VERIFICATION OF GLOBAL EARTHING SYSTEMS

Lothar FICKERT, Ernst SCHMAUTZER, Christian RAUNIG
Graz, University of Technology – Austria
lothar.fickert@TUGraz.at, schmautzer@TUGraz.at, christian.raunig@TUGraz.at

Martin J. LINDINGER
Energiewerkstatt Consulting GmbH
m.lindinger@ews-consulting.at

ABSTRACT

This paper is dealing with the verification of global earthing systems (CGS) with a special focus on dangerous voltages to people (touch and step voltages) and to technical systems (telecommunication lines). CGS are defined in a way that no dangerous voltages occur [2], which might be a weak or incomplete definition. In this paper results from own and published earthing measurements [4], [5], [7], [8] (especially touch voltages) in different areas (city, villages, rural areas) are analyzed and compared to simulation results [6], [9] of global earthing systems. Additionally these results are compared to values of earthing systems of large substations and power plants.

Measurements of touch and step voltages inside global earthing systems show that these values are far below given limits in standards. The question arises if this is true in all cases or if there are exceptions.

NOMENCLATURE

CGS.........Common Grounding System
EPR.........Earth Potential Rise (voltage to remote earth)
I_f.............Fault current at MV tests
$I_{local\ earthing\ system}$ Current in the local earthing system of the substation
$I_{LV,\ PEN}$.....Currents in the Protective Earth Neutral conductor of the LV grid
$I_{MV\text{-}shields}$...Currents in MV cable-shields
I_{test}...........Injected current at LV tests
PEN.........Protective Earth Neutral Conductor
R_{CC}..........Current limiting resistor in feeding substation
R_E............Earthing resistance of local grounding system
R_f.............Fault resistance
R_{gw}...........Earthing resistance of buried ground electrodes
$R_{Station}$......Earthing resistance of the station
$R_{Substation}$...Earthing resistance of the substation
Z_{Line}.........Impedance of the line
Z_{Pet}...........Impedance of the Petersen Coil
$Z_{Return\text{-}Path}$ .Impedance of the return-path (e.g. cable shield)
Z_{Tr}...........Impedance of the transformer

INTRODUCTION

Avoiding hazards to human beings and technical infrastructure is a very important issue considering earth faults in electrical grids. Due to the fact that grids with earth-fault compensation can be left in operation during an earth-fault the situation concerning touch and step voltages has to be considered. By the use of Petersen-coils in earth-fault compensated grids the residual earth-fault current is below the limiting values in the basic standards [3]. These low fault currents will lead to special demands and techniques concerning the protection philosophy in grids with earth-fault compensation. To enable a reliable and secure fault localization and selective tripping of the faulty feeder different methods with shortly increasing of the fault current exist [15]. In that case earth fault currents and their effects on the grounding systems have to be considered to avoid hazards. Another problem in grids with earth-fault compensation is the risk of cross-country faults with high fault currents, especially in grids with a high share of aged cables and cable joints. The question arises if under consideration of a specific grounding system increased fault currents will lead to uncontrollable hazards to people. The concept of a global earthing system is a common but still weakly defined topic in literature and international standards do not define this term in a clear way [1], [2]. Clear criteria for CGS are necessary to evaluate the safety of MV/LV grounding systems.

GLOBAL EARTHING SYSTEMS

One simple definition of a common grounding system mentioned in [1], [2] is that no dangerous touch and step voltages can occur. A problem dealing with this definition is that not only the grounding system, its interconnection, the metallic infrastructure buried in earth and the equipotential bonding system but also the neutral point treatment and especially the HV and LV protection scheme and the protection settings have an influence. Fault-duration-depending limits for touch voltages have also an influence whether an area can be seen as a CGS or not. So grid "properties" like neutral point's treatment, short-circuit power, fault location, fault type, cable properties, pylon grounding impedances, ground wire properties and LV grid configuration (TT- or TN-system) with MV connected neutral have an influence on voltage hazards such as touch and step voltages [10].

Different simulation models to calculate the current distribution during a phase to ground fault in a CGS have been published in the last years [6], [10] and [12].

Also experimental work carrying out field tests concerning safety in CGS has been done and published in [7], [12] and [13].

For the calculation and the verification of the measurements the potential coefficient method for calculating earthing systems was adapted for simulating global earthing systems. For the simulation of a global earthing system it is realistically assumed that all metallic infrastructures in the soil, which have a contribution to the earthing of the area, are concentrated along the streets. So the metallic infrastructure is simulated as long horizontal earthing electrodes under the streets. If the assumptions are made this way, the simulations can be compared to simulated earthing grids of large substations or power plants. With the help of these simulations it can be shown that global earthing systems behave like earthing systems of large substations and show touch voltages in the same range or lower (depending on the overall area of the global earthing system).

As mentioned before in some cases high touch voltages can also occur inside global earthing systems. These high voltages are mainly caused by inductive influences and potential transfers via isolated metallic structures. This is also proven with measurements results that will be shown in the paper. Locations where these high touch voltages can occur can be detected and handled guaranteeing the safety of people and technical equipment. Both simulations and measurements shows a maximum touch and step voltage between 20 to 30 V/kA corresponding to an effective grounding transfer impedance of 20 to 30 mΩ.

GROUNDING MEASUREMENTS

To verify the safety of people and technical systems, grounding measurements at a low voltage level were carried out at first.For the grounding measurement a mobile generator set (auxiliary source) was installed in a 110/10 kV substation. The beat frequency method in combination with a Fourier transformation was used for the measurement. This method allows an elimination of influences of other electrotechnical equipment during the measurement [10].

The test circuit was arranged through a connection between the phase conductor and the substation grounding in a 10/0.4 kV substation (see fig. 1).

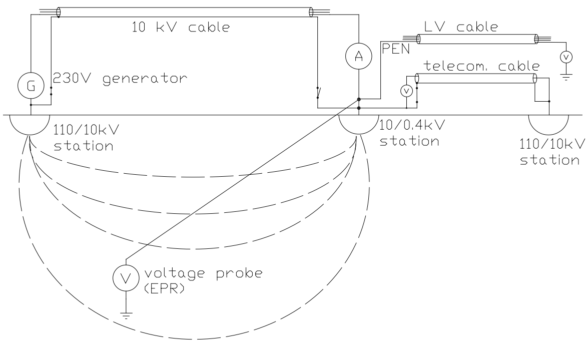

Figure 1: Illustration of the electrical circuit for the low voltage grounding measurement

During the measurements the current distribution at the substation, touch and step voltages, earth potential rise (EPR), the ground resistance of the 10/0.4 kV substation and the impedance of the fault loop were analysed.

Also touching and step voltages were measured at selected critical conductive structures and at selected critical points in the LV grid. By help of a telecommunication cable the voltages between the substation and other stations were measured to get the EPR.

Grounding measurements during a power system staged fault test

Due to assumed nonlinearities (current depending cable screening factor, etc.) the grounding measurements were also carried out in a life test with nominal voltage (10 kV). The fault was located in the same station as the tests with the low voltage test generator. One phase was grounded in the 10/0.4 kV substation as it was done in the low voltage tests. To get an defined fault current a healthy phase (not the phase with the single phase to ground fault) is grounded via a current limiting resistor (R_{CC}) and a circuit breaker in the supplying 110/10 kV substation [15]. The used resistor (R_{CC}) can be adjusted between zero and eight ohms.

This method was chosen to prove a new earth fault localization method based on short time high current injection.

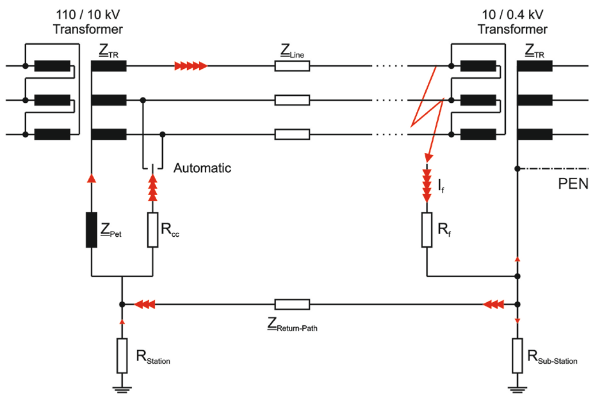

Figure 2: Simplified illustration of the earth fault localization method "short time earthing of an additional healthy phase" [15]

The measurements were carried out with a current limiting resistor of R_{CC} = 4 Ω resp. 8 Ω for safety reasons.

RESULTS

Current distribution at the fault location

Low voltage measurement

Table 1 and table 2 show the injected earth fault current into the test circuit and the current distribution in the faulted substation.

LV measurement (earthed shield)	Current
I_{test}	71 A
$I_{MV\text{-}shield,\ feeding\ cable}$	55 A (77%)

Table 1 Current distribution at low voltage measurements in the test station with both side earthed cable shields

LV measurement (opened shield)	Current
I_{test}	71 A
$I_{MV\text{-shield, feeding cable}}$	11.2 A (16%)
$I_{LV,\ PEN}$	10.7 A (15%)
$I_{local\ earthing\ system}$	57.3 A (80%)

Table 2 Current distribution at low voltage measurements in the test station with disconnected cable shields

An interesting phenomenon was that the treatment of the feeding cable's shield had no direct influence on the loop impedance of the fault circuit. The fault current level with disconnected and connected shield was the same. This could be explained by the construction of the cable (paper insulation and lead shield) and a buried earth wire nearby the feeding cable. As can be seen the shields and the ground electrode of the MV-cable bear the main fraction of the fault current in an direct and controlled way back to the source.

Medium voltage measurement

At both medium voltage measurements (4 Ω and 8 Ω) the current distribution at the fault location was measured (table 3 and 4).

MV measurement (earthed shield)	Current
I_f	948 A (100%)
$I_{MV\text{-shield, feeding cable}}$	762 A (80%)
$I_{other\ MV\text{-shields}}$	52 A (5%)
$I_{LV,\ PEN}$	142 A (14%)
$I_{local\ earthing\ system}$	25 A (2%)

Table 3 Current distribution at medium voltage measurements, $R_{CC} = 8\Omega$

MV measurement (earthed shield)	Current
I_f	1409 A (100%)
$I_{MV\text{-shield, feeding cable}}$	1043 A (74%)
$I_{other\ MV\text{-shields}}$	88 A (6%)
$I_{LV,\ PEN}$	282 A (20%)
$I_{local\ earthing\ system}$	53 A (3%)

Table 4 Current distribution at medium voltage measurements, $R_{CC} = 4\Omega$

Not all phase angles could be measured in the same time and therefore only absolute values are shown in the tables above. The smallest portion of the fault current was the current into the substation's local earthing system, whereas most of the fault current at the fault location is going back in the feeding cable's shield.

Step and touch voltages

The step and touch voltages were measured at about 20 different places like water-hydrants, street lighting systems, installations in private houses etc. The measurements showed that most touch voltages were lower than 5 V/kA (95 % quantile). Only at one point a prospective touch voltage of 20 V/kA was measured. This "high value" was caused by an inadequate electric installation at a building site container.

In this paper only measurements without an additional resistor (1 kΩ) for considering a human body are shown in order to obtain worst case considerations.

Source	Specific touch voltages	Comment
LV-measurements	2,5 V/kA	mean value
LV-measurements	< 5 V/kA	95% quantile
LV-measurements	20 V/kA	maximum value
MV-measurements	< 2,4 V/kA	0,4 kV grid
MV-measurements	1V /kA	10/0,4 kV substation

Table 4 Measured touch and step voltages at low voltage measurements.

During the full stage test (earth fault test) special selected step and touch voltages were measured with transient recorders. The measured touch and step voltages are in good accordance with measurements published in the past by our institute and other authors. One condition of a global earthing system is that all occurring touch and step voltages are below 10 V/kA [10].

The measurements show a trend to a value of approximate 11 V/kA. From this it can be derived that the global earthing system at this fault location has an effective earthing impedance of 11 mΩ.

COMPARISON WITH OTHER MEASUREMENT RESULTS

The measurement results presented in this paper are verified with own and also with published measurement results from other papers describing similar measurements.

Rural areas and small villages

In a rural area (<10 LV consumers per MV/LV substation) a MV/LV substation and two MV OHL terminal towers were measured. For the substation an earthing impedance of 80 mΩ was detected. Even in this area touch voltages less than 13.5 V/kA could be detected (<8 V/kA for a body resistance of 1 kΩ).

At the terminal towers, which were located outside the earth potential rise of the faulted substation, higher touch voltages were measured. That was caused by a potential transfer from the faulted substation to the towers via the cable shield. The highest potential rise of these towers was around 700 V/kA falling to the potential of the remote earth within a few meters, which is much higher than inside global earthing systems. It should be noted that such single towers are usually not a part of a Global Earthing System.

Another measurement was performed in a small village with about 50 houses and a settlement diameter of 700 m. The earthing impedance in this case was 0.35 Ω. Even in this small LV grid the specific touch voltages were less than 10 V/kA inside the village. Outside of the village touch voltages between 65 and 90 V/kA could be detected. This shows that even small villages can be defined as a global earthing system with very low specific touch voltages.

A measurement at a single MV/LV substation with 2 consumers in the LV grid produced an earthing impedance of 1.2 Ω. Even in this case the specific touch voltages were in a range between 20 and 30 V/kA. These values are higher than in urban or suburban areas but nevertheless very small (small enough to declare even this as an area with a global earthing system).

Measurements from literature

In Helsinki, Finland a full staged fault at 110 kV level was published in 1984 [7]. The measured potential differences resulted in all cases below 20 V/kA. Measurements from TU Brno [8] have shown specific touch voltages of 7.1 V/kA (median value) and were carried out in a suburban area. The highest measured value was 22.4 V/kA. In [14] potential differences during an earth fault in an urban MV network that remained under 14 V/kA are published.

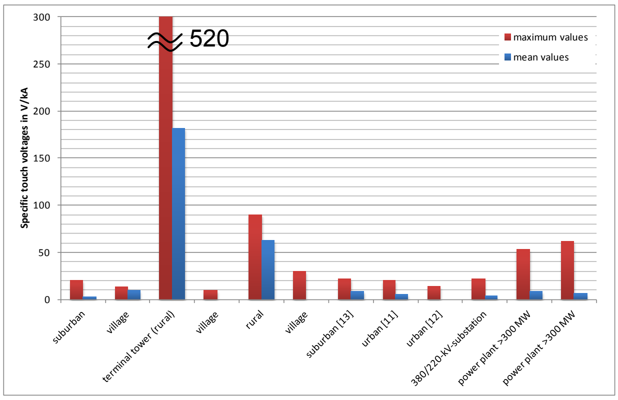

Figure 3: Typical measured specific touch voltages in different areas [10]

In figure 3 a summary of measured specific touch voltages is given.

To get an idea of the size of these touch voltages inside global earthing systems also measured values from HV substations and large power plants (hydro and thermal power plants with more than 300 MW) are illustrated.

It can be noted that specific touch voltages inside global earthing systems are in the same range or below typical values of HV substations or big power plants.

CONCLUSION

From own measurements and literature it can be assumed that global earthing systems are prevailing not only in densely populated regions but also even in scattered settlements.

Taking 80 V as a limit for the advisable / tolerable touch voltage according to EN 50522 the characteristic earthing impedance of 0.01 Ω of a CGS leads to a limit for the phase-to-ground fault current of approximately 8 kA in MV grids.

Also, in the case of a cross-country fault a maximal fault current of approximately 8 kA can be treated / accepted without further investigations.

In the case of compensated grids with a maximal phase-to-ground fault current of e.g. 132 A touch voltages below a few volts can be expected for earth faults in substations. Nevertheless real current injection tests have to be carried out for typical and critical fault locations in order to classify a given grounding situation.

REFERENCES

[1] CENELEC HD 637, 1999, "Power installations exceeding 1 kV a.c.", CENELEC.

[2] CENELEC EN 50522, 2011, *Earthing of power installations exceeding 1 kV a.c.*, CENELEC.

[3] OVE B1/1976, 1976, *Beeinflussung von Fernmelde-anlagen durch Wechselstromanlagen mit Nenn-spannungen über 1 kV*, Österreichischer Verband für Elektrotechnik, Wien, Austria

[4] M. Kuussaari and A. J. Pesonen, 1978, *Earthing impedance measurements of substations*. Paris, Cigre.

[5] J. Scheffler, 2001, "Betrieb und Kenngrößen des Niederspannungsnetzes der Stadtwerke Leipzig," *Energiewirtschaft*, vol. 100, no. 8, pp. 50-56.

[6] A. Campoccia and G. Zizzo, 2007, "Simple Circuit Models for Studying Global Earthing Systems," in *IEEE Powertech*.

[7] J. Valjus and R. Särmäntö, 1984, "Practical earthing measurements of large rural and urban substations," *CIGRE Session*.

[8] P. Toman, 2011, "Experiences with measuring of touch voltage during earth fault in large MV networks," in *Methods and techniques for earth fault detection, indication and location*, Espoo, Finnland.

[9] A. Campoccia, L. Mineo, and G. Zizzo, 2008, "A method to evaluate voltages to earth during an earth fault in a HV network in a system of interconnected earth electrodes of MV/LV substations," *IEEE Transactions on power delivery*, no. 23, pp.

[10] M. Lindinger, 2012, "Nachweis globaler Erdungssysteme durch Messung und Berechnung von verteilten Erdungsanlagen", TU Graz, dissertation.

[11] A. Campoccia, G. Zizzo, "The Quest of global safety", *PowerTech* 2007

[12] F.T.J. van Erp, F. Provoost, A.P.J. van Deursen, P.L.J. Hesen, 2005, "Modelling and live measurements of step and touch voltages at LV customers in urban areas caused by MV faults", *CIRED Conference*.

[13] J.B.M. van Waes, F. Provoost, J. van der Merwe, J.F.G. Cobben, A.P.J. van Deursen, M.J.M. van Riet, P.C.T. van der Laan, 2000, "Current distribution in LV networks during 1-phase MV short-circuit", *IEEE*.

[14] W. Castor, R. Fenkl, and H. Grünert, 2009, "Umstellung der Sternpunkterdung im 20-kV Kabelnetz", *EW*, vol. 4, Jg. 108

[15] Lindinger, Fickert, Schmautzer, Raunig, 2011, "Grounding Measurements in Urban Areas-Comparison of Low and High Voltage Measurements in Common Grounding Systems", *PES IEEE Powertech 2011*