RECOMMENDATION PCRA 004
October 2005 – Rev. 0

CEFRACOR
CENTRE FRANÇAIS DE L'ANTICORROSION

Committee for Cathodic Protection and Associated Coatings

Recommendations for the compatibility of grounding and cathodic protection

DISCLAIMER: The present recommendation has been consensually established by the members of the committee "Cathodic protection and associated coatings" of CEFRACOR. It reflects the general opinion in the trade and might be used as such as a basis representing at the best the state of art at the date of issue. Nevertheless, it shall not commit in any manner the CEFRACOR and the committee members by whom it was established.

SUMMARY

1) SCOPE

The purpose of this document is to clarify the interaction between the grounding of a structure and its cathodic protection and to find the best compromise in order to ensure the effectiveness of the latter and in the same time being compliant with the regulatory provisions related to the protection of people with regard to the electrical hazards.

Note: The specific constraints related to EMC (electromagnetic compatibility) and the techniques that may prevent their detrimental effects are not addressed in this document. They remain to be taken into account together with the development of the techniques in this field.

2) STANDARDS , REGLULATORY AND PROFESSIONNEL REFERENCES

2.1) French reference documents

Arrêté du 31 Mars 1980	1980	Réglementation des installations électriques des établissements réglementés au titre de la législation sur les installations classées et susceptibles de présenter des risques d'explosion.
Arrêté du 26 Mai 1978	1978	Conditions techniques auxquelles doivent satisfaire les distributions d'énergie électrique
Arrêté du 17 Mai 2001	2001	Lignes de télécommunication. Article 68. Tension induite limite
Décret N° 88 1056 du 14 Novembre 1988	1988	Protection des travailleurs dans les établissements qui mettent en œuvre des courants électriques.
Arrêté du 28 Janvier 1993	1993	Protection contre la foudre de certaines installations classées (SEVESO).
Arrêté du 28 Octobre 1993	1993	Circulaire d'application de l'arrêté du 28 Janvier 93
NF C 15 100 du 13 Mai 1991	1991	Installations électriques à basse tension. Chapitres 44 Protection contre les surtensions, et 54 Mises à la terre et conducteurs de protection
NF C 15.106 du 26 Mai 1993	1993	Guide pratique- Section des conducteurs de protection, des conducteurs de terre et des conducteurs de liaisons équipotentielles.
NF C 17. 100	1997	Protection des structures contre la foudre. Installation de paratonnerres
NF C 17.102	1995	Protection des structures contre la foudre. Installation de paratonnerres à pointes ionisantes
NF A 05.613	1995	Protection électrochimique contre la corrosion. Protection cathodique des cuvelages de puits
NF EN 12954	2001	Protection cathodique des structures métalliques enterrées ou immergées. Principes généraux et application pour les canalisations.
PrEN 50443	2005	Applications ferroviaires – Installations fixes - Effets des perturbations électromagnétiques causées par les lignes ferroviaires en courant alternatif sur les canalisations
PrEN 11636	2005	Influences électromagnétiques des voies ferrées sur les canalisations enterrées
NF EN 13636	2004	Protection cathodique des réservoirs métalliques enterrés et tuyauteries associées
NF EN 14505	2005	Cathodic protection of complex structures
CEN wi 0021904		Cathodic protection of well casings
UIC Cahier Technique 1991	1991	Recommandation pour la protection des installations industrielles contre les effets de la foudre et des surtensions

UIC Complément au Cahier Technique 1991	1993	Recommandation pour la protection des installations industrielles contre les effets de la foudre et des surtensions pour l'application de l'arrêté du 28 Janvier 1993 concernant la protection contre la foudre de certaines installations classées
UIC N° DT 67 Rapport GESIP N°94/02 version 2000	2000	Recommandation pour la protection des installations industrielles contre les effets de la foudre pour l'application de l'arrêté du 28 Janvier 1993 concernant la protection contre la foudre de certaines installations classées

2.2) Foreign reference documents

NACE RP0177-2000	2000	Mitigation of alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems
NACE RP0193-2001	2001	External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms
NACE RP0286-2002	2002	Electrical Isolation of Cathodically Protected Pipelines
API RP 651	1997	Cathodic Protection of Aboveground Petroleum Storage Tanks

3) OVERVIEW OF THE PROBLEMS

3.1) Grounding circuit

Basically, the problem addressed in this document is based on the incompatibility between, on one hand the standard in force that imposes the interconnection of all the metallic structures, and on the other hand, an adequate implementation of the cathodic protection that must protect buried structures. As a matter of fact, the interconnection of the buried structures entails also a common grounding of all these structures.

The grounding systems, traditionally made out of copper (used because of its features of stability over the time), pose the following problems with regard to the cathodic protection:

- A copper grounding grid, connected to the structure under cathodic protection, may drain more than 90% of the protection current. In fact, the polarization of copper is less good than that of steel, it requires 10 to 20 times more current. According to the configuration, it may even be impossible to correctly polarize the steel structure.
- If the cathodic protection is not effective anymore, there is a risk of corrosion of the structure due to the galvanic coupling between the copper and the steel to the detriment of the steel.
- The effect of the cathodic protection current may lead to alkali deposits at the surface of the copper, which may in certain cases, depending on the type of soil, lead to an increase of the grounding resistance.
- Numerous other drawbacks can be evoked (list not intended to be exhaustive): heterogeneity of the cathodic protection hard to adjust depending on the areas close to or far away from the electric groundings (overprotection and under protection coexist), difficulty to carry out reliable measurements (the potential of the copper masking the others), the 100 mV criterion is not applicable, difficulty to implement a protection by sacrificial anodes, etc.

3.2) Electrical interference due to above ground HV power lines (specifically on pipelines)

The presence of a HV power line close to a pipeline can be a source of dangerous electrical interference for this structure, as well as during normal operation of the power line, as when faults occur on the line.

There are two types of influence of alterative currents on the buried structures:

a) Short term interferences caused be a failure of the alternative current HV power line or by operational changes (conductive and/or inductive effects). In the vicinity of a tower of the energy transmission network, when an insulation fault occurs of the HV line pole, the potential difference between the pipeline (at the remote earth potential) and the local soil (grounding of the pole) may reach several kilovolts, and lead to the puncture of the pipeline and the transmission of hazardous voltages along the pipeline. The inter ministerial order of May 26th 1978 titled « technical conditions to which shall comply the distribution of electrical energy »develops in its 75th article (modified in the « Journal Officiel » of March 16th 1982) the measures to be implemented in the vicinity of electrical power lines and metallic pipelines, as well for conductive as inductive problems.

b) Interference of long duration caused by induction during normal operation (inductive interference). For instance, the safety of personnel is not ensured anymore when the voltage between the structure and the soil exceeds the value of the safety voltage (60 VAC for the pipelines, ordinance of May 17th 2001 and prEN 50443). The potential produced by permanent induction from the HV power line on a nearby buried pipeline can exceed this value. Moreover, permanent alternative voltages exceeding 5 VAC may lead to risks of corrosion at small defects in high resistance coatings.

3.3) <u>Interconnections of metallic masses</u>

The reasons motivating the choice of the interconnection of metallic masses are important. They should be well known in order to consider acceptable solutions that may reconcile the incompatibilities between these standards and the cathodic protection.

On should well distinguish the risks of lightning and other potential surges that may lead to damage to electrical equipment, the electrical hazards for personnel as well as the means to ensure their protection.

For the risks of lightning, theoretically, on could not implement a grounding circuit. It is useless with respect to the issue equipotentiality as mentioned above. Moreover, the grounding resistances, measured at low frequency (50 Hz) are totally different from the value of their impedance which is to be considered at very high frequency (lightning). In fact, the grounding systems are of no use for the evacuation of the lightning currents, they only act as a protection of personnel against the hazards related to the potentials at industrial frequencies. Because of this fact they have been made mandatory by the legislation in force.

For the protection of persons the important criterion consists of avoiding a potential difference, which is deemed hazardous, between two regions of the human body. In case of a potential test post, for instance, a grounding system should be installed at the location where the individual is supposed to touch a point at which the potential is different from the one where his feet are in contact with the ground.

A person is always supposed to be exposed to a potential difference if he touches two parts that are electrically isolated one from each other (for instance two metallic structures separated by an insulating joint). It is this reason that justifies the interconnection of the metallic structures.

By interconnection of metallic masses one should understand the interconnection of the structures (including rebar of concrete and the grounding systems of buildings), the grounding of the premises (safety of personnel) and the lightning protections.

The essential objective is to ensure a preferential path of return, of the lowest resistance, for the currents to the ground. Moreover the potential gradient created at the ground surface by the flow of the current is diminished with regard to what it would be on individual groundings (safety of personnel). The interconnection provides also a useful redundancy in case of the rupture of a cable or other liaison.

For the protection of electrical equipment against lightning, it is important to realize a good equipotentiality in order to enable a uniform evolution of the potentials (it is the difference of potential between different elements of a component that leads to degradations). It is for this reason that the lengths of the cables or other liaisons (e.g. braids) should be as short as possible with respect to the liaison of areas that shall be equipotential.

In any case, it is illusory to want to avoid the flow of currents of extremely short duration.

4) <u>RECOMMENDED SOLUTIONS</u>

Any electrical solution considered and that entails particular equipment on the structure shall remain compatible with the cathodic protection.

The proposed alternatives that are accepted by the inspection bodies will consist in avoiding the effective interconnection of the metallic masses and in the same time providing an adequate response to the reasons for which these interconnections are required.

4.1) Separation of the circuits by an insulating joint

The insulating joint separates a classically grounded above ground structure from the buried pipeline under cathodic protection i.e. maintained at a potential of approximately -1V with regard to the Cu/saturated $CuSO_4$ reference electrode. This buried pipeline is considered to be isolated from the ground, especially with modern high resistance coatings, and may be subjected to electrical interference (see § 3.2.). In order not to jeopardize the effectiveness of the cathodic protection, it is to be avoided to connect this pipeline directly to a classical grounding system of bare copper. See possible solutions in the following chapter.

Long pipelines protected by older types of coatings that present a low ground resistance (which can be less than 1 ohm) can be considered as being “grounded”. As a matter of fact, they are not concerned by the influence of HV power lines addressed in § 3.2.

A protection system (polarisation cell on other, see § 5) must be installed in parallel over the insulating joint. The protection of personnel is ensured if the threshold potential of the protection device is low. If this threshold potential remains hazardous for people (spark-gap or no protection system on a non-shunted solution joint) the protection against the risks due to a potential difference over the insulating joint, will consist in rending impossible any simultaneous contact by a person with both sides by making the whole inaccessible (isolating housing or suitable coating over a sufficient length, etc.).

4.2) Structures not isolated by insulation joint

The absence of insulating joints can be voluntary (installation of a shunt) or accidental (insulation failure of the joint). In this case, the inconvenient presented in 4.1 shall be avoided.

4.2.1) Grounding systems having a potential of approximately -1V with regard to a Cu/$CuSO_4$

For complex structures equipped with cathodic protection, it is recommended to make the grounding out of galvanized steel in stead of copper. The current requirement is less than with copper, the current losses are therefore diminished and the galvanic coupling remains favourable for the steel. Of course it shall be avoided to mix grounding of copper and galvanized steel in the same geographic area and on the same structure. So this solution is possible for a new installation or when the existing copper grounding system is disconnected.

In the same way, this solution is well adapted to a small isolated installation, an in-line shut-off valve station, a pig trap. With regard to the hazardous touch potential, a conventional grounding system can be replaced by a grating of galvanized steel or a zinc ribbon buried close to the surface of the ground located around the valve and connected to the pipeline. This installation causes less losses of current of the cathodic protection but may influence the potential measurements, according to the position of the reference electrode.

The grounding of certain small structures (small LPG bulk vessels) may be achieved by the galvanic anodes themselves. The galvanic anode, as a matter of fact, plays a role of the of ground connection and except for their decay over the time, which has to be monitored, they favourably replace the ground connection. It is sometimes recommended to add some galvanized steel grounding pins in order to conduct important fault currents and thus ascertain the ground connection if the monitoring is not deemed effective enough.

4.2.2) Separation of grounding systems

The absence of grounding systems of large buried vessels is justified by the fact that they play a role of the ground connection themselves (GESIP 94-02 / 6.1.3.1).

For a small installation, another solution consists in a locally and temporary grounding only during the presence of personnel and with all operating procedures in order to ensure that this grounding (and its disconnection after the intervention of the personnel) is systematically carried out for instance through the opening/closing of the door of the installation. The cathodic protection remains effective beyond the time of intervention. The risk of corrosion is therefore very limited over the time which is acceptable.

For environmental protections reasons, tight membranes, which are excellent dielectrics, are more and more installed around buried storage installations (e.g. bottoms of tanks). The membranes enable to diminish considerable or even cancel the problems of compatibility with the grounding systems, as the cathodic protection system (anodes) is then confined between the membrane and the structure to be protected, whereas the grounding systems are outside the membrane.

In the same way, one may take advantage of a new installation realized in an enclosure (e.g. concrete sarcophagus) by covering the wall of this enclosure with an electrical insulation such as polyane or other (very important parameter for the study of the cathodic protection).

4.2.3) Taking into account of the grounding system for the dimensioning of the cathodic protection

The alternative consists in taking into account all ancillary metallic surfaces (groundings, piping…) and over-dimensioning the cathodic protection installation ("global or integral cathodic protection").

The additional cost of the cathodic protection installation is therefore partly compensated by the cost savings made by simplifying the electrical insulation. Moreover, the maintenance ids reduced since it is not anymore necessary to monitor the effectiveness of the insulating joints, to stop the production for their possible replacement, to check the insulating devices (spark-gaps, cells, ..) or to carry out expensive and sometimes complex investigations on ground connections during periodic works which may entail electrical modifications (additional sensors, new connections, etc.).

The drawback of this type of installation is that it disturbs the cathodic protection measurements at the approach of these equipment and to make the coating fault detection (DCVG or other) more delicate.

For a new installation, one may consider a local cathodic protection with judiciously located anodes in thoroughly define d areas with a detailed study of the grounding system and of the location of the ground connections.

It is recommended to foresee an important distance of the grounding with regard to the structure in order to avoid a shielding effect of the protection current and recommend the use of coated copper cables for the liaison of the structure to the grounding system and to maximize the use of all other previously mentioned solutions (grounding system of galvanized steel, insulating membranes around the structure).

5) INSULATION AND DE PROTECTION EQUIPMENT

5.1) Insulating joints

a) Insulation kit: The whole is composed of a flange gasket (made out of a material providing tightness with regard to the carried fluids in the operations conditions), the sleeves and the washers adapted to the bolting. The whole is made out of elements providing the assembled equipment a resistance exceeding 100 MΩ for a maximum operating voltage of 1 kV.

b) High voltage type monobloc insulating joint. The test voltage at the factory is 10 kVAC in the case that protection is required against induced potential surges due to a mutual induction phenomenon. The electrical stress applied to a hydrocarbons pipeline must not exceed 5 kV (ministerial order of May 26th 1978 publish in the official bulletin of the French Republic of April 27th 1982).

5.2) Protection of insulating joints

In order to avoid to ignite an arc in the insulation joint due to fault currents or lightning some thousands of amperes should be enabled to flow during a brief instant through a device installed over the insulating joint.

5.2.1) Electronic cells

A first category of devices blocks continuous currents up to a given threshold (potential difference between in- and outlet of the device). Above this threshold the device is conducting with a very low resistance (mOhm). This threshold is higher than the voltage of the Insulation cathodic protection, but remains below the hazardous voltages for human beings. These devices also conduct the alternative currents which may possibly create a hazard for human beings and risks of corrosion.

The following devices can be mentioned:

a) The polarization cells or “liquid cells” composed of nickel plates immerged in a potassium hydroxide electrolyte solution and that operates according to electrochemical principles. These polarisation cells require maintenance to top off the liquid as well as a protection against frost.

b) Other devices composed of electronic elements often associates (diodes capacitors, spare gaps…) and of adapted size.

These devices can be compliant the ATEX directive (material usable in explosive atmospheres) or integrated in an ATEX compliant enclosure.

5.2.2) Spark-gaps

The spark-gap blocks currents (direct and alternating) up to a breakdown voltage. Beyond this threshold it enables to conduct a current discharge of several kA and a lightning current intensity even much higher during a few microseconds.

It is therefore necessary to evaluate the fault currents (phase/ground, the atmospheric risks …) in order to determine the size of the spark-gaps to be used and the protections to be implemented (3 to 15 kA).

It typically enables to protect an insulating joint by avoiding its deterioration by a lightning strike but its breakdown voltage in higher than the safety voltage for the human being.

A spark gap is composed of an enclosure containing an insulating, neutral rare gas or an assembly of electronic components. Both types can be ATEX compliant.

Important notes:

- The equipment comprises electrical connection bonds that shall not be modified or prolonged.
- The same devices may serve to protect two adjacent structures that shall remain isolated one from the other by limiting the risk of breakdown of the insulation material (e.g. between a pipeline under a railway crossing and its metallic sleeve).

5.3) Protection of power supply units of equipment

Electrical and/or electronically equipment may be electrically connected to the pipeline. Their power supply to generally from the mains. Lightning arresters and potential surge arresters exist to protect these equipment against voltage surges due to lightning or fault currents. These components are installed on the primary power supply circuit and/or on the secondary circuit of a rectifier, or any other electrical device.

A lightning arrester is generally of similar technology as a spark-gap (gas, spark,…) with a high capacity of lightning strike current flow but having a protection threshold voltage rather high (breakdown voltage ≤ ~3,5 kV).

For potential surge arresters other technologies are used in order to bring the protection threshold voltage below 1 kV.

a) Varistors (they made decay over the time, so equipment having a warning light or index should be preferred),

b) Zener diodes (especially on the secondary circuit, typically a moulded bridge of opposite potential of 1600 V).

A lightning arrester and different types of potential surge arresters can be coupled together in order to obtain the complementary effect.

The specific characteristics of this type of equipment are especially given by their current flow capacity (rated current and maximum current), protection threshold voltage and the duration to breakdown. The choice depends on the type of protection required: lightning (short duration, high peak intensity) or fault current (lower intensity but longer duration).

In any case, the effectiveness of a lightning arrester depends on its capability to limit the over voltage and secondarily to evacuate current.

Some potential surge arresters do not have a thermal circuit breaker. When the short circuit is made, they lead to an interruption of the electrical power supply circuit by the opening of a safety device.

A lightning arrester that is specific for cathodic protection is available on the market. It behaves like a large HF capacitor up to 6V, then like a rapid peak shaver (diode threshold) in order to support the lightning current under a potential of 15Volts. Afterwards it comes back to its initial state. Exceeding a 100 kA it comes in safety short circuit.

In order to increase the effectiveness of these products, in all cases, liaisons as short as possible are required in order to limit the reaction time due to the inductances from the cables.

Certain equipment may increase EMC disturbance (electromagnetic compatibility) and other on the contrary may reduce them.

The choice and the installation of such devices is complex and often require the support of specialized companies.

5.4) Grounding of alternative currents without affecting the cathodic protection

For the current induced by a HV electrical power line (alternative current of a few amperes at the most) grounding through simple electrochemical capacitors of very high capacity (e.g. 10 mF) is suitable. In fact, a capacitor conducts the alternative current but not the direct current. Therefore it has not any influence on the cathodic protection. This electronic component does not resist high voltages neither high currents. In case of over load, it deteriorates normally in open-circuit condition, similar to a fuse.

Other solutions may be adequate such as the grounding by galvanic anodes of pipelines which are coated with a highly insulating coating like polyethylene or fusion bonded epoxy.

6) IMPORTANT NOTES

6.1) Potential test post: in order to mitigate the risk of contact with the connection cable of a potential test post, its extremity shall be equipped with a standardized IEC4 type insulating connection. In addition, the measurement devices employed shall be compliant with the local regulations.

6.2) Protection of devices against lightning: the actual grounding has only a minor influence as mentioned previously. Once the equipotentiality is ensure with very short connection cables, the protection of the equipment is ascertained. It is therefore sufficient to interpose a device such as a lightning arrester in a connection enclosure, between all grounding cables of the devices or components involved (superstructure, instrumentation, shielding of shielded cables, etc …) and the common grounding system of the site.

However on shall ensure that all equipment (spark gaps, polarization cells, potential surge arresters…) would be conducting in case of failure, in order to ensure an electrical connection synonym of safety and compliance with the legislation.

6.3) Sizing of the cables: A cable (grounding, equipotential bond, protection against lightning) is calculated for given operating conditions (dissipation of energy i.e. maximum intensity for a given duration). A calculation sheet (design tool) with the parameter values taken into account is therefore required.

6.4) Given the absence of regulatory provisions and awaiting the European standard EN 13636, it is recommended, for a new project, to ask advice from an inspection organisation in order to validate the technical solution chosen. The validation should be formalized by a calculation sheet during the design.

6.5) The operator shall foresee a maintenance plan for all the equipment adapted to their failure mode. An inspection after a thunderstorm is often carried out. For obvious reasons of safety all work on these equipment shall be interrupted during a thunderstorm (visible lightning or audible thunder).