LIMITING THE DANGER OF ELECTRIC CURRENT SHOCK IN RELATION TO THE MEAN OF NEUTRAL POINT EARTHING IN THE MV NETWORKS

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SUMMARY

The factors affecting the danger of electric shock caused by earth faults in medium voltage networks have been discussed. A particular attention has been paid to the earthing of MV poles and MV/LV substations. The dependence of the hazard voltage level on MV network zero or neutral point earthing arrangement and on the operation efficiency of earth fault protection systems has been presented. The reliability of overcurrent and admittance protection systems operation for different values of resistance in a place of earth fault have been analysed.

1. INTRODUCTION

In Poland, the medium voltage falls in the range between 1 and 60 kV. However, in practice the distribution network voltages are 15 kV and 20 kV but 6 kV and 10 kV may still be found, whereas the networks owned by MV customers are often 6 kV rated. The distribution networks are predominantly cable laid in urban areas and mixed overhead and cable laid beyond municipalities.

An increase in earth fault capacitance current results from the development of cable-laid networks, however the most dangerous effects of such increase are observed in the aerial part of these networks. In Poland, there is practically no record of electric shock accident occurring alongside the cable-laid networks nor in the substations powered by cable-laid networks.

Unfortunately such accidents occur in the aerial networks due to the lack of proper earthing systems or a lack of tripping by earth fault protection systems rather than by the lack of compliance with supplementary protection rules and conditions applied in Poland.

An example of such hazard, which actually no precautions are available against, would be a damage to a conductor grip causing a lowering of this conductor between the poles so much that a human being is able to make an accidental contact with it.

The safe operation of cable laid MV networks and the low voltage network supplied by them is the result of a number of factors like:

- lying the cables underground excludes the hazard of making contact with them,
- earth fault are characterised by low values of current flowing to the earth (the earth fault current returns paths are cable return conductors and cables metal sheaths),
- in most cases the transition resistances in the place of the fault are small, what in turn enables easy detection of an earth fault by protection relays,
- during earth faults on MV/LV substations the strong interacting of magnetic conjugation between the cable main conductors and of the return conductor or the cable sheath decrease the current flow to ground through the station's earthing,
- usually the earthing resistances of a MV/LV substations are small due to its connection with the cable return conductor or the cable sheath and due to its connection to PEN conductor of low voltage lines,
- equalisation of potentials in the urban areas by the use of natural earthings (existing accessible underground metal structures).

In the aerial networks MV the danger of electric shock caused by the earth fault may appear in the place and in the vicinity of the earth fault current flow to the earth. It should be mentioned that in Poland concrete steel reinforced poles are widely used, sometimes steel construction poles can be seen whereas the wooden ones are seldom encountered. Different phenomena, listed below, are to be dealt with depending on a location of an earth fault:

- near the MV poles equipped with additional protection based on protective earthing the problem of dangerous shock touch voltage appears, whereas in case of a earth fault on such pole the conditions are preferable for the detection of such earth fault by protections due to low transition resistance to the earth; only the arcing earth faults with unstable current may pose some problems,
- near the MV poles without the necessity of additional earthing installation, especially on sandy soil characterised by the high resistivity when the level of hazard touch voltages is significantly greater than the acceptable one, the earth fault detection by protection relays maybe the problem,
- in other locations near a bare conductor of an aerial line after its falling onto the soil or onto the garden fence for example, the phenomena cannot be quantitatively analysed and the electric shock danger depends on effectiveness of the earth fault protection system,
- at a MV/LV substation the danger appears in form of important touch and step voltages near the substation earthing caused by current flowing through it and is distributed through a protective wire PE of the TN type low voltage networks to the attached covers of customer electric devices in cases when the protective and neutral point earthings are not separated. In fact, the majority of the LV networks in Poland operate under TN arrangement, which is considered by a number of authors [1] to be the best one, and the separation of earthings is not applied.

2. MEANS OF MV NETWORK NEUTRAL POINT CONNECTION TO THE GROUND

In Poland, the following means of MV network neutral point connection to the ground are common:

- isolated neutral system which is more and more rare and has only prevailed in the networks with small capacitance current,
- arc suppression coil earthing (Petersen coil) which is the most common and particularly present in the utility owned distribution networks,
- resistance earthing which is widely applied in the cable-laid networks and boasts a growing share in the aerial networks.

The aerial network with neutral point earthed via a resistor is deprived of the advantage of systems equipped with a arc suppression coil that is extinguishing a considerable part of temporary earth faults with no need of autoreclosing.

It is scheduled for this year in Poland to start operation of networks earthen via a system of resistor and Petersen coil in parallel. The rules to be followed for such mean of MV neutral point operation have been elaborated in Poland by the authors of this paper. A suitable choice of parameters of the devices located at the neutral point, aiming to limit the MV network overvoltage level during the earth faults, enabled nearly two-fold reduction of the earth fault current comparing to the resistance neutral earthing for the same level of MV overvoltages. That implies that the conditions for protective and system earthings are less demanding [2].

The connection of MV network neutral point to the earth by a resistor is willingly applied as it limits the MV network overvoltages during the earth faults and this in turn makes cable faults less likely .

In Poland the parameters of earth fault protections are no longer a valid argument for exchanging a Petersen coil with a primary resistor.

It is known that in protection systems against the earth faults the overcurrent criterion mustn't be applied in the compensated networks. This accounts for the worldwide use of the directional protections sometimes equipped with an additional unit forcing the active zero sequence current component (AWSCz) for the protection purposes. However, the directional criteria are not always reliable what is particularly the case during the arcing earth faults and in cases where the higher harmonics deform the current's curve. In such cases the determination of the angle between fundamental harmonic of the zero sequence current and the zero sequence voltage is rather difficult task regardless how sophisticated digital methods might be employed.

In Poland, the admittance protections have become common. The determination of admittance basing on the average values, which are not sensitive to the deformations, proved very efficient in the case of arcing earth faults [2]. During last two years the digital protection system CZIP, elaborated partly by Poznan University of Technology, have functioned very well. It seems that this concept of protection against the earth faults can be adapted also elsewhere in the world.

The usage of a primary resistor causes an increase of earth fault currents and entails stricter demands for additional protection earthing against the electric shock in the earthing points. The effect of the network's neutral point connection to the earth on a level of electric shock danger and on the efficiency of the protection systems has been discussed below.

3. CONDITIONS FOR THE CHOICE OF DEVICES IN MV NETWORK'S NEUTRAL POINT

Unlike the choice of Petersen coil for a given value of the network's zero sequence capacitance current which is widely agreed to result in slight overcompensation, the choice of a resistor is being argued. In cable-laid networks, because of a minor danger of electric shock, the resistance value forcing the network zero sequence current in the range of 300-500 A is assumed regardless of the capacitance current. In the aerial networks due to increased danger of electric shock when the value of the forced earth fault current increases the resistance value resulting in resistance component of zero sequence current on the level 1.2 of the zero sequence capacitance current component is recommended. Under this condition the overvoltage factor during earth faults are always less than 2.

In the networks earthed by the mixed system of resistor and Petersen coil in the parallel connection of resistance forcing zero sequence resistance current on the level 0.8 of the zero sequence capacitance current was chosen basing on the simulative calculations (3) for the compensation factor in the range of 0.8-1.2 .

4. DANGER OF ELECTRIC SHOCK IN THE NEARBY OF AERIAL NETWORK POLES.

The main cause of danger in the nearby of MV poles stems from the loss of isolation in one of conductors of the line and a flow of current down the pole to the ground.

The shock touch voltage is a function of the earthing current and can be described by the following formulae:

$$\mathbf{U}_{\mathbf{rd}} = \alpha_{\mathbf{d}} * \alpha_{\mathbf{dr}} * \mathbf{I}_{\mathbf{uz}} * \mathbf{R}_{\mathbf{z}} \qquad (1)$$

where

α_d - touch coefficient denoted as a ratio of touch voltage and the earthing voltage resulting from the earthing current flow (this coefficient depends on the potential distribution around the pole and in theory takes any value from the range of 0 to 1 but in practice however the range is narrowed to 0.3-0.7),

α_{dr} - shock touch coefficient denoted as a ratio of shock touch voltage over a touch voltage (theoretical values like above, however the coefficient depends on the resistivity of the soil which implies the dependence on the weather conditions, the measured values sometimes approach the limit values 0 and 1).

R_z - the earthing resistance of the pole

I_{uz} - the earthing current, which in this case equals the current of the earth fault current.

The value of I_{uz} can be described by the following formulae:

$$I_{uz} = \beta * I_{poj} * k_d \quad (2),$$

where:

I_{poj} – earth fault zero sequence capacitance current of the network,

β - the earth fault coefficient.

The earth fault coefficient for earth fault in the vicinity of HV/MV substation through a transition resistance and in the case of neglecting the longitudinal impedance of the network, can be given as

$$\beta = \frac{1}{\left|1 + \omega * C_s * R_z\left[d_z + j(1-k)\right]\right|} \quad (3).$$

The quantities used to determine the earth fault coefficient are described below:

k_d - coefficient of earth fault conductivity of the network which in practical terms is given by:

$$k_d = \left|d_z + j(1-K)\right| \quad (4),$$

C_s – zero sequence capacitance of MV network,

R_z – transition resistance in the place of an earth fault (for example earthing resistance of the pole),

K - coefficient of earth fault current compensation given by:

$$K = \frac{1}{\omega^2 L_d C_s} \quad (5),$$

where:

ω - pulsation of the network,

L_d - inductance of the compensating Peterson coil,

d_z - damping coefficient.

The value of damping coefficient can be calculated using the following formulea:

$$dz = \frac{1 + G_s R_u}{\omega C_s R_u} \quad (6),$$

where:

G_s – earth fault zero sequence conductance of the network (resultant of all the lines, Petersen coil and zero sequence resistive current forcing arrangement - AWSCz),

R_u - earthing resistance of the MV network neutral point.

In the formula (1) one can assume that

$$U_z = I_{uz} * R_z \quad (7)$$

where the quantity Uz is often referred to as the earthing voltage or the potential of earthing with respect to the ground reference. It directly affects the danger of the electric shock.

When assuming (7) formula (1) rewrites to:

$$U_{rd} = \alpha_d * \alpha_{dr} * U_z \quad (8).$$

The quantities and the coefficients given above take different values depending on the mean of earthing the MV neutral point connection to the ground. Table 1 contains the example sets of values specific for a 15 kV network with a capacitance earth fault current equal to 86.6 A. When calculating dz coefficient it has been assumed that in a network with isolated MV neutral point G_s=0.2*10^{-3} S whereas in a compensated network it is two-fold greater.

The dependence of the earthing voltage U_z of a pole against its earthing resistance has been plotted in figure 1 and the curves numbering corresponds numbers given in the last column of table 1. The curve number (3) is not marked because the AWSCz arrangenemt almost does not influence the earthing voltage.

Values given in the third row of the table (1) calculated basing on the formula (6) are valid for Petersen coil with the AWSCz (zero sequence resistive current forcing arrangement) device switched on - a configuration analysed further on in the paper.

The earthing voltages and thus the shock voltage are the greatest in a network earthed with a resistor. In case of resistances in the place of the earth fault greater than 20 Ω a similar or slightly higher level of shock voltages may occur in the network with isolated MV neutral point. Among the given examples the compensated network yields the smallest values of the earthing voltages. A parallel connection of a Peterson coil to the resistor results in lowering considerably the level of earthing voltages comparing to the values present in systems with isolated neutral point.

In the case of poles equipped with the additional earthing to protect against the possible dangerous touch voltages the earthing resistances practically do not exceed the value of 30 Ω. In such cases the limitation of dangerous touch voltages is most difficult in networks with isolated neutral point and with resistance earthing of neutral point. The level of shock touch voltages near the concrete poles depends also on :

- shock touch coefficient α_d which in turn depends on the potential distribution around the pole, that is the configuration of the protective earthing,
- hazard voltage touch coefficient α_{dr} which depends on the transition resistance in the place of earthing and which values fall into the range of 0 to 1.

The specifications of 15 kV network with zero sequence susceptance ωC_s=0.01 S. This network was referred to when making the plots presented in fig. 1 and in the example calculations.

Table 1

Method neutral point earthing	d_z	k_d	a number denoting a curve
Isolated neutral point	0,02	1,000	1
Petersen coil (K=1,2)	0,04	0,236	2
Petersen coil with AWSCz (AWSCz current: 20 A)	0,25	0,269	3
Resistor (R_u=80 Ω)	1,27	1,616	4
Resistor (R_u=125 Ω) and Petersen coil (K=1,2)	0,84	0,863	5

In the conditions of high humidity of the soil the value of α_{dr} may approach a disadvantageous value of 1. Its decreasing can be achieved by painting the exposed well conducting parts of the pole and by application of the others isolating coverings. It is not always easy and economically justifiable. There is a hazard of damaging such coverings with a course of time by the atmospheric influence or by casual human interference. Besides, painting the coverings will not limit the step voltages which are not limited by the standards.

The coefficient α_d can be decreased by the appropriate configuration of the protective earthing for example by implementation of ring type earthing instead of a singular horizontal or singular vertical ones.

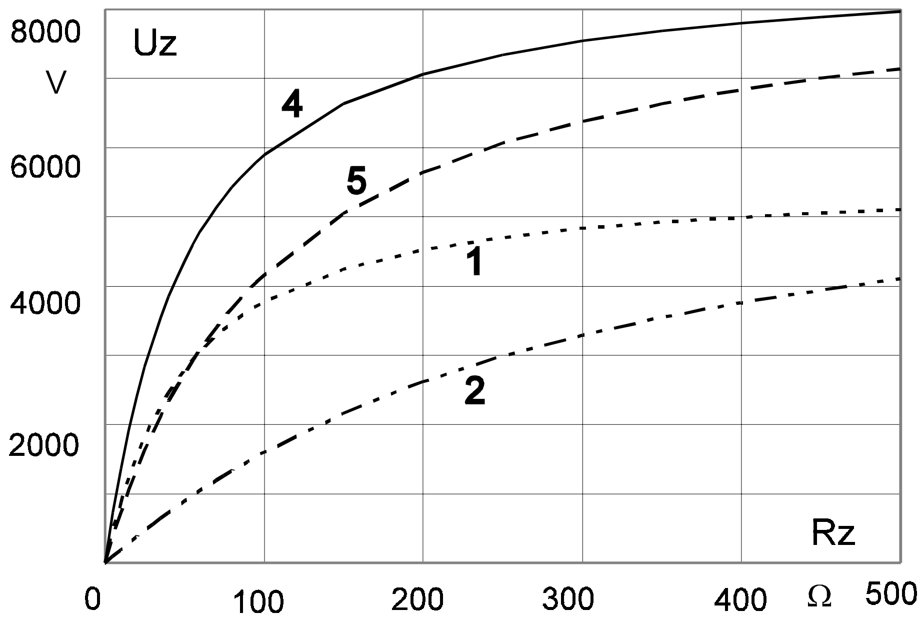

FIGURE 1. Dependence of the earthing voltage U_z on the pole on its earthing resistance R_z. The curves are denoted according to the table 1.

5. ELECTRIC SHOCK HAZARD DURING EARTH FAULTS IN MV/LV SUBSTATIONS

The substations supplied by the MV aerial lines operating together with the aerial LV outgoing lines definitely belong to the most difficult case concerning the electric shock hazard. In such networks the change in the mean of neutral point connection to the earth into resistance requires a detailed analysis of a danger level and should be followed by implementation of the appropriate technical solutions reducing such a danger.

Prior to the decision upon choice of the mean of the neutral point connection to the earth the examination of resistances of substation's earthings should be done. When evaluating the extent of protection against the electric shock the acceptable values of disturbances voltage and touch voltage given in the international standards [4] should be taken into account. It should be mentioned that these standards provide two curves. The first one relates to the disturbances voltage at the earthing of a MV substation whereas the second provides the acceptable values of the touch voltage in a low voltage network during the earth fault in the MV/LV substation. A research carried out in several power distribution companies in Poland has proven that the LV aerial networks of TN type always reveal locations (the buildings situated nearest to the station for example) where almost entire disturbance voltage takes on a form of the touch voltage. It is most likely to be encountered in the older types of LV networks with lack of additional earthings of PEN wire on the poles and in the points of customer connections to the network.

In order to avoid reconstruction of the earthings of MV/LV substations to fulfil the save level of hazard voltages it is necessary to shorten the times of the earth faults and to reduce the earth fault currents to a level imposed by limiting of MV overvoltages taking into account the conditions needed for correct operation of earth fault protection relays.

6. RANGE OF EARTH FAULTS DETECTED WITH THE PROTECTION RELAYS

The efficiency of the earth fault protections as a function of transition resistance in the earth fault place is a second major problem in the MV networks and plays a deciding role on their operation safety. It should be taken account that even the most efficient protection does not totally eliminate the possibility of electric shock accidents. The events like a line conductor falling on an isolating fence are almost undetectable. Mistaken is the claiming that the application of simple overcurrent relays can improve well the reliability of networks with either isolated neutral point or with neutral point earthed with a resistor. The plots presented in figure 2 relate the kcI coefficient versus transition resistance in the place of earth fault denoted as Rp for the three operating modes of neutral point connection to the earth in a network with zero sequence capacitance current equal to 100 A. The plots number (2) and (3) are not analysed because overcurrent protection are not applied for the Petersen coil MV neutral point earthing. The kcI coefficient is defined as a ratio of the zero sequence component of a line's current over a value pre-set in a relay. The remaining assumed parameters of this line are given in table 1. For a zero sequence line current of a 5A (Fig.2a), so having the contribution to the network capacitance current 0.05, the current sensitivity coefficient kcI greater is than 1 for the range of transition up to 700 Ω and the relay is able to trip in such conditions. However, for the zero sequence line current 20 A (Fig.2b), so having the contribution to the capacitance current of 0.2, the range of detectable resistances lowers to 150 Ω regardless on neutral point operation mode. Research conducted in Poland proves the occurrence of numerous earth faults outside the mentioned above range of transition resistances, including the earth faults through the poles with no protective earthings. The greater the contribution of a given line to the network zero sequence capacitance current the worse are the conditions to detect the earth fault using the overcurrent protection.

In this aspect it is recommended to apply the admittance protections with the overvoltage start-up whose usage is limited by the damping of a zero sequence voltage during earth faults through the resistance. The dependence of voltage sensitivity coefficient on resistance value in the place of the earth fault is shown on fig. 3 for the various means of MV network neutral point connection to the earth. The kcU coefficient determines the relation between the measured zero sequence value of voltage and the value pre-set on the relay. The curves from fig. 3 where plotted for the assumption than the pre-set value of zero sequence voltage on the relay, because of possible voltage asymmetry, is 15% of phase voltage for the networks with isolated neutral point and with Peterson coil in the neutral point. In the MV network with neutral point resistance earthing and for the mixed system of neutral earthing there is no important voltage asymmetry so the pre-set level of zero sequence voltage on the relay can be lowered to 5% and such a value was used to obtain the plots in fig. 3.

It can be seen that the best conditions for the protective relays operation exist in the network with the earth fault current compensation. The range of detectable transition resistances in such case reaches 1000 Ω. The mixed system of neutral point earthing is also advantageous because the range of detectable transition resistances is similar to the case of Petersen coil and is greater comparing to the case of neutral point earthing with resistance only or neutral point isolation.

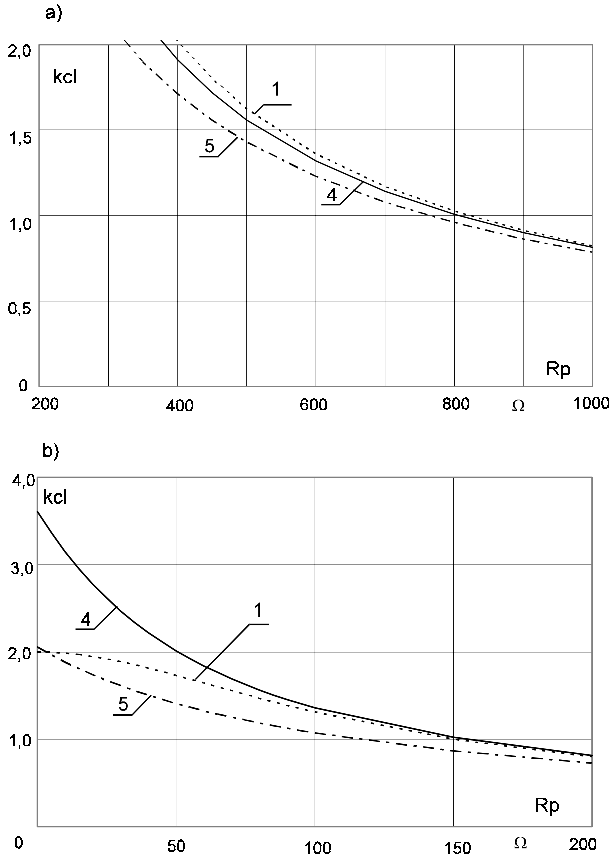

FIGURE 2. Dependence of the current sensitivity coefficient of zero sequence current relays on the transition resistance in the place of the earth fault in the networks with different means of neutral point connection to the earth. The curves are numbered according to table 1. Plot a) refers to the line with contribution to the network zero sequence capacitance current equal 0.05, plot b) to the case when this contribution equals 0.2 .

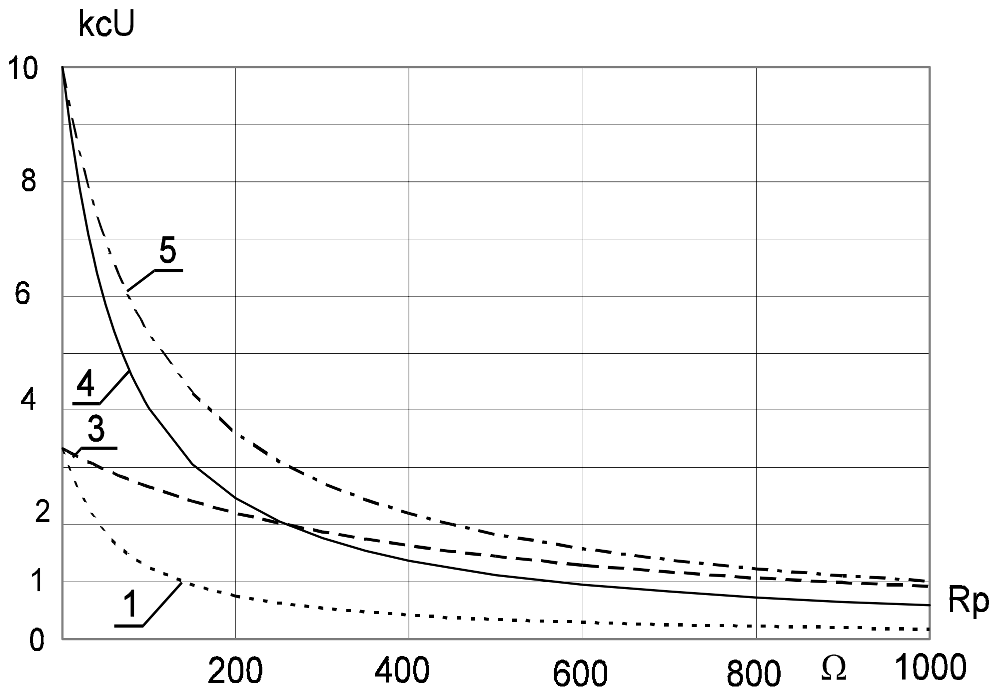

FIGURE 3. Dependence of voltage sensitivity coefficient of admittance relays on transition resistance in the place of the earth fault for different means of MV neutral point connection to the earth. The network parameters and curves numbers are related in table 1.

7. CONCLUSION

The analysis presented shows the interdependence between the electric shock hazard and the operating mode of MV neutral point. The electric shock hazard can be minimised by the careful choice of devices together with their parameters to be connected between the MV neutral point and the earth. The mixed system of parallel arrangement of resistance and Petersen coil seems to be very promising as it keeps the advantages of arc suppression coil and ensures the proper operation condition for the protection system to detect and switch off in acceptable time delays the MV lines with the earth fault.

The hazard voltages existing during the earth faults can be kept within the acceptable limits by the execution of proper protection earthings of MV and LV network components creating the electric shock hazard. Such means provide the proper earthing resistance values and proper voltage distribution in places where the presence of human beings is frequent.

The level of electric shock hazard is also dependant on the effective operation of earth fault protections. In many cases their effectiveness can be improved by replacing the protection modules sensitive to the zero sequence current by the modules sensitive to the zero sequence admittance enabled by the pre-set value of zero sequence voltage. In the designing stage of MV network earth fault protection systems the time delays in switching off the faulted MV lines should be less then 1 second in cases of aerial lines in particular.

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