Artykuł opublikowany: International Conference on Elekctricity Distribution - CIRED, 1-4 June 1999, materiały konferencyjne wydane na CD-ROM pozycja 2_22.

LIMITTING THE DANGER OF ELECTRIC CURRENT SHOCK DEPENDING ON THE MEANS OF ZERO POINT EARTHING IN THE MV NETWORKS

Witold Hoppel, Józef Lorenc
Politechnika Poznańska, Instytut Elektroenergetyki, ul.Piotrowo 3a, 60-965 Poznań (Polska)
tel.+48 61 8782279 - FAX + 48 61 8782280
Jerzy Andruszkiewicz
Energetyka Poznańska S.A. ul,Nowowiejskiego 11, ...Poznań, (Polska)
tel. FAX

SUMMARY

The factors affecting the danger of electric current shock causedby earthing disturbances in medium voltage networks have been discussed. A particular attention has been payed to the earthing of SN posts and MV//nn stations. A dependance of a level of danger on the means of zero point earthing and the efficiency of protection systems has been presented. The reliability of performance of overcurrent and admittance pretection systems for different values of transition resistance in a point of the earthing have been analyzed.

1.INTRODUCTION

In Poland, the medium voltage networks fall in the range between 1 and 60 kV. However, in practice the professional power engineering operates mostly on 15 and 20 kV but 6 and 10 kV may still be found, whereas the industrial power engineering relies on 6 kV. Single networks, regarded as connected galvanic units, in the urban areas are cable-laid, whereas in the remaining areas they are partially cable-laid and aerial.

An increase in shorting capacitor results from the development of cable-laid networks, however it is to the detriment of the aerial part of these networks. In Poland, there is practically no record of shock accident occuring alongside the cable-laid networks nor the stations powered by them.

This is not the case of aerial networks where such accidents occur due to the lack of ellementary protection or failure of earthfault protections rather than lack of complience with supplementary protection conditions.

An example of such hazard, which actually no precautions are available against, would be a damage to a cable hung between the posts causing a fallof this cable enough for a human to make an accidental contact with it.

The security of MV cables and thus medium voltage networks can be implemented by a number of factors like:

-lying the cables underground, which excludes a hazard of making contact with it,

-earthfault shortings along the line with some minor flow of the current to the ground - the circuit is closed mainly by the return conductors (¿y³y powrotne) and cables covering (pow³oki),

-in most cases with small transition resistances in the spot of the fault, which in turn enables easy detection by an earthfault protection,

-during MV/nn faults strong interacting with magnetic conjugation which should reduce the effect of the return conductor or the cable covering and decrease the current flow to ground thriugh the station's earthing,

-small earthing resistances of a MV/nn station as the stations are connected with the return conductor or the cable covering and due to a PEN cable of a low voltage line,

-equalizing the potential in the urban areas with natuarl earthings.

In the aerial networks MV the danger of electric shock casued by the earthfault might appear in the spot and the viscinity of the earthfault current. It should be mentioned that in Poland concrete reinforced posts are widely applied, sometimes steel posts can be seen whereas the wooden ones have been almost entirely replaced. Different phenomena are to be dealt with depending on a location:

-near the MV posts with additional protection based on protective earthing there appears a problem of an electric shock voltage upon contact, whereas in case of a shorting with the earthfault on such post the conditions are preferable for the earthfault protections which is due to low transition resistance, only the discontinuous shortings with unstable current might pose some problem,

-near the MV posts without supplementary protection, assuming a level of shock voltages significantly greater than the acceptable one (which is the case for a sandy soil of a great resistnce value), the earthfault protections might fail to work,

-other locations near a bare wire of an aerial line after falling onto the soil, in a garden for example, which cannot be quantitatively analysed affect the reliability of the earthfault prtections,

-at a MV/nn station the danger appears together with a shock voltage caused by a flowing current through the earthing of the station or its viscinity, a voltage distributed through a protective wire PE of the low voltage networks TN to the attached covers of the electric devices. In fact, in Poland a majority of the nn networks operate under MV system, which a number of authors [1] considers the best, and the splitting of earthings is not applied.

2.THE EARTHING OF A ZERO POINT OF A NETWORK

In Poland, the following modes of performance for a network's zero point are common:
-isolated which is more and more rare and has only prevailed in the networks of small capacitor current,
-earthed via Petesen coil which is the most common and particularly present in professional power engineering,
-earthed via resistor which is widely applied in the cable-laid networks and boasts a growing share in the aerial networks.

The aerial network earthed via a resistor is deprived of the adavantage of a compensated network that is the supressing a considerable part of temporary shortings via Petersen coil with no need for SPZ autoamtics and a switch.

It is scheduled for this year to set to work new networks earthed with a resistor and a Petersen coil in parallel connection whose principles have been elaborated by the authors of this dissertation. A suitable choice of parameters of the devices located at the earthing spot, taking a level of shortings as a criterion, enabled a two-fold reductin of the shorting current. That implies that the conditions for protective and working earthings are less demanding [2].

The earthing with a resistor is willingly applied as it limits the earthfault shortings and this in turn makes a cable fault less likely .

In polish conditions the parameters of earthfault protections are no longer a valid argument for changing a Petersen coil with a primary resistor.

It is known that the overcurrent criterion mustn't be applied in the compensated networks. This accounts for the worldwide popularity of the directionl protections which use an additional unit forcing the active component for the protection purposes. However, the directional criteria are quite unreliable partcularily during the discontinuous
shortings and those where the higher harmonics deform the current's curve.

In these cases the determination of the angle between primary harmonics of the zero current and the zero voltage prove a tremendous task regardless of how sophisticated digital methods might be emplyed. In Poland, the admittance protections have become common. These are based on the average values which are not sensitive to the deformations and prove very efficient in the discontinuous shortings [2]. During last two years they have functioned very well in the digital systems CZIP which were elaborated with the participation of Politechnika Poznanska. This polish concept for the protection can be adapted elsewhere in the world.

The usage of a primary resistor causes an increase of earthing currents and entails stricter damands for additional protection against the electric shock in the earthing spots. The effect of the network's zero point on a level of electric shock danger and on the efficiency of the protections has been discussed beneath.

3.PRELIMINARY CONDITIONS FOR A CHOICE OF DEVICES IN THE NETWORK'S ZERO POINT

Unlike a condition of a choice of a Petersen coil for a given value of the network's capacity current which is widely agreed to be a slight overcompensating, the choice of a resistor is being argued. Because of a minor danger of electric shock in the cable-laid networks a vlue from the range 300-500 A is assumed regardless of the capacitor current. In the aerial networks due to increased danger of electric shock when the current increases a value of 1.2 of the capacity current is recommended. Under this conditionthe shortings are always less than 2.

Whereas in the networks earthed with a resistor and a Petersen coil in the parallel connection a value of 0.8 of the capacitor current was obtained based on the simulations (3) with the compensation factor in the range of 0.8-1.2 .

4.A DANGER OF THE ELECTRIC SHOCK AT THE POSTS OF THE AERIAL NETWORKS

The main cause of danger at a MV post stems from the loss of isolation in one of the working wires of the line and a flow of current down the post to the ground.

The shock voltage upon contact is a function of the earthing current and is described with the following formula:

$$\mathbf{U_{rd}} = \alpha_{\mathbf{d}} * \alpha_{\mathbf{dr}} * \mathbf{I_{uz}} * \mathbf{R_z} \qquad (1)$$

where

α_d - contact coefficient denoted as a ratio of voltage upon cantact over the earthing current (this coefficient depends on the potential distribution around the post and in theory takes any value from the range of 0 to 1, in practice however the range is narrower 0.3-0.7),

α_{dr} - shock coefficient upon contact denoted as a ratio of shock voltage upon contact over a voltage upon contact (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 aproach the limitting values 0 and 1).

R_z - the earthing resistance of the post

I_{uz} - the earthing current, which in this case equals the current of the earthfault shorting given by the following formula:

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

where:
I_{poj} - earthfault capacitor current of the network,
β - the earthfault coefficient which, given near resistance earthing and neglecting the longitudinal impedance of the network, can be given as

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

k_d - a coefficient of earthfault conductivity of the network which in practical terms is given by:

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

C_s -- earthfault capacity of the network

R_z - resistance in the earthfault spot (for example earthing resistance of the post)

K -- a coefficient of earthfault compensation given by

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

where:

ω - working pulsation of the network,

L_d - iductivity of the compensating Peterson coil

d_z - - damping coefficient given by

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

where:

G_s - earthing conductance of the network (resultant of all the lines, Petersen coil and AWSCz devices),

R_u - earthing resistance of the network's zero point.

In the formula (1) one can assume that

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

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

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

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

The qantities and the coefficients given above take different values depending on the means of earthing the zero point. Table 1 contains the example sets of values specific for a 15 kV network with a capacitor current equal to 86.6 A. When calculating dz coefficient it has been assumed that in a network with isolated zero point G_s=0.2*10^{-3} whereas in a compensated network it is twofold greater.

The dependence of the earthing voltage of a post against its resistance has been plotted in figure 1 and the curves numbering corresponds to the data in table 1.

It states in the third row of the table (1) and the formula (6) that together with the Petersen coil there is an AWSCz device switched - a configuration analyzed further on in the dissertation.

The earthing voltage and thus the earthfault voltage are the greatest in a network earthed with a resistor. In case of resistances greater than 20 Ω a similar or slightly higher level of electric shock currents might occur in a network with isolated zero point. Among the given examples the compensated network yields the smallest values of he earthing voltages. A parallel connection of a Petersoncoil to the resistor results in lowering considerably the level of earthing volategs com

Dla słupów z dodatkową ochroną przeciwporażeniową, czyli wyposażonych w uziom ochronny, rezystancje uziemienia nie przekraczają praktycznie wartości 30 Ω. W takich przypadkach ograniczanie zagrożenia porażeniowego jest najtrudniejsze w sieciach o izolowanym punkcie zerowym lub uziemionych przez rezystor.

Zagrożenie porażeniowe przy uziemionych słupach linii SN zależy również od:

- contact coefficient α_d which in turn depends on the potential distribution around the post, that is the configuration of the protective earthing,
- electric shock coefficient upon contact α_{dr} which is related to the transition resistance in the spot of erathing, its values fall into the range of 0 to 1.

Table 1

The specifications of a network with a voltage rating of 15 kV and the susceptance of earthing ωC_s=0.01 S. This network was referred to when making the plots and doing the example calculations.

Method of earthing the zero point	d_z	k_d	a number denoting a curve
Isolated zero 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 humudity of the soil the value of ( ) might approach a disadvantegous value of 1. Its decreasing can be achieved by painting the exposed well conducting parts of the post and applying the electroisolating coverings. It is not always easy and economically justifiable. There exist hazards of damaging the covering with a course of time by the atmosferic influence or by casual human interference. Besides, painting the coverings will not limit the shock voltages upon step which are not normalized.

The ( ) can be decreased by the appropriate cofiguration of the protective earthing implemented by a roundabout earthing (otokowe) instead of a singular horizontal or singular vertical.

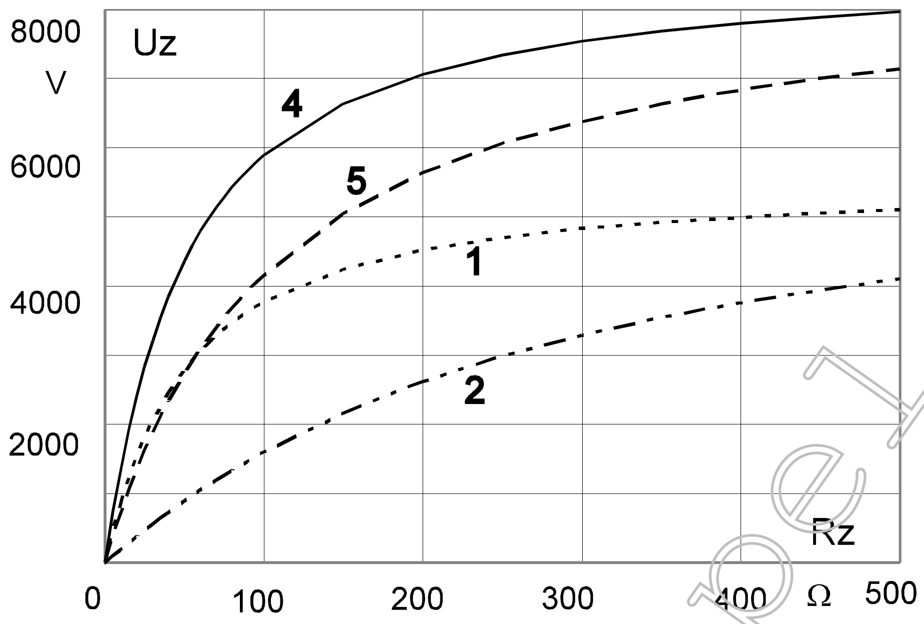


FIGURE 1. Dependence of the earthing voltage on a U_z post on its earthing resistance R_z. The curves are denoted according to the table 1.

5.THE ELECTRIC SHOCK DANGER DURING EARTHING IN THE SN/NN STATIONS

The stations powered by the aerial lines operating together with the aerial outlets of the low voltage lines definitely belong to the most difficult case. In such networks a transition to earthing with a resistor requires a detailed analysis of a danger level followed by implementing the appropriate technical solutions reducing this danger.

Prior to the decision upon choice of a mode of the zero point should be the examination of a resistance of station's earthing. When evaluating the extent of electric shock protection the acceptable values of disturbances voltage and contact voltage are referred to the international standards given in [4]. It should be mentioned that these standards provide two curves. The first one relates to the disturbances voltage at the earthing of a SN station whereas the second provides the acceptable values of the contact voltage in a low voltage network during the earthfault in the MV/nn station. A research carried out in a few departments of energetics in Poland has proven that the aerial networks of low voltage TN always reveal locations (the bulidings situated nearest to the station for example) where almost entire disturbances voltage takes on a form of the contact voltage. It is most likely to be encountered in the older type networks nn which lack the additional earthings of a PEN wire on the posts and terminals.

In order to avoid expanding the earthings of the SN/nn stations it is necessary to shorten the times of the earthfaults and to reduce the earthfault currents to a level imposed by the overcurrent protection and the conditions for the earthfault protection to switch.

6. A RANGE OF THE EARTHFAULTS DETECTED WITH THE EARTFAULT PROTECTIONS

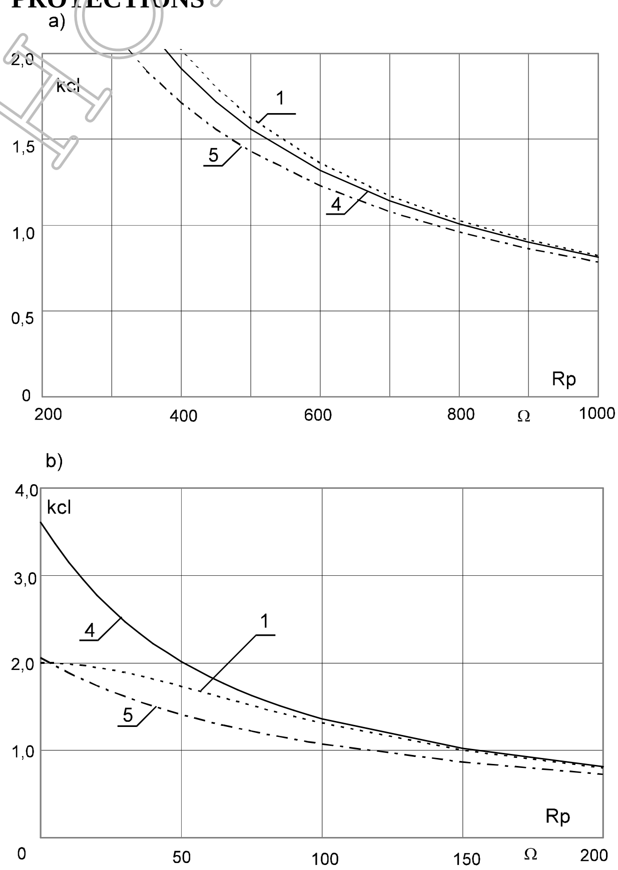
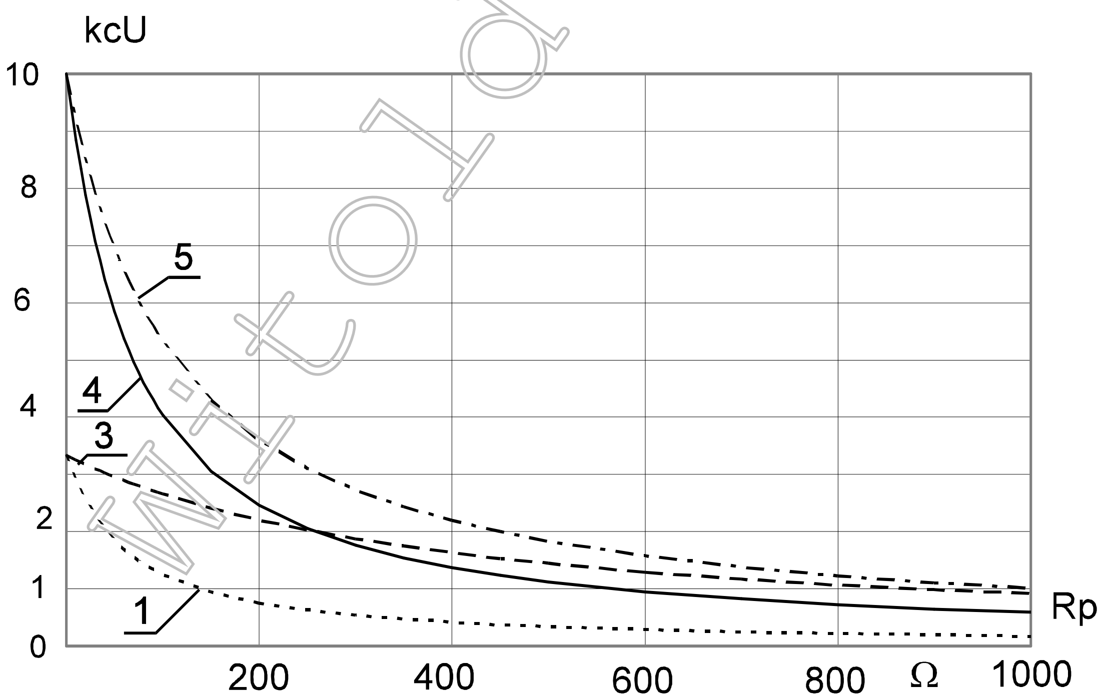


FIGURE 2
Dependence of the current sensitivity coefficient of zerocurrent protectionson the transition resistance in the spot of the earthfault in the networks with different perfomance modes of the zero point. The curves denoted according to table 1. Plot a) refers to the network in which the capacitor current contributes a value of 0.05, plot b) where this contribution equals 0.2 .

The efficiency of the earthfault protections as a function of transition resistance in the earthfault spot is a second major problem in the MV stations and plays a deciding role on their security. It should be taken account of that even the most efficient protection does not totally eliminate the accidents with the electric shock. The events like a cable falling on an isolated fence are undetectable. Mistaken is the claiming that the simple overcurent protections can be applied scoring well on the reliability in a network with either isolated zero point or earthed with a resistor. Firgure 2 plots the kcI versus transition resistance in the spot of earthfault denoted as Rp for three working modes of a zero point in a network with capacitor current equal to 100 A. The kcI coefficient is defined as a ratio of the zero component of a line's current over a value preset in a protection. The remaining preset parameters of this line are given in table 1. A current of a 5A line (Fig.2a) having a contribution of 0.05 on a scale of transition to 700 Ω will boast a value of current sensitivity coefficient kcI greater than 1 thus enabling the protection. However, a current of 20 A line (Fig.2b) having a contribution of 0.2 reduces the value of detectable resistances down to 150 Ω regardless of a zero point mode. Research proves the occurance of numerous earthfaults outside this range, including the eartfaults through the posts with no protective earthings. The greater the contribution of a given line to the capacitor current of the network the worse are the conditions to detect the earthfault with the overcurrent protection.

In this respect it is recommended to apply the admittance protections with the overvoltage start-up whose usage is limitted by the damping of a zero voltage comns is often a decisive factor of a level of electric shock danger. In number of cases this reliability can be improved by applying the units combining the admittance criteria with voltage criteria.

It should be also assumed that the delay times of activating the earth fault protections in many MV lines, aerial in particular, should never exceed one second.



Rys.3. Zależność współczynnika czułości napięciowej zabezpieczeń admitancyjnych od rezystancji przejścia w miejscu zwarcia dla różnych rodzajów sieci. Objaśnienia krzywych wedlug tablicy 1.

7.WNIOSKI

Przedstawiona w referacie dyskusja wskazuje na związki między ochroną od porażeń a sposobem uziemienia punktu zerowego sieci napowietrzno-kablowych. Minimalizowanie zagrożenia uzyskuje się przez właściwy dobór parametrów urządzeń w punkcie zerowym sieci oraz wykonanie odpowiednich uziemień. Wiąże się to z wartością rezystancji uziemienia i kształtowaniem korzystnego rozkładu potencjałów w miejscach szczególnie niebezpiecznych. Na stopień zagrożenia porażeniowego ma często decydujący wpływ skuteczność zabezpieczeń ziemnozwarciowych. W wielu przypadkach tą skuteczność poprawi zastosowanie, w miejsce kryteriów prądowych, członów o łączonych kryteriach admitancyjnych i napięciowych.

Należy również zakładać, że czasy opóźnień działania zabezpieczeń ziemnozwarciowych dla wielu linii SN, zwłaszcza napowietrznych będą musiały być mniejsze od 1 sekundy.

Literatura

[1] Bigelmaier G.: Układy sieci elektroenergetycznych i ochrona przeciwporażeniowa w publikacjach IEC. XI MIędzynarodowa Konferencja Naukowo-Techniczna "Bezpieczeństwo Elektryczne", Wrocław 1997.

[2] Lorenc J., Marszałkiewicz K., Andruszkiewicz J.: Admittance criteria for earth fault detection in substation automation systems in polish distrybution power networks. CIRED, Birmingham, June 1997.

[3] Michalik M., Rebizant W., Hoppel J., Lorenc J.: Optimization of MV network neutral point earthing mode with respect to transient ground-fault overvoltages . Materia³y 8th SCC Conference, Bruksela, paŸdziernik, 1998.

[4] International standard IEC 364. Part4: Protection for safety. Chapter 44: Protection against overvoltagez. Section442 - Protection of low-voltage installations against faults between high-voltage systems and earth.