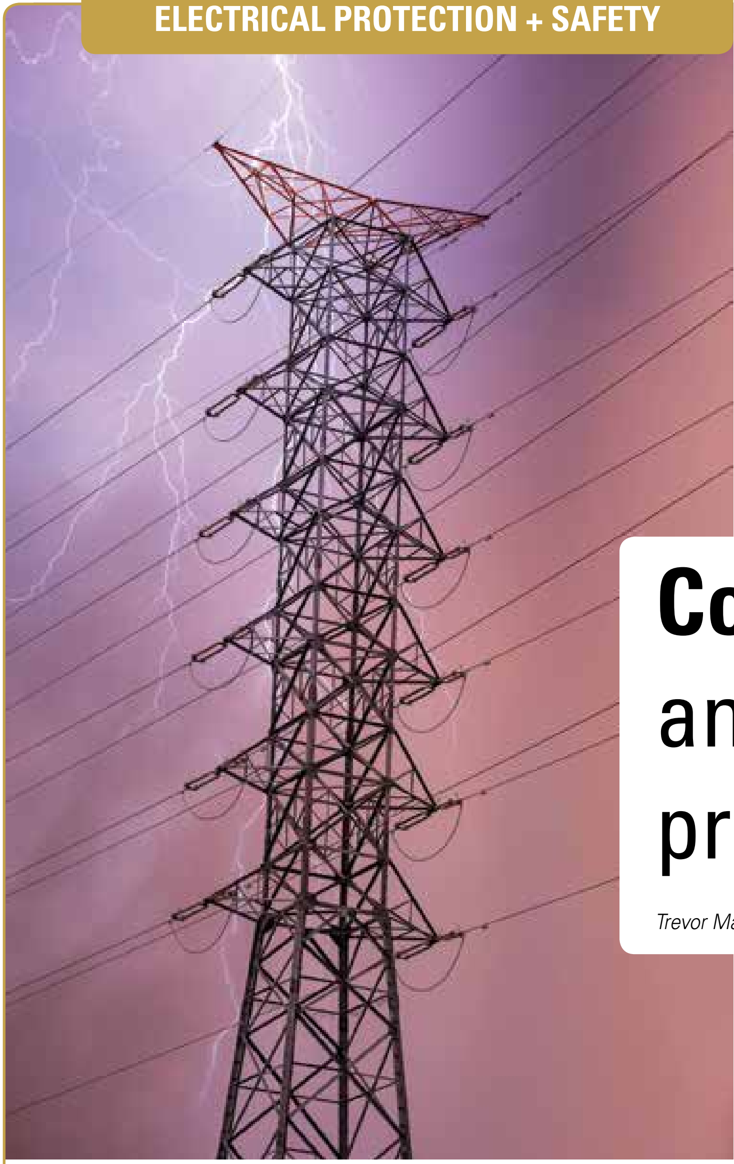

Corrosion of earthing and lightning protection systems

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Generally, earthing and lightning protection systems are designed and installed to last between 20 to 30 years… which can be achieved, given the right conditions.

In order to achieve a life span of 20 to 30 years, the correct appraisal of the site conditions, environmental factors, soil resistivity values, types of conductors and components must be carefully assessed. The correct site evaluations and subsequent design and installation should prevent premature corrosion of the earthing and lightning protection conductors, connectors and components and thereby increase the life expectancy of these protection systems. There are various factors that could cause corrosion of the earthing and Lightning Protection System (LPS), they are as follows:

- Electrochemical corrosion (most cases)
- Galvanic corrosion
- Corrosion at buried connection points
- Air-borne corrosive particles
- Incorrect combination of materials

Figure 1: Corrosion of 10 mm solid galvanised conductor – after eight years.

Electrochemical corrosion

Corrosive soils: Conductors in direct contact with the soil or water (electrolytes) can corrode owing to stray currents, corrosive soils and cell formation. It is not possible to protect earth electrodes from corrosion by completely enclosing them, this is because the use of protective sheaths have high electrical resistance and therefore eliminate the effectiveness of the earth electrodes. Earthing systems made of the same material are prone to corrosion as a result of corrosive soil conditions and the formation of concentration cells. The risk of corrosion depends on the earthing materials and the type and composition of the soil.

Soil resistivity: The relationship between soil resistivity and corrosiveness can be appraised, as a general guide *Table 1* can be used:

Soil resistivity - Ω.m	Corrosiveness
0 - 10	Very severe
10 - 100	Moderate to severe
100 - 1 000	Mild (if aerated)
> 1 000	Probably not corrosive

Table 1: Relationship between soil resistivity and corrosiveness. Source: SANS 10199: 2010 [1].

The results are sometimes difficult to interpret where dry soil is underlaid with moist soils and where the soil types vary with depth. In these cases, the soil resistivity should be determined at the planned depth of the earth electrodes.

If the soil conditions are deemed to be corrosive due to low soil resistivity values, then the appropriate measures should be employed to mitigate the corrosiveness of the soil. These would include the choice of conductor type and the sealing of connection points to prevent corrosion.

Heterogeneous soils: It is vitally important to carry out numerous soil resistivity soil surveys when conducting a site evaluation. The soil resistivity values give a good indication on whether the soil conditions are Homogeneous or Heterogeneous. When the soil resistivity values differ substantially across the site, this indicates that the soil conditions are Heterogeneous. The variance in the soil conditions can lead to corrosion of the earth termination conductors if the incorrect type of conductors and connection points are installed.

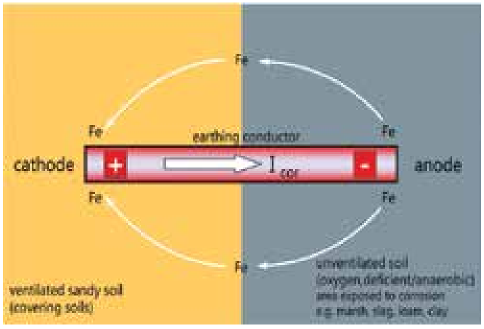


Figure 2: Formation of concentration cell in heterogeneous soil.

Cell formation

Corrosion damage due to cell formation is on the increase. A cell is formed between different types of metals with very different electrolyte potentials are immersed into an electrolyte (soil). With this in mind, it is not commonly known that the reinforcing of concrete foundations can become the cathode of a cell and hence cause corrosion to other buried services. Owing to changing construction methods, larger reinforced concrete structures in the ground result in the surface ratio of anode / cathode becoming more and more unfavourable with the risk of corrosion of non-precious metals being increased.

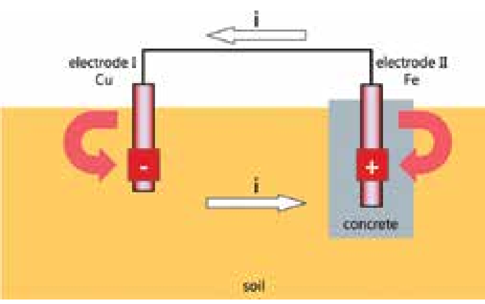


Figure 3: Formation of cell electrode in soil/ iron in concrete.

Today, the aim is to interconnect all earth electrodes and other buried metal installations to establish equipotential bonding and thus ensure maximum safety against excessive step and touch voltages in the event of a fault current or lightning strike. The only way of preventing or reducing the risk of corrosion of the earth termination systems and the other metallic installation connected to them is to choose suitable earth electrode materials.

Selection of earthing materials

Hot dipped galvanised steel: Galvanised steel may be embedded in concrete. Foundation earth electrodes, earthing and equipotential bonding made of galvanised steel may be connected to concrete steel reinforcing.

Copper clad steel: Various anti-theft conductors are made of copper sheathed steel. The properties for copper apply to the sheath material but damage to copper sheath presents a high risk of corrosion of the steel core. Therefore care must be taken not to damage the copper layer.

Bare copper: Bare copper is very resistant to corrosion due to its position in the electrochemical series. Moreover, when copper conductors are connected to other buried metallic installations made of more 'non-precious' materials (e.g. steel), bare copper provides additional cathodic protection of the earth termination system, this however is at the expense of the 'non-precious' metals.

Stainless steel: High-alloy stainless steels are inert and corrosion-resistant in the ground. Since the surface of stainless steel earth electrode materials passivate within a few weeks of installation into the ground, they are neutral to other precious and non-precious materials.

Combination of earth electrodes made of different materials

All of the material, configurations and minimum dimensions of the earthing materials / earth electrodes are according to *Table 7*, SANS / IEC 62305-3 [2] (included with the online version of this article).

The cell current density resulting from the conductive combination of two different metals that are buried leads to the corrosion of the metal acting as the Anode.

It is therefore extremely important to design earth termination systems taking into account the various different metals that may be buried. When combined with buried steel installations (pipes, tanks etc.), the earth electrode materials like bare copper or stainless steel will always behave as cathodes when they are covered with soil. The bonding to these buried installation must therefore be carefully considered to prevent corrosion of these buried metallic installations.

Concrete steel reinforcing of foundations

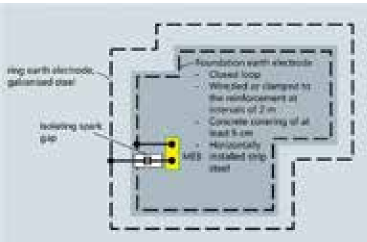
The steel reinforcing of concrete foundations can have a very positive potential (similar to copper). Earth electrodes and earthing conductors that are directly connected to the steel reinforcing of large concrete foundations should therefore be made of copper or stainless steel. This in particular applies to short connecting cables in the immediate vicinity of the foundations or at the rebar bonding terminals.

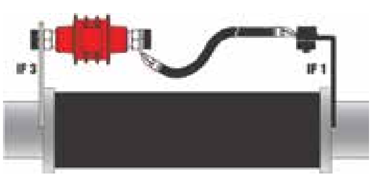
Material with small area	Material with large area			
	Galvanised steel	Steel	Steel in concrete	Copper
Galvanised steel	+	+ Zinc removal	–	–
Steel	+	+	–	—
Steel in concrete	+	+	+	+
Steel with copper sheath	+	+	+	+
Copper / StSt	+	+	+	+
+ Combinable		–– Not combinable		

Table 2: Material combinations – earth electrodes.

Installation of isolating spark gaps

It is possible to interrupt the conductive connection between buried installations with very different potentials by integrating isolating spark gaps. By installing spark gaps at the connection point between the two dissimilar metallic buried objects, it is no longer possible for the corrosion currents to flow. In the case of a surge, the isolating spark gap trips and interconnects the installations for the duration of the surge. Spark gaps should not be installed for protective and operational earthing systems since these earth electrodes must always be connected to the system they are designed to protect.





Figures 4, 5, 6: Spark gap used for equipotential bonding between two dissimilar metallic buried installations.

Other anti-corrosion measures

Externally induced currents: Current flow that causes corrosion of buried conductors, connections and electrodes can also be induced by outside sources. Often the presence of nearby Overhead Powerlines and Railway Lines can induce currents into the ground as part of their current return path. These induced currents can cause rapid corrosion to buried earth termination conductors, connection points and components. Only copper or stainless steel should be installed in such cases, particular attention should also be paid to the types of components and below ground connections that are installed. Additional protection of the connection points should be installed by means of a corrosion protection covering (e.g. wrapped with a anti-corrosion tape).

Galvanic corrosion: Quality engineering and LPS design requires the understanding of material compatibility. Galvanic corrosion (also called ' dissimilar metal corrosion') is the process by which the different metals/ alloys in contact with each other oxidises or corrodes. The compatibility of two different metals may be predicted by consideration of their anodic index.

A spectacular example of galvanic corrosion occurred in the Statue of Liberty when regular maintenance checks in the 1980s revealed that corrosion had taken place between the outer copper skin and the wrought iron support structure. Although the problem had been anticipated when the structure was built by Gustave Eiffel to Frédéric Bartholdi's design in the 1880s, the insulation layer of shellac between the two metals had failed over time and resulted in rusting of the iron supports. An extensive renovation requiring complete disassembly of the statue replaced the original insulation with PTFE.

In order to prevent galvanic corrosion of the earthing and lightning protection systems, the following procedures should be undertaken:

- Selection of the appropriate materials with similar anodic potential is preferable
- Use of bi-metallic clamps must be employed when joining two dissimilar metals

	Hot dip Galvanised steel	Aluminium alloy/ aluminium	Copper	StSt	Titanium	Tin
Hot dip galvanised steel	Yes	Yes	No	Yes	Yes	Yes
Aluminium alloy/ aluminium	Yes	Yes	No	Yes	Yes	Yes
Copper	No	No	Yes	Yes	No	Yes
StSt	Yes	Yes	Yes	Yes	Yes	Yes
Titanium	Yes	Yes	No	Yes	Yes	Yes
Tin	Yes	Yes	Yes	Yes	Yes	Yes

Table 3: Compatible metal combinations.

Earth entries made of galvanised steel

Earthing conductors made of galvanised steel must be protected against corrosion at the point of entry into the ground. The protection of these galvanised conductors must be at least 300 mm above and below the surface of the earth. A moisture-proof sheath, e.g. PVC insulation or heat-shrinkable sleeves can be used. It is however preferable to use stainless steel or copper conductors to provide corrosion protection.

Figure 7: Unprotected galvanised steel earthing conductors entering the soil (corroded).

Other anti-corrosion measures

Below ground connections: Below ground connection of conductors and electrodes probably constitutes the most vulnerable portion of the earth termination system to corrosion. In many cases, the correct conductors and electrodes are selected but inferior connection points corrode rapidly, resulting in an unsafe installation. There are various types of below ground connections, but two main types of connections can be used:

- The **thermite welded connections** form a molecular bond between the two connecting parts. Provided that the two connecting parts can be combined (see *Table 3*), then thermite (or cadwelded) connections are very corrosion resistant. In corrosive soils additional protection by of means wrapping the connection with anti-corrosion tape is recommended
- In order to ensure that the below ground connections have the equivalent corrosion resistance as the corrosion protection layer of the earth termination system, the **clamped or crimped connections** must be equipped with a suitable corrosion protection layer e.g. wrapped with an anti-corrosive tape

Figure 8: Protection of connections with anti-corrosion tape.

Aluminium conductors: Aluminium conductors are used for various lightning protection elements like the air termination system and the down conductor system. Aluminium conductors are however quite vulnerable to corrosion and care should always be taken when these conductors are installed. Aluminium conductors should never be installed in the following conditions:

- Aluminium conductors should never be installed directly on or in calcareous building surfaces such as concrete, limestone and plaster
- Aluminium conductors should never be installed directly into the ground
- Aluminium conductors should never be installed in areas where airborne corrosive particles exist

Airborne corrosive particles

The presence of airborne corrosive particles can cause rapid corrosion of air terminals, external down conductors and above ground connection points. Corrosion can be prevented by means of a proper site evaluation and correct design, this would involve obtaining the correct site information from the site authorities. Stainless steel conductors, guides, connections and finials are recommended in corrosive environments.

Figure 9: Unprotected aluminium down conductor – incorrect installation.

Conclusion

When backfilling earth electrodes trenches, pieces of slag and coal must not be in direct contact with the earth electrode material. The same applies for construction waste. Care should also be taken during the backfill of earthing trenches not to backfill with rocks and large stones, these elements can damage any protective coating of the earth electrode materials and cause corrosion. Cathodic protection systems are installed to buried pipelines, vessels and tanks to prevent corrosion on these buried structures. It is imperative that the cathodic protection systems are equipotentially bonded into the site`s earthing and lightning protection systems, this bonding is carried out to prevent damage due to potential differences between the two systems. Conventional equipotential bonding however will result in the effectiveness of the cathodic protection system being greatly or totally reduced. It is therefore necessary to utilise spark gaps for this equipotential bonding, the bonding must also be strategically placed in vulnerable positions such as the isolating flanges. This type of bonding is essential in zoned or classified areas where dangerous sparking must be avoided. Besides cable theft, corrosion prevention is probably the single most important factor in ensuring the longevity of the earthing and lightning protection systems. In order to prevent corrosion of the earthing and lightning protection components, the following steps should be taken:

- All earthing and lightning protection components should be tested in accordance with the SANS / IEC 62651 [3] series of standards. Component certificates should also be supplied by the installer.
- Proper site assessments must be carried out including the carrying out of various soil resistivity surveys, appraisal of the soil`s corrosiveness and the determination of the various external factors

that can cause corrosion of the earthing and lightning protection components.

- Quality engineering and properly designed protection systems must be employed taking into account the various corrosive elements that may exist on the site and the correct combination of the various LPS conductors.
- Additional protection measures such as the use of anti-corrosive tape on the below ground connections should be installed on sites that could be corrosive and where clamped or crimped below ground connections exist.
- Bi-metallic joints must be installed when two dissimilar metals are joined.
- Copper parts should never be installed above galvanised or aluminium parts unless those parts are provided with protection against corrosion. Extremely fine particles are shed by copper parts which result in severe corrosive damage to galvanised parts even where the copper and galvanized parts are not in direct contact.
- LPS should be constructed of corrosion-resistant materials such as copper, aluminium, stainless steel and galvanised steel.

> *Corrosion is the reaction of a metal material with its environment which impairs the characteristics of the metal material and its environment.*

References

[1] SANS10199. 2010. The Design and installation of earth electrodes.
[2] IEC 62305-3. 2006. Protection against lightning – Part 3: Physical damage to structures and life hazard.
[3] SANS/IEC 62651. 2013. Nuclear power plants - Instrumentation important to safety - Thermocouples: characteristics and test methods.

Trevor Manas started his lightning protection career at Pontins in 1991. After spending some years in sales, he was promoted to the position of director in 1996, in charge of ensuring the company`s compliance with the earthing and lightning protection codes of practice. In 1999, Trevor became the managing director of Pontins. In 2013, Pontins formed a partnership with DEHN Africa. Enquiries: Email trevor@pontins.co.za