PROOF OF A GLOBAL EARTHING SYSTEM

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ABSTRACT

High-voltage facilities require an earthing system, whose most important task is to protect humans from the impact of earth faults. The effectiveness of such an earthing system depends on the type and arrangement of earthing conductors and the distribution of fault currents. Besides the functional target in utilities and industrial companies the cost effectiveness and practical aspects with respect to asset management play a large role. The existence of a global earthing system shows a possibility for cost effective earthing system design according to IEC 61936 [1] and EN 50522 [2]. On the basis of a large industrial complex "Industrie Park Höchst" operated by "Infraserv GmbH & Co Höchst KG" this paper shows how and via which procedures the verification of a global earthing system can be achieved

INTRODUCTION

Infraserv Höchst operats the "Industriepark Höchst", one of Europe's largest chemical and pharmaceutical sites. The area of the site covers 460 ha with more than 120 production plants, 800 buildings, 72 km of roads, 57 km of railway tracks and 800 km of pipelines. The 10 kV medium voltage networks are fed by 110/10 kV transformers.

The 110 kV systems feeding the site as well as the 10 kV systems at the industrial site are operated with resonant earthing (arc suppression coils).

Due to internal safety requirements Infraserv Höchst was asked to verify the safety with respect to touch voltages in case of earth faults in the medium voltage networks.

Global earthing system

Inside coherent residential areas, city centres, business districts or industrial parks the conditions are optimal for protective earthing due to tight interconnections through cables and pipes and the small distances between buildings and structures. Reflecting these conditions, the term "global earthing system" was created.

In the mentioned standards the global earthing system is defined as an equivalent earthing system created by the interconnection of local earthing systems and which ensures, by the proximity of the earthing systems, that there are no dangerous touch voltages. Furthermore the standards allow proving the existence of the global earthing system for individual configurations by sample measurements or calculations.

With respect to the wording in standard EN 50522 [2] "Inside the global earthing system areas there is no need to verify the resistance to earth or the earth potential rise because a basic design of earthing system is sufficient" the proof of existence of the global earthing system in a defined area can save efforts with respect to the design of earthing systems and for checking individual locations with high- or medium voltage equipment.

PHYSICAL CONDITIONS

The global earthing system describes favourable conditions leading to tolerable or even negligible potential differences and touch voltages within a defined area.

The informative annex O of EN 50522 [2] lists typical cases where the global earthing system could exist:

- "substation is surrounded by buildings with foundation earth electrodes and the earthing systems are interconnected e.g. by cable sheath or low voltage protective earth conductors;
- substation is feeding city center or densely built up areas;
- substation is feeding suburban area with many distributed earth electrodes interconnected by protective earth conductors of low voltage system;
- substation with given number of nearby substations;
- substation with given number and length of outgoing earth electrodes;
- substation connected via cables with earth electrode effect;
- substation is feeding extended industrial area; substations are part of system with multi earthed high voltage neutral conductor."

Unfortunately there is no simple method for the identification of areas with the global earthing system. Therefore some principal considerations are required:

Infeed conditions 1:

System is fed from outside of the interconnected earthing system. In case of an earth fault the single-phase fault current entering the earth grid returns on different ways. Parts of the single-phase fault current return via (Figure 2 of EN 50522 [2]):

- the transformer neutral within the station area,
- earth wires or cable screens,
- earth electrodes and earthing conductors connecting parallel earth grids and the earth grid of the station itself.

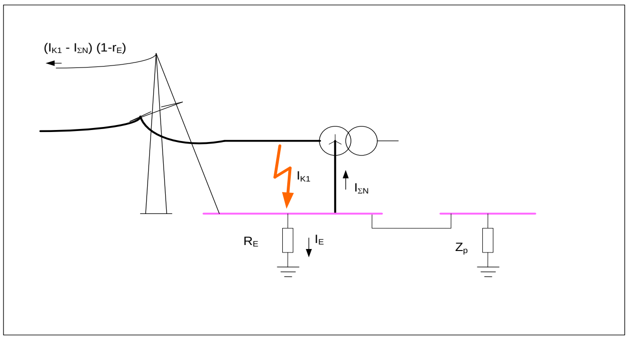

Figure 1: Infeed conditions 1 [2]

The earthing current flowing through the different impedances or resistances to earth connected in parallel primarily causes the earth potential rise and therefore the measurable touch voltages in the surrounding.
It is evident that the following factors reduce the earth potential rise as well as the absolute potential differences inside the interconnected surrounding:

- low resistance or impedance to earth,
- low earth fault current.

Another principle measure is increasing the permissible touch voltage by decreasing fault duration.
But even in case of large resistances to earth and large fault current it is possible to find the global earthing system with tolerable touch voltages and small potential differences in a defined area by close interconnection of different parts of earthing systems, interconnection of all conductive parts (common bonding network) and or potential grading. Examples could be inside of areas covered by industrial plants or large power plants. Considering these cases special care is required with respect to the boarders of that defined area and to transferred potentials.

Infeed conditions 2:

The voltage level is located inside of a limited interconnected earthing system (Figure 2).

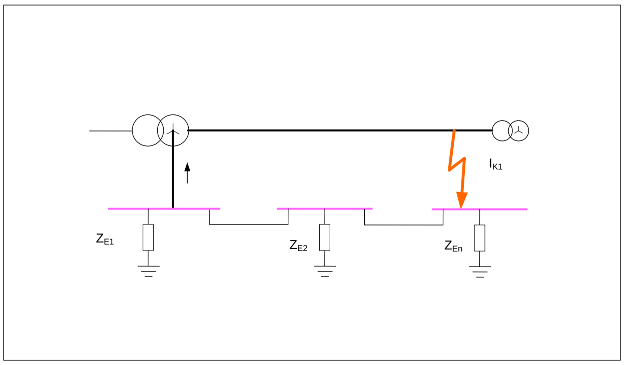

Figure 2: Infeed conditions 2

In this case the earth fault current is returned via interconnected earth electrodes, earthing conductors, PE-conductors, cable sheathes and conductive parts of infrastructure like pipes or railway tracks. Only a negligible part of the earth fault current flows via earth. Therefore the earth potential rise against a remote earth becomes small. Touch voltages and other potential differences inside of the interconnected system are caused by fault current contributions flowing via the mentioned conductive parts. In case the materials and the cross sections of different earth fault current paths are sufficient the permissible touch voltages are kept. In general this can be ensured by a proper basic design of the interconnected earthing system.

Typical conditions

Typically both infeed situations are combined. E.g. considering the conditions of an industrial site a limited number of substations (e.g. 110/10 kV substation) feed a large number of consumer substations (e.g. 10/0.4 kV) located exclusively at the industrial site with a closely interconnected conductive infrastructure.
Therefore in principle an evaluation of global earthing system conditions for each voltage level located at the site (> 1kV) is required.
In practice, with respect to the limited number of related high voltage substations (e.g. 110/10 kV) it is often possible to carry out an individual design (basic design and evaluation of earth potential rise) or an individual check. Furthermore this individual method gives the possibility to ensure that the requirements with respect to transferred potentials according to EN 50522 [2] are satisfied. Transferred potentials have to be evaluated even in case of the global earthing system according to EN50522!
Considering the large number of consumer substations (e.g. 10/0.4kV) it is feasible to use the economic and technical advantages of the definition of a global earthing system for a general statement of the safety in case of an earth fault. Precondition is that the existence of the global earthing system is proven. The standards IEC 61936 [1] and EN 50522 [2] allow the proof of the existence of the global earthing system via sample measurements or calculation.
As the definition of the global earthing system is based on keeping the permissible touch voltages the proof of the existence of the global earthing system can be performed via sample touch voltage measurements at selected number of locations and stations.

Test method

As the current distribution in the ground beneath medium voltage stations is fairly unpredictable the actual touch and step voltages can only be obtained from measurements in a reliable way. The suitable method for large ground grids is the current injection method according to EN 50522 [2]. With this method the ground potential rise, the touch and step voltages under fault conditions can be obtained as well as the impedance to

earth of the ground grid.
In general the test method describes the infeed condition1 due to the fact that the test line needs a minimum distance between the tested system and the “remote earth electrode” in order to get a gradient area in the surrounding of the tested earthing system which is not influenced by the remote earth electrode.
However as the heavy current injection test allows to simulate the real fault conditions the test method is also adequate for simulating the earth fault conditions in the global earthing system. Furthermore the test circuit can also be used for measuring the complete circuit impedances of the test circuit summarizing the impedance to earth of the tested earthing system, the remote earth electrode and the impedances of the test line. The test circuit of the heavy current injection test according to EN 50522 [2] is shown in figure 3.

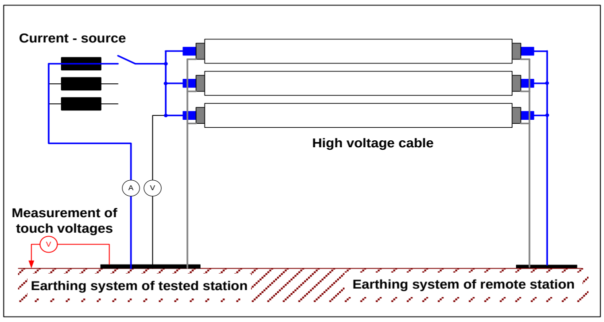

Figure 3: Test circuit of the heavy current injection test

The tested stations have to be selected carefully to ensure checking worst case conditions in the defined area.

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One of the 110/10 kV substation had been checked by the individual heavy current injection test for the location and the surrounding of that substation years ago. The test showed that the earthing system of the substation fully meets the requirements of the former HD637 [3]. The investigation of the technical conditions in this industrial area with respect to the possible characteristics of the global earthing system showed the following:

- The substation (110/10 kV) and the consumer substation (10/0.4 kV) feed a densely built industrial site.
- The whole area is covered with a dense network of 10 kV cable systems. The cable sheathes of the cable systems are completely installed with earthing at both sides of the cables.
- The consumer substations are built in or surrounded by buildings with foundation earth electrodes. The older buildings (year of construction <1960), which were built without foundation earth electrodes, are equipped with additional earth rods or horizontal earth electrodes.
- The different local earthing systems are located very closely together and are interconnected by PE or PEN conductors of low voltage systems, in addition, the local earthing systems are interconnected via separate earth electrodes.
- In addition, the main areas are conductively interconnected by a dense network of pipes and railway tracks.

Therefore the industrial site shows most of the possible characteristics of the global earthing system.
Based on the compliance with the general possible characteristics it was decided to carry out the proof of the global earthing system in the area of the “Industriepark Höchst” with respect to the earth fault in the 10 kV systems via sample measurements using the test circuit of the heavy current injection test.
With respect to the evaluation of the measured results the permissible touch voltage as well as the relevant earth fault current have to be determined according to EN 50522 [2].
In case of a system operated with resonant earthing without automatic switch off of faulted circuit, Figure 4 of EN 50522 [2] gives a permissible touch voltage value of U_{Tp} = 80 V.
Table 1 of the standard EN 50522 [2] shows that the relevant current has to consider the residual current of the system, the reduction factor of the fault current carrying line, and in case of a location with arc suppression coils additionally the rated current of the coil itself. $I_{res} \leq 60$ A was given as an upper limit of the residual current of the considered 10 kV systems.

Scope of the measurements

The following measurements were carried out:

- Heavy current injection tests at selected consumer substations at unfavourable locations
- Heavy current injection tests at locations with higher earth fault currents (substation with Peterson coils)
- Proof of interconnection of different supply areas

For the above mentioned tasks 14 consumer substations were selected. 14 test circuits covering test lines with lengths between 1.4 km and 5.5 km were created by interconnection of different 10 kV cable sections. For the test lines leading from one end to the other end of the industrial site were selected to find the largest circuit impedances even if these conditions could not be considered as “normal operation”. In addition some of the tested consumer substations were located close to the boarder of the industrial site or in areas where actually all other structures were temporarily removed.
The following values were measured or determined for each of the tested consumer substations:

- Potential rise / potential differences in the surrounding of the tested locations,
- Touch voltages at exposed locations inside and outside of buildings,
- Potential differences inside of the local earthing

systems,

- Transferred potentials transferred via conductive structures like pipes or PE/PEN conductor of low voltage systems,
- Test current and test current distribution in the surrounding of infeed location,
- Impedance to earth (apparent impedance to earth) and
- Impedance of test circuit.

Test currents in the range of 50 A to 150 A were used.

Test results

The following diagrams summarize the main results of the tests. The results were referred to the maximum local earthing currents, based on the design criteria of the 10 kV networks and the local rated current of arc suppression coils (Peterson coil).

Potential rise/ maximum potential differences

The values show the potential differences between infeed point and different locations in a distance of up to 800 m in the surrounding of the infeed points. Due to the fact that this value dropped mainly over conductive structures the value may be defined as apparent earth potential rise even if it is partly measured at conductive structures. Figure 4 shows the maximum values measured in the surrounding of tested consumer substations.

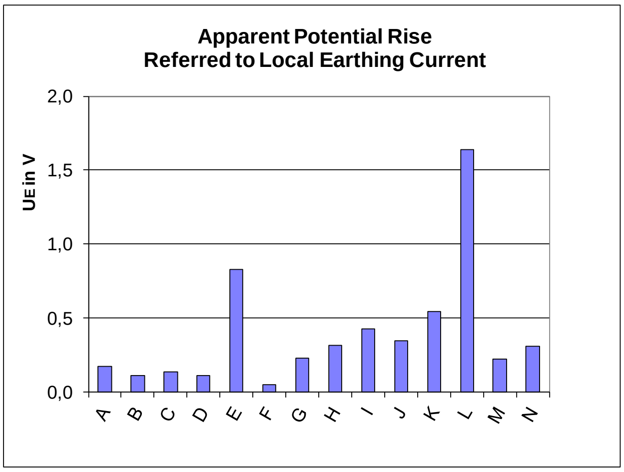

Figure 4: Maximum apparent potential rise

Considering the test conditions the "apparent impedances to earth" shown in figure 5 were determined.

The above mentioned results are basically used for interpretation of different conditions inside the industrial site, whereas the measured touch voltages are the decisive results for an evaluation with respect to the requirements of standards.

The measurements of potential differences and apparent impedances to earth showed that the global earthing system is not a measure like potential grading or equipotential bonding which could be carried out at a single location. It is the interaction of different conductive structures like e.g. piping, cabling, railway tracks or foundation earth electrodes in the surrounding of the considered location.

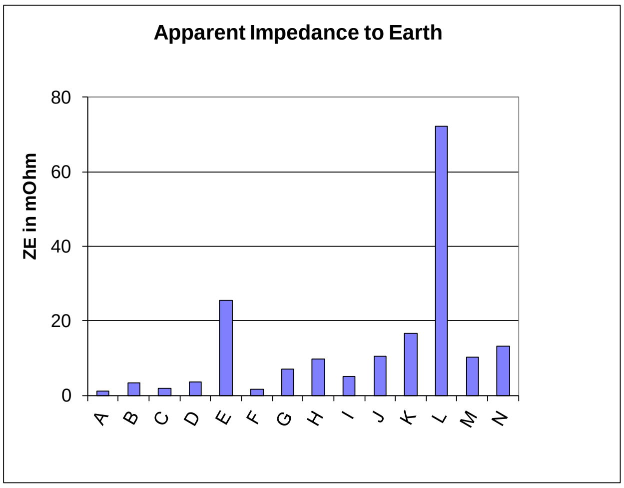

Figure 5: Apparent impedances to earth

Touch voltages

All measured values were much smaller (< 2%) than the permissible touch voltage U_{Tp} of 80V. The results are shown in figure 6.

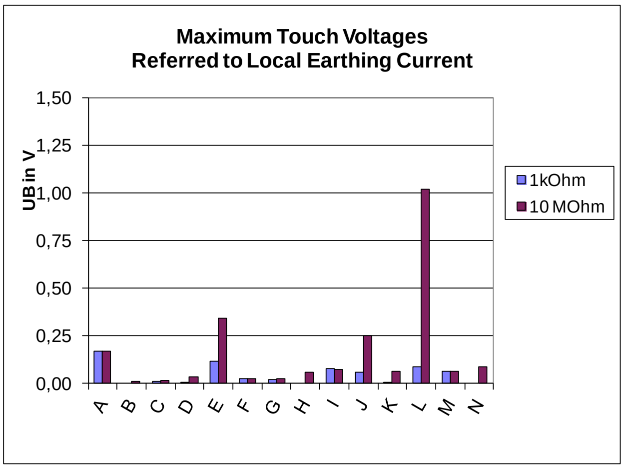

Figure 6: Maximum measured touch voltages

Based on the measured touch voltages and the compliance with the characteristics it can be stated, that the industrial site of "Industriepark Höchst" is a "global earthing system"!

Impedance of test circuit

The impedance of the test circuit gives an additional possibility for a general evaluation of the tested area. In case the maximum apparent potential rise is smaller than the permissible touch voltage U_{Tp} any intolerable touch voltage is not possible. Considering a typical consumer substation (connected via standard XLPE cables; without arc suppression coil installed in the consumer substation; the maximum residual current of the system of $I_{res} \leq 60$ A; the permissible touch voltage of U_{Tp} =80 V) the required maximum apparent impedance to earth for a general evaluation comes to:

$$Z_E = \frac{U_{Tp}}{r_E I_{res}}$$

Z_E	-	Apparent impedance to earth
U_{Tp}	-	Permissible touch voltage
$r_E = 0.5$		reduction factor
I_{res}	-	Residual current

$$Z_E = 2.66\ \Omega$$

Due to the fact that the test circuit impedance is composed of the apparent impedances to earth of the tested system and the remote earth electrode and the test line impedance the test circuit impedance can be considered as an upper limit for general evaluation of a global earthing system without further detailed calculation of each part.

Figure 7 shows the results of the measured test loop impedances. Even the maximum loop impedance is clearly smaller than the calculated value of 2.66 Ω for a general evaluation. This result underlines the touch voltage measurements.

In principle this test circuit impedance is composed of the conductor impedances of the test line and the meshed conductors of the equipotential bonding system in the area. Typically, in the global earthing system (infeed condition 2) the test line impedance is the largest contribution. This is underlined by the results of the apparent impedance measurement shown in figure 5.

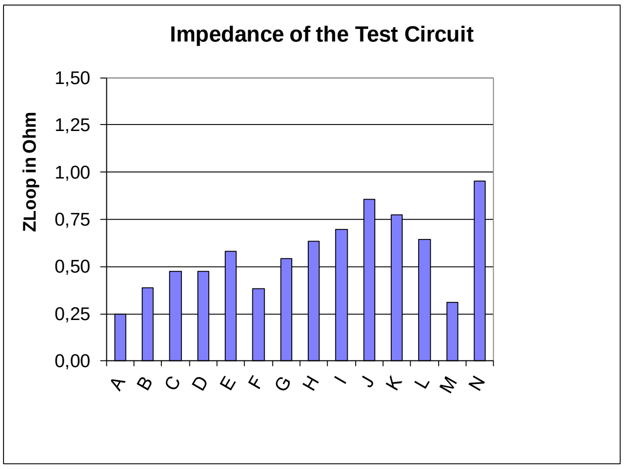

Figure 7: Impedances of test circuit

SUMMARY

Based on the measured touch voltages and the compliance with the characteristics of a global earthing system the investigation showed, that the "Industriepark Höchst" fulfills the requirements defined in EN 50522 [2] on the global earthing system with respect to the fault conditions in the 10 kV network.

That result saves the large effort for the individual check of the consumer substations in the industrial site.

In addition to the touch voltage measurement and the compliance check with the characteristics of the global earthing system, the measurement and the evaluation of the test circuit impedance provides an additional means of general assessment of safety earthing conditions in global earthing systems in case the voltage level is limited to the discussed area (infeed conditions 2). Precondition is that the test circuits are selected carefully and showing the worst case conditions in the investigated area.

It is strongly recommended to carry out these additional impedance tests with the approved method of heavy current injection test according to EN 50522 [2] with a sufficient test current.

REFERENCES

[1] IEC 61936-1, 2010-08, Power installation exceeding 1 kV a.c. – Part 1: Common rules

[2] EN 50522, 2010-11, Earthing of power installation exceeding 1 kV a.c.

[3] HD 637 S1, 1999-5, Power installation exceeding 1 kV a.c.

[4] K. Hentschel, S. Höne, Cired 2009, Paper 0769: Definition of criteria to operate 20 kV networks with arc suppression coils according to standards

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