USE OF A GLOBAL EARTHING SYSTEM TO IMPLEMENT THE SAFETY REQUIREMENTS FOR PROTECTING AGAINST INDIRECT CONTACTS IN HV SYSTEMS

M. Desmedt
Electrabel
Belgium
marc.desmedt@electrabel.com

J. Hoeffelman
CPTE
Belgium
jean.hoeffelman@cpte.be

D. Halkin
Laborelec
Belgium
didier.halkin@laborelec.be

ABSTRACT

The Belgian legislation on protection against electrical shocks due to indirect contacts in HV, introduced in 1983, is based on a set of requirements concerning the local earthing systems, the automatic interruption of the supply and some passive safety measures.
It is, since long, well known however that the actual safety of HV installation is, for a great part, ensured by the existence in the network of a “global earthing system” (GES), i.e. an equivalent earthing system created by the interconnection of local earthing systems and forming a quasi equipotential surface.
Since the introduction of this GES concept in the European standardisation and on basis of some systematic assessment of the actual situation in the networks it became logical to propose some modification of the Belgian legislation in this field.
The present paper highlights some important safety requirements of the European standard, explains how the assessment of some parts of the MV network has been performed and describes how the concept of GES, together with the measurement and control of the local earthing systems, has been introduced in the proposal for modification of the General Regulation on Electrical Installations.

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M. Desmedt
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INTRODUCTION

The Belgian legislation on protection against indirect contacts in HV was introduced in 1983.
These regulations aimed at preventing accidents due to dangerous step voltages or touch voltages and the spread of high potential to areas with low potential and vice-versa.
The safety philosophy was based on setting up a high-quality local earthing system, with active protection by interruption of the supply, completed, if necessary, with other passive safety measures.
However, protection based solely on a local earthing system is not realistic. Various studies carried out in the period 1983-1990 demonstrated that the solution to the problem was present in the network itself. By making interconnections between a multitude of local earthing systems with protective conductors (which themselves frequently have an earthing effect, e.g. lead sheaths of paper/lead cables), a “global earthing system” is achieved. These studies show that such a system is capable of keeping touch voltages at a secure level.
During the years 1998-1999, document HD 637-S1 “Power installations exceeding AC 1 kV (DC 1.5 kV)” was drawn up by CENELEC Technical Committee 99X. Chapter 9 - EARTHING SYSTEMS deals extensively with the problem of earthing systems, and thus also with protection against indirect contact in HV. At the international level, this document represented the first occasion that the principle of a global earthing system was treated in a normative document.
In Belgium we have now completed the task of putting all these considerations into practice.

PERMISSIBLE TOUCH VOLTAGE

The determination of the maximum value of the permissible touch voltage U_{Tp} is based on the application of standards IEC-479-1 and Cenelec HD 637-S1.
Without additional resistances, the value of the permissible touch voltage U_{Tp} for contact between hand and foot depends on the duration of the fault current (see table 1):

Duration of the fault current in s	U_{Tp} in V
0.5	230
1	100

Table 1 – Permissible touch voltage

Taking into account an additional resistance $R_a = Ra_1 + Ra_2$ (where Ra_1 is the resistance of the shoes and Ra_2 is the resistance between shoes and earth), we obtain the maximum value of the permissible touch voltage U_{STp} (see table 2). This value is depending on the ground type (always considered here under wet conditions).

	U_{STp} in V			
Ground	**Not defined**	**gravel – ballast**	**brick – tiles**	**tarmac – asphalt**
Duration of the fault current in s	$R_a = 1$ kΩ	$R_a = 2.5$ kΩ	$R_a = 4$ kΩ	$R_a = 8$ kΩ
0.5	500	700	1 000	1 500
1	200	300	400	550

Table 2 – Maximum value of the permissible touch voltage

It is necessary here to make the relation between U_{STp} and U_E (i.e. the increase in potential of the local earthing system with respect to a neutral earth, as a result of the expected maximum fault current).

If we assume that there is a voltage drop (as a part of U_E) at the earth surface with increasing distance from the location of the earth electrodes, then values of U_E higher than U_{STp} can be permitted.

According to Cenelec HD637-S1 it is assumed that the voltage drop with respect to an earth point 1 m away from the earth electrode amounts to 50% of U_E. The maximum permissible value of U_E may then amount to the double of U_{STp}.

GLOBAL EARTHING SYSTEM (GES)

Definition of the concept of “global earthing system”

According to HD 637, a global earthing system is defined as “*an equivalent earthing system created by the interconnection of local earthing systems that ensures, by the proximity of the earthing systems, that there are no dangerous touch voltages. Such systems permit the division of the earth fault current in a way that results in a reduction of the earth potential rise at the local earthing system. Such a system could be said to form a quasi equipotential surface.*”

Application of the GES concept in the Electrabel network

On basis of the above criteria, Laborelec was asked in 1999 to investigate how a distribution network with a relatively high density of local earthing systems behaves. The study investigated the behaviour of about 16,000 MV/LV transformer cabins under real fault conditions.

Assuming a maximum fault current I_{max} of 1 or 2 kA (limitation by an impedance near to the source) and a maximum fault duration of 1 second, a possible exceeding of the permissible touch voltage U_{STp} (2 U_E with R_a=2.5 kΩ) was found in only 1 % of the cases (see table 3).

This calculation was done in a conservative way because for each of the local earth resistance a value of 10 Ω was arbitrary chosen. In fact this value is in most cases lower than 10 Ω or even than 5 Ω.

U_E in V	Number of cabins for I_{max} = 1 kA	Number of cabins for I_{max} = 2 kA
0-199	10522	3.716
200-399	1749	7.755
450-599	59	664
600-799	4	105
800-999	1	12
1000-1199	0	3
1600-1799	1	0
2600-2799	0	1

Table 3 – Number of cabins with a defined earth potential rise U_E

The cases where the permissible potential rise was exceeded concerned stand alone cabins (interruption of the continuity of the protection conductor, cabin in antenna or situated at a long distance from other cabins), which couldn’t be considered as involved in a GES.

Remarkable was also the fact that the value of the local earthing resistance at the place where the fault occurred was not decisive for the computation of the potential rise.

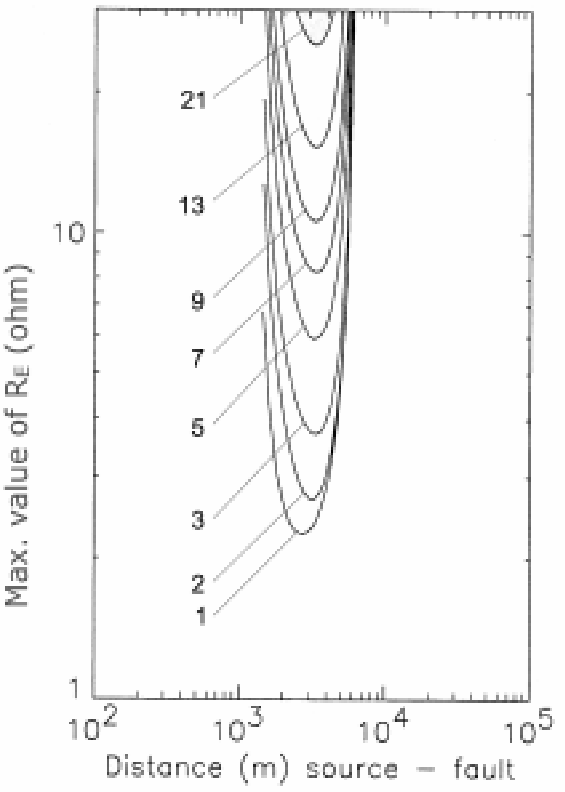
This confirms the assumption that a global earthing system is effectively present in areas with a high residential density and in areas with highly developed industrial activity.

On the other hand, by means of calculations, a procedure was developed to identify cabins that might present a risk. The study showed that installations located near the power source (HV/MV substation) enjoy some advantage since the fault current returns to the source mainly via the protective conductor and doesn’t contribute a lot to the earth potential rise. Remote installations also enjoy some advantage since the fault duration is always lower than 0.5 s and in many cases even lower than 0.3 s. Furthermore, the fault current is then limited by the impedance of the loop.

This is highlighted in figure 1, where for a maximum fault current of 2 kA and a potential rise U_E limited to 800 V, the maximum value of the local earth resistance R_E (for a MV/LV cabin) has been calculated in function of the distance to the source, taking into account the number of cabins upstream the considered installation (lowest curve 1 cabin, next curves representing 2,3,5,7,9,13,21,29 cabins).

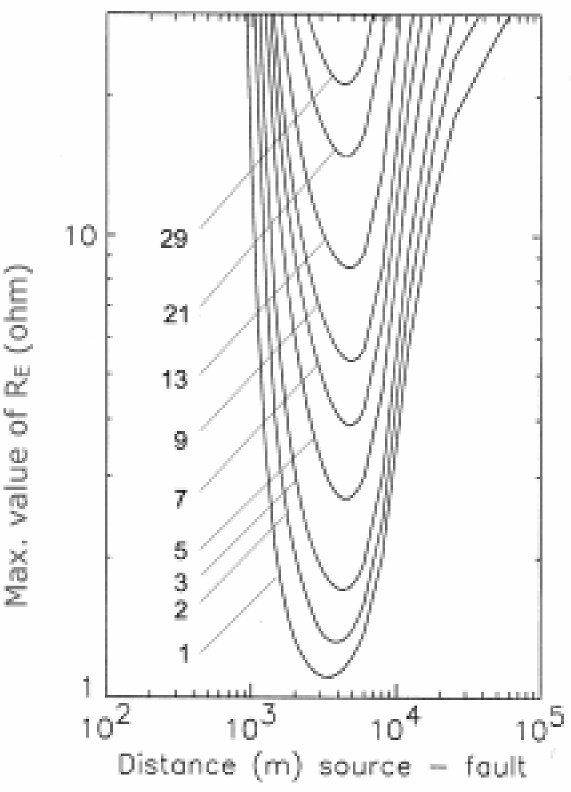
Two cases have been considered: figure 1a applies to a single feeder involving 150^2 aluminium paper-lead cables with the lead sheath in contact with a soil of 1000 Ωm resistivity, whereas figure 1b applies to a feeder equipped with the same kind of cables but with an outside PE insulated sheath.

Even with a relatively high value of the soil resistivity, the earthing effect of the paper-lead cables leading to higher permissible values for the local resistances is clearly visible in these figures.



cable type : Al 150^2 paper-lead
maximum fault current : 2 kA
U_E max : 800 V

Figure 1a



cable type : Al 150^2 PE
maximum fault current : 2 kA
U_E max : 800 V

Figure 1b

PROPOSAL FOR A NEW REGULATION

The conclusions of the Laborelec study together with the publication of the CENELEC standard HD 637 gave us the opportunity to propose some important modifications to the Belgian national regulation (RGIE / AREI).

In this proposal the following principles have been developed:

Requirements for a global earthing system

The minimum requirements, that have to be met by an earthing system for receiving the status of “global earthing system”, are based on the above considerations but laid down conventionally.

In practice, a GES is supposed to exist when at least 20 local earthing systems are connected together by protective conductors, provided the length L of the connection between two successive local systems is not greater than:

$$L \leq 500 \frac{S_m}{16(mm^2)} \text{ (in m)}$$

(S_m = weighted average cross-sectional area of the protective conductors forming part of the connection, in mm^2)

A GES is also assumed to exist if it involves a set of cables with earthing effect having a total length of at least 1 km and if the mean length of each part of cable without earthing effect doesn’t exceed L.

It should be noted here that the continuity of the protective conductors must always be assured in the connection sleeves, switching and transformer stations.

Mixed situations involving cables with earthing effect, together with local earthing systems, are also allowed.

Local earthing system

The principle of the global earthing is based on the interconnection of the local earthing installations by means of protection conductors, which, in turn, are connected to the source. This means that each local earthing only contributes to a small extend to the global system, and is of limited importance. Therefore the maximum earth resistance value of each individual installation, connected to a global earthing system, may rise up to 15 Ω.
This can be achieved, for instance, when the following set of earth electrodes are buried in a ground of 100 Ωm (figure 2):

- 8 m vertical earth rod (with a rod diameter of 0,02 m);
- single 10 m length earth loop buried at a depth of 0.5 m;
- four 1.5 m earth rods connected to an earth loop of 8 m length.

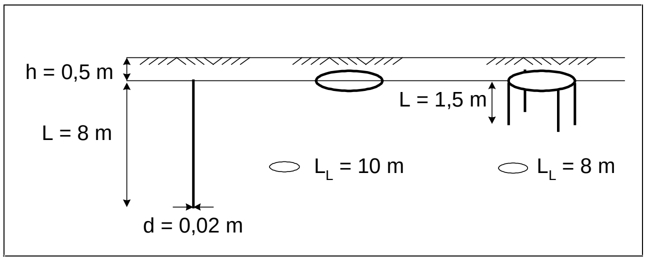


Figure 2 - Examples of local earthing systems achieving compliance

This approach is in fact rather conservative, since the soil resistivity in Belgium (upper layer) is generally lower than 100 Ωm.
If the soil resistivity at a depth of 1 m is greater than 150 Ωm, the maximum value that has to be taken into consideration for each individual earthing becomes:

$$R_E \leq 15\frac{\rho_E}{150}\Omega$$

Checking the earthing systems

The control is based on two principles:
- maintenance of the local earthing system;
- checking the continuity of the connection with the other local earthing systems in the global earthing network.

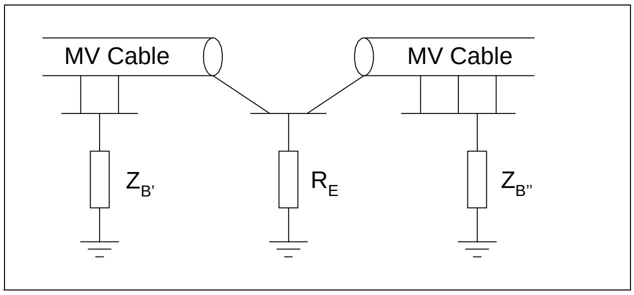


Figure 3a – Electrical circuit of an interconnected local earthing system

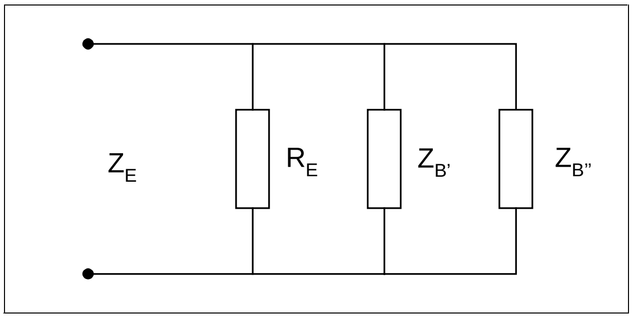


Figure 3b – Equivalent circuit for Z_E

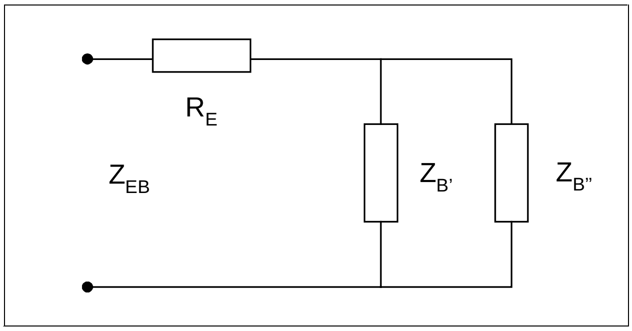


Figure 3c – Equivalent circuit for Z_{EB}

Control before putting into service

Before putting the HV installation into service the earthing resistance is measured. This value is called the initial value of the earth resistance R_E of the local earthing system. It serves as reference value for the next periodical control(s). The R_E value (related or not to the value of ρ_E) permits to verify that the necessary earthing facilities have in fact correctly been installed.

Periodical controls

During the first periodical control the impedance Z_E will be measured (figure 3b). This is the impedance of the local earthing system interconnected with the resulting impedance Z_B of all the other earthing systems in the network ($Z_{B'}$ $Z_{B''}$ …).

Z_E, which is the parallel connection of R_E and Z_B, can be considered as the impedance of the global earthing system, locally measured. This impedance has to be smaller than R_E. In practice the value of Z_E is mostly smaller than 1 Ω.

If such is the case, then only the loop impedance Z_{EB} will be measured during the next controls, i.e. the impedance of the loop created by R_E in series with Z_B (see figure 3c). This can be done without disconnecting the earthing conductor (measurement by means of current clamps).

The Z_{EB} value has to be smaller than the highest of two reference values R_E + 50% or R_E + 1 Ω, i.e:

$$Z_E < Z_{EB} < 1.5\ R_E$$

or

$$Z_E < Z_{EB} < R_E + 1\ \Omega$$

These conditions (the latter in case of a low R_E value) are necessary for staying independent of R_E variations due to different earth moistness conditions.

If Z_{EB} doesn't fit these conditions, R_E has to be measured again together with an additional check of the continuity by the measurement of Z_{EB}.

The purpose of this control is thus rather a verification that nothing unusual has happened (interruption of the continuity, important change in the value of R_E …) than a new measurement for getting an exact value of the local earth resistance. The measurement of Z_{EB} is easy to perform (no necessary disconnection of cable shields) and gives important information about the efficiency of the earthing system.

CONCLUSIONS

The above explained approach is fully in line with the prescriptions of CENELEC HD 637-S1.

A big step forward will be accomplished at national level by adapting the Belgian regulation concerning the protection against electrical shocks by indirect contact in HV installations. This will be achieved by introducing the concept of global earthing system into the regulation and by moving from a complicate set of requirements and measurement rules, applied to the local earthing systems, towards a much more efficient control of the global safety.

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