The Modern Solutions Applicable in Determination of Earth-Fault Parameters in the MV Network

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Abstract—**This paper presents modern applicable methods of measurement of the earth-fault parameter of the MV network. Methods based on additional source of forcing of the network voltage asymmetry are described. The aspects of practical use of such methods are revealed. The notes of exploitation experience of authors with use of devices utilizating these methods are presented.**

Keywords;* *compensated MV network, earth-fault current compensation coefficient, earth-fault parameters meter, pulse injection, additional voltage source

I. INTRODUCTION

The Petersen's coil with tap controlled inductance is most popular device used for earth-fault capacitance current compensation in polish MV distribution network [1],[2]. Large amount of manufactured coils are devices with selected range of compensation currents (typical range from 15÷30 A to 100÷200 A). These devices usually have five switching taps for inductance control. Parallel connection of two inductors allows to accurate selection of reactance, what effects in better adjustment of coil parameters to network condition. The ability of inductor tuning depends on device construction and earth-fault capacitance current value. Together with increasing the maximal value of nominal current of the coil resolution of setting value is decreased.

The change of MV network topology causes the change of value of the network's earth-fault capacitance. Maintenance of the required earth-fault compensation coefficient using tap controlled inductors is possible, but continuous verification of compensation tuning is needed. The assessment of earth-fault compensation coefficient can be done with various existing methods.

The only one method used to obtain the earth-fault parameters' values until recently was a technical method based on earth-fault test. This method has a few disadvantages. During the test the overvoltage appear in a network, which results in damage of insulation or substation devices. The earth-fault test requires switching-off the line, what finally causes lack of the power supply. This inconvenience effects in a small amount of the fault tests carried out.

The another method of the earth-fault parameters' determination used in case of lack of possibility of the test making is analytic calculation method. However, application of this method demands in-depth knowledge of MV network structure (overhead lines, wires and cables data required), what is sometime difficult to obtain. It is become an impulse to development of the brand new technical methods of earth-fault parameters assessment, where the information about earth-fault parameters are achieved based on measurement taken during connection additional voltage source to neutral point of the MV network.

Therefore different types of source are used: fixed frequency source, variable frequency source and pulse source. Common method widely used in Poland utilize additional source working with fixed frequency with the fundamental frequency of the power grid. Systems based on this solution were developed in Institute of Electric Power Engineering of the Poznan University of Technology and is still under improvement process. In following sections of this paper selected methods are described.

II. VARIABLE FREQUENCY SOURCE METHOD

The method based on additional current source was developed also in China [3],[4]. It relies on variable frequency current signal injection into neutral point of the network. The scheme of the measurement circuit for this method is presented in Fig. 1.

While current signal I_w with variable frequency is injected into neutral point of the network, the U_p voltage signal is recorded. To obtain the network resonant frequency f_0 value, the frequency of I_w current should be found, for which the phase shift angle between forced current I_w and measured U_p voltage. There are two solutions of this problem: first method is based on changing the value of frequency of the forcing source with fixed step, however research process is time consuming and relatively inaccurate, second method utilize the interpolation algorithm.

III. FIXED FREQUENCY SOURCE METHOD

The MPZ meter (pol. Miernik Parametrów Ziemnozwarciowych, in eng. Earth-Fault Parameters Meter) allows to designate value of earth-fault compensation level in normal operating condition of the network

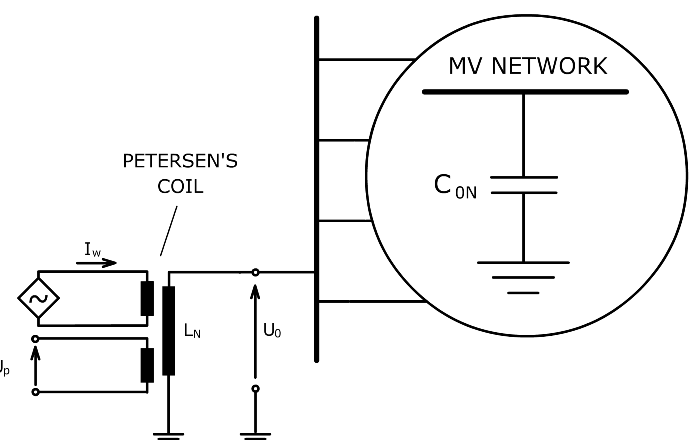

Figure 1. Scheme of equivalent circuit for variable frequency source method.

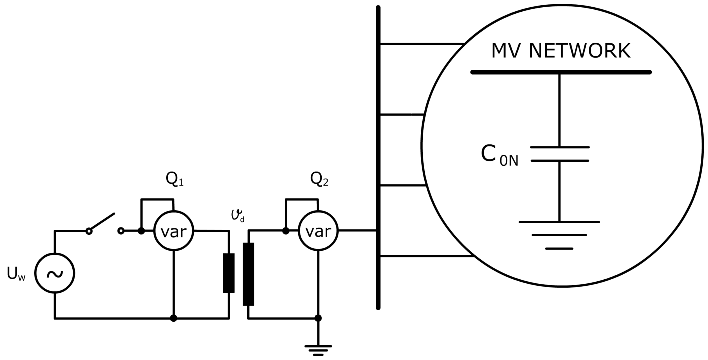

Figure 2. Scheme of equivalent circuit for fixed frequency source method.

(without a fault). The MPZ meter can operate as autonomous device or as a part of the algorithm within power protection device or system. In MPZ system measuring signals are obtained in the result of appearance of the additional voltage in neutral point of the network. The method described in patent No PL-150320 is used in the MPZ device for determination of the earth-fault parameters of the network. This method can be applied for compensated networks with active current forcing component. The scheme of measuring system is shown in Fig. 2.

Additional fixed frequency voltage source is connected to current forcing circuit of the compensation coil and voltage generated by this source is transformed to network's rated voltage level. Calculation of the earth-fault current compensation coefficient is based on one of the following method: power method or susceptance method. The basic rules of both method are presented in next subsections.

A. Reactive power method

The power method is also called varometer method, because the measurements of reactive power are used for calculation of the results, measuring circuit is shown in Fig. 2.

If two measured values of reactive power are known:
Q_1 – value of reactive power taken from voltage source U_w,
Q_2 – value of reactive power of the load of additional source caused by network capacitance C_{0N}.

The value of the earth-fault current compensation coefficient s can be determined based on:

$$s = \frac{Q_1}{Q_2}. \tag{1}$$

For practical use the following assumption is made, overcompensation state is marked with positive sign and undercompensation with negative sign.

B. Susceptance power method

Taking for calculation values of measured voltage U_w and U_0, instead of reactive power values the susceptance of each circuit can be determined, what can be formed as (2) and (3):

$$B_1 = \omega C_{0N} \upsilon_d^2 s, \tag{2}$$

$$B_2 = \omega C_{0N}. \tag{3}$$

The value of earth-fault current compensation coefficient s is determined with following relation:

$$s = \frac{B_1}{B_2} \frac{1}{\nu_d^2}. \tag{4}$$

Similar to varometer method the following assumption about sign of the coefficient s is made: overcompensation state is marked with positive sign and undercompensation with negative sign.

IV. Network's resonance frequency method

The concept of RSB–MPZ system (pol. Rozproszony System Bezprzewodowy – Miernik Parametrów Ziemno-zwarciowych, in ang. Distributed Wireless – Earth-Fault Parameters Meter), which is capable to determine the earth-fault parameters of the compensated MV network and line share ratios under normal operating conditions (without a fault) is based on distributed measurement system installed in MV substation [5],[6],[7]. The basis for earth-fault parameters calculation such as: earth-fault current compensation coefficient, line share coefficient and damping coefficient are measurements of residual values of voltage and current (U_0, I_{0Li}) taken simultaneously in each line bays of the MV substation during operation of the additional voltage source U_w connected to the forcing winding of compensation reactor. According to measured signals, earth-fault current value for i-th feeder can be obtained as:

$$I_{CLi} = \frac{U_n}{\sqrt{3}} \frac{I_{0Li}}{U_0} \nu_i, \tag{5}$$

where:
I_{CLi} – earth-fault capacitive current of the i-th line,
U_n – rated voltage of the network,
U_0 – zero-sequence voltage component measured during additional voltage source Uw operation,
I_{CLi} – zero-sequence current component measured in the i-th line during additional voltage source Uw operation.

In practice all measurement data are taken from secondary circuit of MV distribution substation, therefore zero-sequence voltage component value measured at secondary winding terminals of voltage transformers

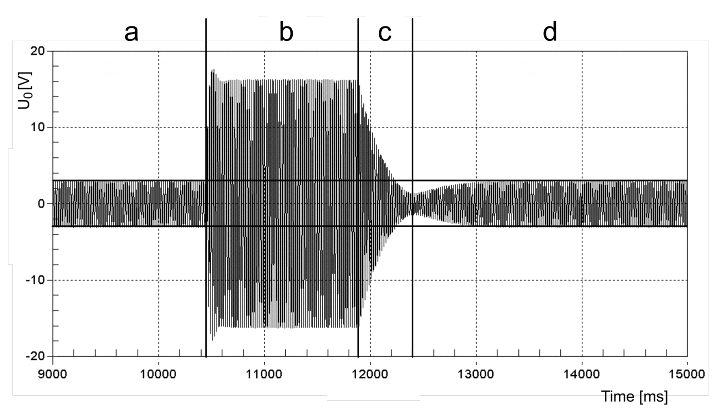

Figure 3. The waveform of the residual voltage recorded during measurements: a) normal operating state, b) additional voltage source connected, c) damped oscillations after additional source disconnection, d) normal operating state.

during additional voltage source operation can vary from 0 V to 100 V, so the formula (5) can be written in practical form:

$$I_{CLi} = 100\frac{I_{0Li}}{U_0}\nu_i, \tag{6}$$

where:
U_0 – value is measured at zero-sequence filter during additional source operation.

Determination of earth-fault current compensation coefficient and network damping coefficient value using this method is more complicated. The method is based on resonance circuits theory and requires knowledge about U_0 voltage transient after switch-off of additional voltage source from secondary winding of Petersen's coil. Developed method of earth-fault parameters determination allows to obtain the values of the earth-fault current compensation coefficient s and networks damping coefficient d_0. It is based on measurement of U_0 voltage frequency changes – characteristic part of recorded signal has to be found, where the amplitude envelope and frequency changes in very particular way while the additional voltage source is operating.

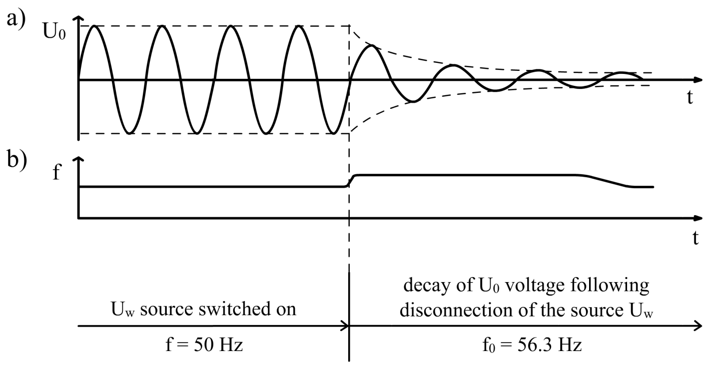

Figure 4. The waveform (a) of the residual voltage and calculated corresponding frequency (b) during measurement process recorded in compensated network ($s > 1$).

Fig. 3 presents U_0 voltage transient during the operation of the additional voltage source connected to neutral point of MV network. Characteristic fragment of U_0 voltage waveform, where damped oscillations occur, is used for earth-fault current compensation coefficient value determination and marked in Fig. 3 with letter "c".

Assuming that circuit leakage is about 2÷3%, the frequency of fading out fragment of the U_0 waveform is a result of parameters of the resonance circuit. The calculation of the value of the resonance frequency f_0 is based on length of a single period of U_0 signal. The determination of beginning of the damped oscillation occurrence is based on changes of the frequency and the amplitude envelope. The calculations of earth-fault current compensation coefficient s and damping coefficient d_0 are based on average frequency taken from first four periods of damped oscillations of U_0 waveform.

The following formulas are used:

$$s \approx 1 - \frac{f_0^2}{f^2}, \tag{7}$$

where:
f_0 - average frequency of damped oscillations,
f - fundamental frequency of the network,

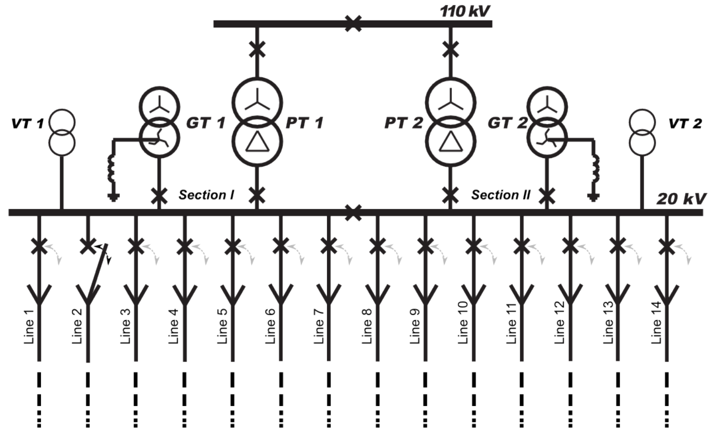

Figure 5. Scheme of 20kV network with disconnected line No. 2.

and

$$d_0 = \frac{1}{T_0}\ln\left(\frac{A_n}{A_{n+1}}\right), \tag{8}$$

where:
A_n, A_{n+1} – values of succeeding U_0 signal extremes after source disconnecting,
T_0 – time between subsequent extremes of U_0 signal during oscillations.

The asymmetry voltage U_{asc} can cause in error in earth-fault current compensation coefficient calculation, therefore a solution for reduction of impact of the U_{asc} have been proposed. Measured U_0 signal is composed of two components: asymmetry voltage U_{asc} and additional voltage source U_w. When parameters of U_0 signal before additional source operation are known, and making assumption that frequency and amplitude of subcomponent originated from U_{asc} voltage is constant

TABLE I
COMPARISON OF RESULTS OF THE COEFFICIENT s OBTAINED FROM FIXED SOURCE METHOD (FSM) AND RESONANT FREQUENCY METHOD (RFM)

Disconnected Line No.	Coefficient s [%] FSM	Coefficient s [%] RFM
1	18.82	17.36
2	N/A	118.71
3	35.02	31.26
4	43.87	39.85
5	36.24	33.45
6	-8.12	-6.96
7	12.50	11.56
8	1.69	1.87
9	3.63	3.59
10	1.30	1.52
11	7.95	7.62
12	2.77	2.88
13	7.88	7.38
14	8.10	7.74

N/A-Measurement result not available for this method in time domain during the measurement, the U_{asc} component can be reduced with mathematical operations on U_0 voltage sampled data.

The verification of described earth-fault current compensation coefficient and damping coefficient determination method was based on results of simulation, measurement in MV network and analytic calculation. The comparison of obtained results confirmed that developed method can be applied for earth-fault parameters determination.

The results of measurement presented below comes from registration made with power protection device (CZIP system) in typical 20 kV network (Fig. 5) in normal operating conditions, during operating of the MPZ system based on additional fixed source method. For each result given in table the different line feeder was disconnected from the substation busbars for the measurement purpose.

The values of s coefficient obtained with developed algorithm are approximate to results given by MPZ meter. When line No. 2 is disconnected, the MPZ meter is out of measurement range, but with new method it is still possible to determine the value of the earth-fault compensation coefficient.

V. Conclusion

Developed in Institute of Electric Power Engineering of the Poznan University of Technology the MPZ systems based on different methods helps to determinate values of following parameters: earth-fault compensation coefficient, network damping coefficient and line shares of network capacitive current.

The RSB–MPZ system allows earth-fault parameters determination in compensated MV network with continuous electrical power delivering to consumers. The earth-fault parameters assessment is provided by zero-sequence current and voltage measurements using distributed data acquisition system installed in MV substation. The measurements are taken simultaneously by each sensor and controlled by supervising unit. Obtained results are stored in database for future analyze. Field tests confirmed operational correctness of the system. The test results are comparable with estimated values of earth-fault parameters. The best advantage of RSB–MPZ is ability to determining value of earth-fault coefficient s with single measurement of U_0 waveform. In the future, measurement result could be used to automatic setting system of earth-fault relays in case of the network configuration change.

References

[1] A. Leikermoser, F. Ortolani, *New techniques for compensated networks: tuning the Petersen coil, determining the network parameters and preforming earth-fault current prediction and reconstruction*, CIRED,19th conference on electricity distribution, Vienna. May 2007

[2] A. Leikermoser, F. Ortolani, *Neutral compensation and network monitoring - test field experience in determining resonant point and homopolar parameters with active and passive pulse injection*, CIRED, 20th conference on electricity distribution, Praga, 2009.

[3] X. Yao, Z. Xiangjun, L. Zhanglei, Y. Wentao, *Novel Control Techniques of Petersen Coil*, IEEE International Conference on Industrial Technology, Chengdu, 21-24 April 2008.

[4] X. Yao, Z. Xiangjun, W. Yuanyuan, *Some Novel Techniques for Insulation Parameters Measurement and Petersen Coil Control in Distribution System*, IEEE Trans. on Industrial Electronics, 2009.

[5] B. Staszak, J. Handke, J. Lorenc, *Earth fault MV network parameters: measuring procedures in the RSB–MPZ wide-spread measuring system*, Poznan University of Technology Academic Journals In Electrical Engineering, Poznań, 2008.

[6] J. Handke, A. Kwapisz, J. Lorenc, B. Staszak, *Wireless wide-spread data acquisition system for ground-fault parameters*, Poznan University of Technology Academic Journals In Electrical Engineering, Poznań, 2007.

[7] J. Handke, *Wireless distributed data aquisition system for ground-fault parameters determination*, Intertech 2008 - I International Interdisciplinary Technical Conference of Young Scientists, Poznań, 2008.