Reliability of earthing system as significant factor determining EMC, the power quality, and lightning protection

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Abstract: One of the main requirements for EMC and lightning protection earthing systems is to provide their reliable service for long time (usually not less than 20 - 30 years). Main phenomenon influencing reliable performance is the corrosion affecting earthing system components, especially of earth electrodes and earth conductors. The Polish company Galmar – manufacturer of copper coated earth electrodes and conductors started in Poland the long-term project of field corrosion tests of earth rods made from different materials. Results of field corrosion tests after 2, 4 and 6 years exposure of earth rods in different soil types in Poland are discussed in the paper.

Introduction

Life. Property. Performance. Money. Each one of these important design elements is vulnerable to the effects of any kind of interference currents. So it is important properly design and install an electrical earthing system on every outside plant or installation and assure its reliable long time service.

One of the important factors in designing a protective system is to determine if a considered plant or installation is exposed or non-exposed to electromagnetic interference. An exposed low voltage system is vulnerable to unwanted sources of current and voltage.

Different kind of protective measures shall be provided for aerial, direct-buried, and underground installations when there is exposure to:

- ground potential rise from accidental contact with power conductors operating at more than 300 V to ground (i.e. fault or short circuit),
- voltage induction,
- man-made interference,
- lightning disturbances.

A reliable protection system requires effective bonding and earthing (grounding).

Bonding refers to the electrical interconnection of conductive parts designed to maintain a common electrical potential. Bonding conductors shall be sized to be of sufficient gauge to carry anticipated fault or interference currents.

Earthing (grounding) refers to the electrical connection of electrical, telecommunication or signal equipment to an effective electrical ground, which can be the vertical down lead of a power system multi-ground neutral, a grounded neutral of a secondary power system, or a specially constructed earthing (grounding) system.

In design process of any kind of earthing system it is important to assure high quality of its components and long time proper functioning and stability of their performance and technical characteristics. Most important are here adequate mechanical strength of material used for electrodes, conductors and clamps and their high corrosion resistance in different type of soils.

General requirements for earth electrodes and earth conductors

When dimensioning and selecting material of earth termination system the following parameters shall be taken into account:

- the highest value of current dissipated into the earth,
- duration of current flow,
- geo-electrical and physical parameters of the soil.

The earth electrodes and conductors should be constructed of corrosion-resistant materials such as copper, galvanized, electrodeposited or stainless steel. The material of the earth termination system and earth conductors should be electrochemically compatible with the material of the connection elements and the mounting elements, and it should have a good corrosion resistance to a corrosive atmosphere or moisture. Connections between different materials should be avoided, otherwise they are to be additionally protected against corrosion.

Corrosion of metal will occur at a rate depending on the type of metal and the nature of its environment. Environmental factors such as moisture, dissolved salts (thus forming an electrolyte), degree of aeration, temperature and extent of movement of electrolyte combine to make this condition a very complex one.

Extended earthing systems may suffer from different ground conditions. This can enhance the corrosion problems and needs special attention. To minimise corrosion of an earth termination system it is necessary to:

- avoid the use of unsuitable metals in an aggressive environment;
- avoid contact of dissimilar metals, of substantially differing electrochemical or galvanic activity;
- use an adequate cross-section of conductors, bonding straps and conducting terminals and clamps to ensure sufficient corrosion life for the conditions of service;
- provide appropriate filling or insulating material in not welded conductor joints, so as to exclude moisture;
- use sleeve, coat or isolate metals sensitive to corrosive fumes or fluids to the location of the installation as appropriate;
- consider galvanic effects of other metallic items to which the earth electrode is to be bonded;
- avoid designs where natural corrosion products from a cathodic metal (e.g. copper) could impinge on, and plate out as metallic copper on an anodic metal (e.g. steel).

Unification of requirements and tests of earth electrodes according to international standards

The manufacturer or supplier of earth electrodes and earth conductors shall provide adequate information in his specification related to the test results carried out with the specimens of electrodes and conductors performed according to appropriate standards [1,2,3,4,5].

The fundamental requirements of different standards for type tests of earth electrodes, earthing conductors and clamps and joints are:
- mechanical tests of earth joints and clamp (bending, tensile, compression and)
- adhesion test of copper coated steel rods;
- environmental (corrosion) test;
- electrical tests.

These requirements are based upon sound engineering principles, research, records of tests and field experience and an appreciation of the problems of manufacture, installation and use assuring reliable performance of the system for at least 20-30 years.

The materials and dimensions of earthing electrodes commonly used and recommended in IEC and EN standards are copper or steel with different protective coatings (zinc galvanised or electrodepostied copper) with different shape and dimensions. There are some differences in requirements related to this paramters in IEC standards worked out by different IEC Technical Committees (TC). It should be emphasized that all the three involved Committee (TC 81X, TC 99X and SC 64A) recommend a common earthing system, if possible for EMC, lightning protection and electrical installation.

The detailed analysis of tables included in IEC publications point out differences both in terms and in sizing figures. In Table 1 are listed actually proposed by appropriate working groups of IEC TC81 (WG11) and CLC TC81X (WG2) values of earth electrodes dimensions suggested as common requirements for IEC and EN standards related to earth electrodes. The values presented below are the minimum among the ones used by different Technical Committees and are still under consideration [6,7].

Laboratory corrosion tests

The 0,5 m long samples of steel rods with copper coatings having thickness not less than 0,250 mm and rods with hot-dip zinc coatings having app. 0,08 mm thickness were totally immersed for 28 days in separate tanks containing the water solution of $CaCl_2$ and Na_2SO_4 having pH 5–9. The volume of solution was app. 10 times bigger than volume of tested samples.

After the exposure the samples have been washed with distilled water, dried and inspected. The corrosion rate was calculated using gravimetrical method from the loss in weight of samples as the uniform rate: V_m [g/m^{2}twenty-four hours] and V_p [mm/year]. Exemplary pictures of samples before and after the corrosion tests are shown in Figure1 and corrosion test results are characterised in Table 2.

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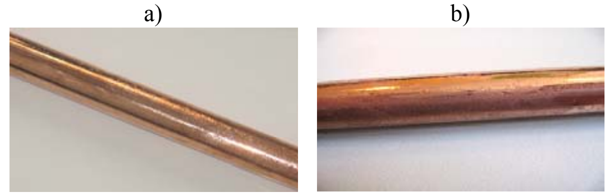

c) d)

Figure.1. Pictures of earthing rod samples before and after laboratory corrosion tests with: a) standard copper electrodeposited coating before test, b) standard copper electrodeposited coating after test, c) hot-dip zinc galvanized coating before the test.

Table 1. Material, configuration and cross sectional area of earth electrodes - according to new proposal of EN50164-2 (IEC 62561 – 2) [7]

Material	**Configuration**	**Cross sectional area** 1)			**Recommended dimensions**
		Earth rod mm^2	**Earth conductor** 6) mm^2	**Earth plate** cm^2	
Copper, Tin plated copper 9)	Stranded		≥ 50		1,7 mm diameter of each strand
	Solid round		≥ 50		8 mm diameter
	Solid tape		≥ 50		2 mm thick
	Solid round	≥ 176			15 mm diameter
	Pipe	≥ 110			20 mm diameter with 2 mm wall thickness
	Solid plate			≥ 2.500	500 x 500mm with 2 mm thick 10)
	Lattice plate 7)			≥ 3.600	600 x 600 mm consisted of 25 x 2 mm section for tape or 8 mm diameter for round
Hot dipped galvanized steel 2)	Solid round		≥ 78		10 mm diameter
	Solid round	≥ 150 3)			14 mm diameter
	Pipe	≥ 140 3)			25 mm diameter with. 2 mm wall thickness
	Solid tape		≥ 90		3 mm thick
	Solid plate			≥ 2.500	500x500mm with 3 mm thick
	Lattice plate 7)			≥ 3.600	600x600mm consisted of 30 x 3 mm section for tape or 10 mm diameter for round
	Profile	8)			3mm thick
Bare steel 5)	Stranded		≥ 70		1,7 mm diameter of each strand
	Solid round		≥ 78		10 mm diameter
	Solid tape		≥ 75		3 mm thick
Copper coated steel 4)	Solid round	≥ 150 11)			14 mm diameter with 250 microns minimum radial copper coating 99,9 % copper content
	Solid round		≥ 50		8 mm diameter, if 250 microns minimum radial copper coating of 99,9 % copper content
	Solid round		≥ 78		10 mm diameter, if 70 microns minimum radial copper coating of 99,9 % copper content
	Solid tape		≥ 90		3 mm thick, if 70 microns minimum radial copper coating of 99,9 % copper content
Stainless steel	Solid round		≥ 78		10 mm diameter
	Solid round	≥ 176 11)			15 mm diameter
	Solid tape		≥ 100		2 mm thick

1) Manufacturing tolerance: - 3 %.
2) The coating should be smooth continuous and free from flux stains
3) Threads, where utilized, shall be machined prior to galvanizing.
4) The copper shall be intrinsically bonded to the steel. The coating can be measured using an electronic coating measuring thickness instrument.
5) Shall be embedded in concrete for a minimum depth of 50 mm.
6) In case of a foundation earthing system, the earth electrode shall be correctly connected at least every 5 m with the reinforcement steel.
7) Lattice plate constructed with a minimum total conductor length of 4,8 m.
8) Different profiles are permitted with a cross section of 290 mm^2 and a minimum thickness of 3 mm, e.g. cross profile.
9) Hot dipped or electroplated; minimum thickness coating of 1 µm. Tin plating is for aesthetic reasons only.
10) In some countries the cross sectional area may be reduced to ≥ 1.800 cm^2 and the thickness to ≥ 0,8 mm
11) In some countries the cross sectional area may be reduced to 125 mm^2.

Tested copper coated steel rods were practically not destroyed by corrosion process during the tests required by EN 5164-2 [7]. Tested samples having Galmar standard copper coatings had the highest corrosion resistance level (1 or 2) according to Polish corrosion evaluation standard [8]. Their surfaces were smooth and without visible corrosion products.

The samples of earthing rods with hot-dip zinc coatings have been corroded uniformly. The corrosion rate was app.15-30 times higher than in case of standard copper coatings. On the sample surfaces were visible corrosion effects showing of decrement of zinc coating and local uncover of steel rod base (see Figure1), which are not allowed according for LPS earth electrodes according to requirements of EN 50164-2 [7].

Table 2. Results of laboratory corrosion tests

Description of rod coating	**Corrosion effects**			
	Loss in mass [g]	Corrosion rate V_m [g/m^2 24hours]	Corrosion rate V_p [mm/ year]	Corro-sion level [8]
Copper	0,02	0,003	0,001	1
(Galmar)	0,05	0,086	0,004	2
Zinc hot-dip galvanized	0,62	1,10	0,056	5
	0,60	1,06	0,054	5

Field corrosion tests

The steel earth rods with zinc galvanized and copper electrodeposited coatings were embedded in two different sites in Poland (site A - Mielno and site B - Inowroclaw). The zinc coating were two types using galvanized - hot deep coating, technology. The copper coatings were made using original Galmar electroplating technology assuring thickness at least 250 μm of copper coating.

Each of rods consisted of two mechanically joined elements with total length l = 3m. Rods with copper coatings had diameter 16 mm (5/8″), while diameter of steel rods with zinc coating was 20 mm.

The aim of this long term project is to study the corrosion rates in different soils of different kind commonly used steel rod coatings of in the same environmental conditions. This observation is based on comparison of coating stste and thicknes of individual rods after removal every two years from the two soil types in Poland.

In Table 3 are given characteristics of earthing rods removed after two and four year years exposure in natural soil and comparison of their physical condition.

The pictures of fragments of earth rod removed from the soil in both sites after six years exposure are shown in Figure 2 and 3.

The measured average thickness of copper coatings of steel rods made by Galmar was after two, four and six years exposure in soil was similar to the initial one (see table 3).

Earth rods embedded in site A (Mielno) in the upper part (0,5 to 1,5 m from the erth surface) were covered with corrosion deposits joined with original soil, which were well adherent to the rod surface embedded. The lower part of rod had no visible corrosion centres neither after two nor after four years of exposure in soil (see Figure 2).

The earth rods with copper coating embedded in site B (Inowrocław) were covered in the upper part (up to 1,5 m from ground surface) with corrosion deposits in app. 90%, while the lower part (1,5 - 3 m) were covered with corrosion deposits in app. 5% only. The lower part of investigated earth rod did not have visible corrosion effects and was slightly lustreless with original metal colour .

The earth rods with galvanized hot-dip zinc coating installed in both sites were covered with corrosion products along their whole lengths. The thickness of coatings was much less than the initial one (see Table 3). When removing the rod after 6 years it was seen taht zinc coating was completely damaged by corrosion.

Table 3. Results of field corrosion tests

Soil parameters			**Parameters of earth rods coating**				
Site	Type and resi-stivity [Ω m]	pH	Material	Coating thickness [μm] Initial	After 2 years	After 4 years	After 6 years
A – Mielno	Sand	6,5	Copper (Galmar)	260 - 360	260-360	260-350	260-250
	300 – 400		Zinc hot-dip galvanized	50-60	40-50	30-40	30-50
			Zinc electro-deposited		0-15	0-10	0 locally 20
B - Inowroclaw	Sand	7,0	Copper (Galmar)	260 - 360	260-360	260-350	260-350
	80 – 120		Zinc hot-dip galvanized	50-60	40-50	30-40	40-50
			Zinc electro-deposited		0-15	0-10	0 locally 20

Conclusions

In current IEC and EN standards related to earth electrodes the most important requirements are connected with quality and long term performance in different environments, namely to mechanical strength and corrosion resistance. There is proposal of adequate IEC Technical Committees and Working Groups to unify those requirement in different international standards related to earth electrodes for different applications.

Dimensioning of earth electrodes and selection of protective coatings for steel rods and conductors shall base on practical test results performed by independent institutions and manufacturers of this kind of products worldwide, mainly in field conditions which are usually characterized by different environmental parameters.

Laboratory and field corrosion test results show evidence of better corrosion protection by copper coating of steel earth electrodes compared to zinc coatings made using different technologies and having different thickness of coating thus influencing the long term reliability of earthing system.

The results of comparative laboratory and field corrosion tests results of earth rods performed in Poland are in good agreement with similar test results for earth rods with different type of protective coatings and different metals performed in USA in frames of long term study realized by NBS, NCEL and National Electrical Grounding Research Project.

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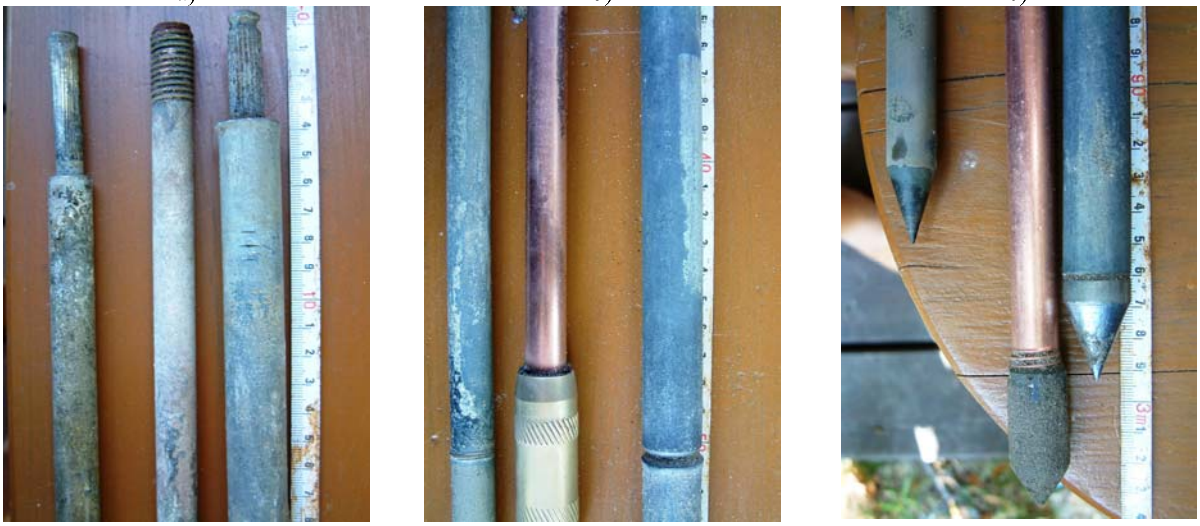

Figure 2. Pictures of earth rod fragments after six years exposure in site Mielno; a) upper part, b) middle part, c) lower part.

a) b) c)

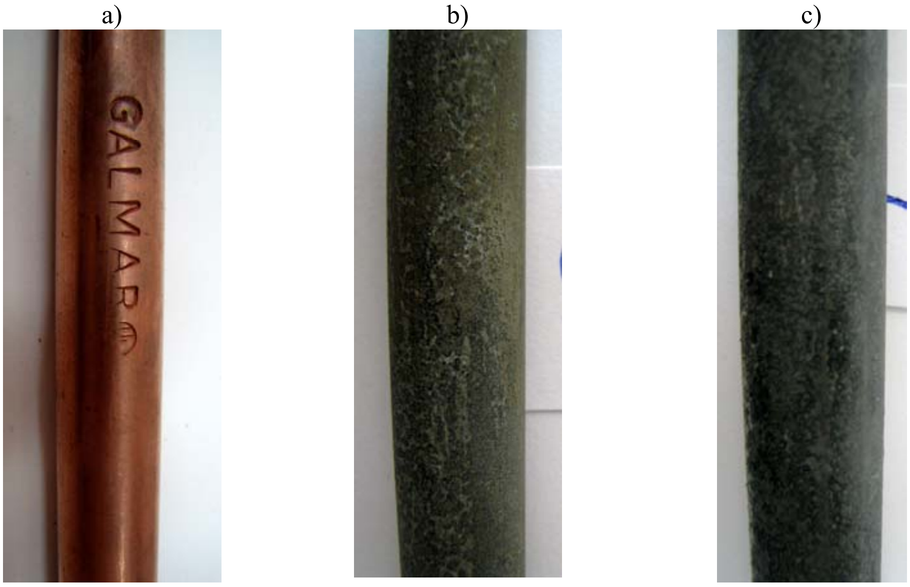

Figure 3. Pictures of earth rod fragments with removed corrosion deposits after six years exposure in site Mielno; a) copper coating (Galmar), b) zinc electrodeposited coating, c) zinc hot-dip galvanized coating.