ***d*** in a faulted line (line 2), while in Table 4 the values of the coefficient ***d*** recorded in the line 2 during the earth fault in line 1 are presented.

Table 3.
The values of coefficient ***d*** for selected case of faulty line

Value of φ angle	Value of ***d*** coefficient
[deg]	[-]
30	0,54
90	0,02
150	0,60
210	0,32
270	0,01

Table 4.
The values of coefficient ***d*** for selected case of healthy line

Value of φ angle	Value of ***d*** coefficient
[deg]	[-]
30	0,05
90	0,08
150	0,04
210	0,07
270	0,06

The effect of the injection of the additional signal in the neutral point of the network during the high resistance earth-fault is visible in the phase shift between the signals of the zero-sequence components of current and voltage, this change in a faulted line is clearly visible. Example waveforms of zero sequence component of current and U_w voltage for faulted and healthy line are shown in Figure 4.

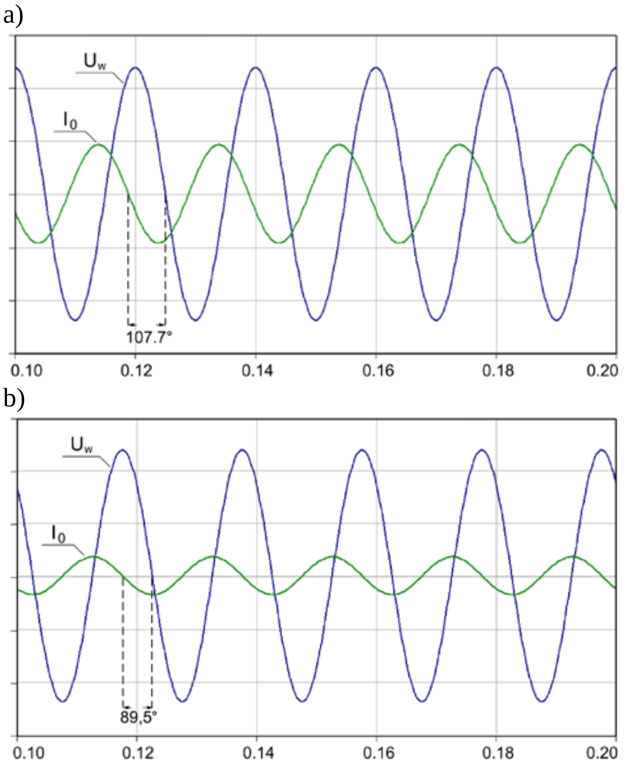

Fig. 4. Example waveforms of I_0 and U_w for faulted (a) and healthy line (b)

The results obtained from the physical model of the MV network also explicitly confirmed ability of using the value of coefficient ***d*** in the implementation of the criteria for identifying line stricken by high resistance short-circuit.

FINAL REMARKS

Results of previous studies based on simulations and laboratory tests have led the authors to attempt to develop the concept of high resistance earth-fault identification algorithm in compensated MV network equipped in device to forcing additional voltage asymmetry. For identification of these earth-fault a protection reacting on value of the coefficient ***d*** can be used.

The benefits of new protection operation scheme are:
– increasing a high impedance earth-fault detection speed,
– much higher impedance boundary of identificated fault,
– improved reliability and safety of a network.

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