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LIGHTNING PROTECTION OF OIL AND GAS INDUSTRIAL PLANTS

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1 INTRODUCTION

Wynnewood, 65 miles south of Oklahoma City, Friday April 27, 2007, just before noon: a tank fire sparked by lightning burns at the Wynnewood Oil Refinery in Garvin County. Two storms hit Wynnewood in less than one hour. They both produced giant lightning bolts. One of them hit a large storage tank holding light oil (naphta, an unrefined form of gasoline) sparking a large explosion. This explosion which blew the roof of the barrels was felt kilometers away. Flames and smokes poured into the sky and boiled hundreds of meters into the air from one tank containing 50,000 barrels of highly flammable naphta and another one containing 30,000 barrels of diesel fuel. The tanks involved in the afternoon's fire reportedly collapsed at night, causing several new explosions... Tank fires are pretty pesky fires, easy to keep contained but hard to fight. Luckily though no one was injured. The reason of this explosion? Case still under enquiry, but the explosion was probably due to incomplete equipotential bonding!

Cilacap, Indonesia, October 1995: a lightning flash struck the Indonesian oil refinery Pertamina in Cilacap, on the Southcoast of Java. This refinery covered one third of the Indonesian inland needs! The tank struck exploded and the burning oil set fire to six other tanks on the plant. Thousands of inhabitants and four hundred Pertamina employees had to be evacuated for safety reasons. There resulted a standstill period of one and a half year. In the mean time oil, petrol, kerosene and diesel worth of about 400,000 dollars daily had to be imported for the supply of Java. The new start was only in Spring 1997. The reason of this explosion? ***Incomplete equipotential bonding***!

Indeed we will notice that ***electrical continuity***, with ***low earthing resistance*** and ***complete equipotential bonding*** are the key words of the lightning protection for such plants and structures.

These are only two famous examples of hazards on oil refineries. Many other ones could be reported. Direct lightning strikes are really a threat for industrial process plants.

2 GENERAL PRINCIPLES

Refineries, oil and gas industrial plants, product pipelines, i.e. process plants belong to the largest and most sophisticated structures to be protected against lightning. They are closely related to the lifelines of complete regions and sometimes entire countries.

Special measures must be taken to insure the reliability, the quality and the efficiency of this peculiar industry. That is why the safe operation of electrical and electronic systems is, without any doubt, the most important parameter. Due to the size, location, construction, use of modern measuring and control technology, reliability is threatened not only by switching operations, but also by lightning surges. The repair costs for replacing damaged systems are much higher than those of installing electrical continuity devices or surge protective devices (SPDs) at insulating pipe flanges, for example. Anyway, the best optimized protection solutions must be worked on.

In general, the necessary precautions are:

- to keep the lightning channel far away from the immediate neighbourhood of flammable and explosive materials;
- to avoid sparking or flashover in joints and clamps, nor at nearby components;
- no overheating of conductors;

- no flashover or sparking due to induced voltages;
- no raising potential of the earth termination system.

2.1 Air termination system

The essential measures consist on

- an air termination network at a safe distance from roofs with flammable and explosive materials;
- an efficient protection over the danger area by catenaries (open air storages);
- a close mesh for the air termination system to intercept every lightning stroke.

Direct lightning strikes in explosive atmospheres have to be avoided: explosive zones must never be classified in LPZ 0_A (see section 3.2).

2.1.1. It is allowed to use a metal container as a natural air termination system provided the container has the required minimum material dimensions (we recommend 5 mm of steel or equivalent, though 4 mm would be enough as stated in IEC 62305-3).

2.1.2. Generally, an air termination system installed on the container is required. In this case, the air termination system consists of air termination wires or cables which are mounted above the container so that this is located within the protection zone of the air termination system and cannot be hit directly.

This protection measure is necessary if the container material is not electrically conductive or if the thickness of the container material does not fulfill the above mentioned requirements. Furthermore, it is recommended to install an air termination system on tanks with a floating roof (see figure 1) and container superstructures with a connection to the inside of the tank (by helping to prevent upcoming sparks inside the tank).

2.2 Down-conductor system and equipotential bonding

The best requirements for the equipotential bonding are described in section 3 (from the IEC 62305-3 standard). We adopt all of them.

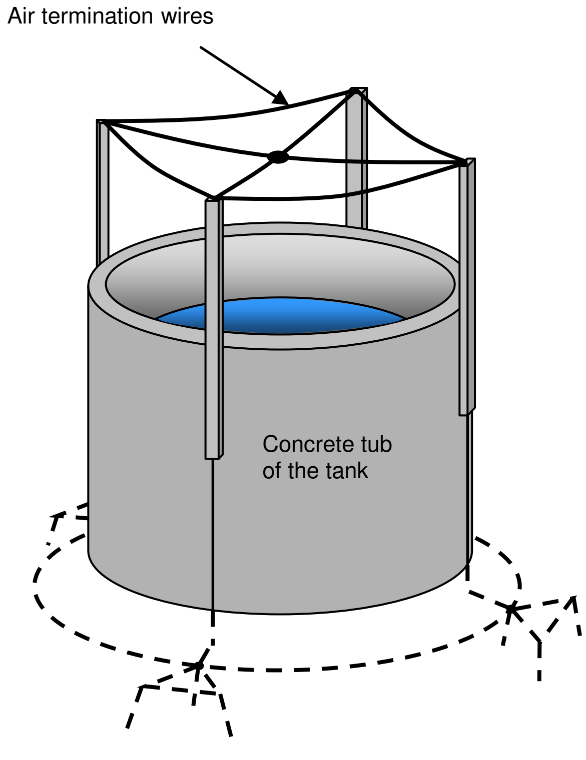

Figure 1. Air termination system for a tank using air termination conductors.

The measures generally consist on

- an increased number of down conductors for greater subdivision of the current;
- no down conductor inside the structure (if possible!);
- adequate cross-sections of conductors;
- reliable and durable joints and connections;
- secure equalization of potentials by screening of the electrical installation and bonding of all metal services, equipments and installations.

2.3 Earth termination system

In order to avoid high potential differences between individual earthing systems, all these earthing systems are interconnected to a single large **earth termination system** which is perfectly equipotential. This is performed by intermeshing the various earthing systems of structures, buildings or installations (see figure 2, according to IEC 62305-3, figure E.42, p. 267). Such a system gives a low impedance between all structures and has significant adavantages related to the electromagnetic compatibility requirements.

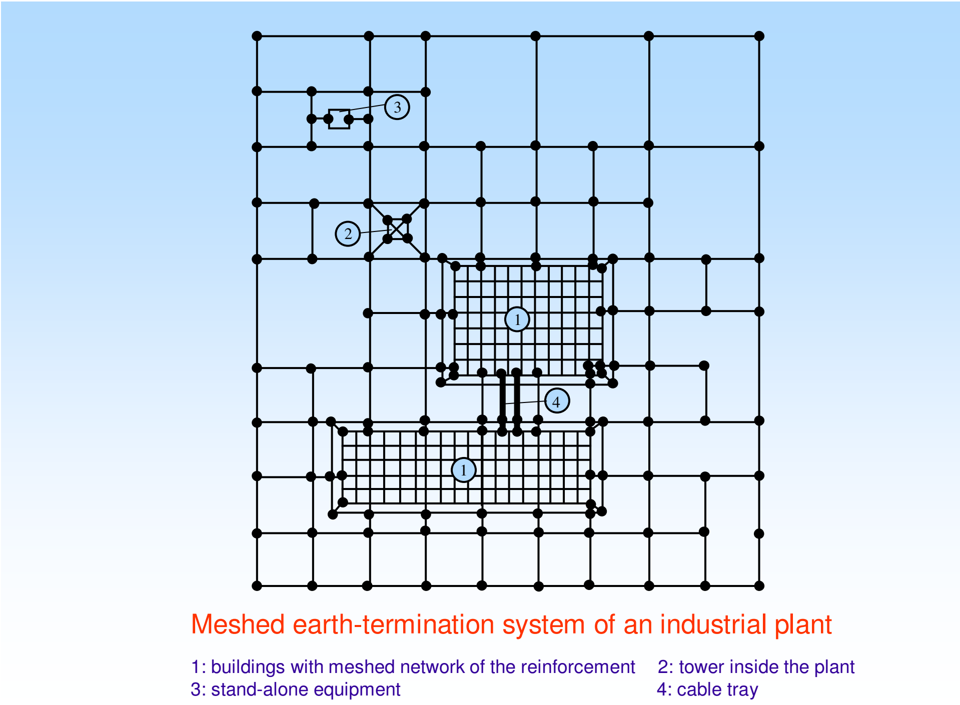

Figure 2. Meshed earth termination system of a plant.

The size of meshes next to various structures and other objects may be in the order of 20 m x 20 m; according to the IEC 62305-3 standard beyond a 30 m distance they may be enlarged to the order of 40 m x 40 m; personally, we do recommend always to install a 20 m x 20 m meshed earth electrode network, including cable trenches, in oil and gas industrial plants.

In this case, even the overvoltage stress at the electrical connecting cables between structures is reduced when a lightning flash strikes.

The common earth termination system includes:

- electrical protective earthing for the protection of people and objects;
- lightning protective earthing for the dispersion of lightning currents to the ground;
- equipotential earthing for a functional (uninterrupted and safe) operation of electrical and electronic installations.

The construction of separate earth termination systems for protective earthing is forbidden in oil and gas industrial plants, since it would be too dangerous (sparkovers in explosive zones!).

3 WHAT DOES THE IEC 62305 INTERNATIONAL STANDARD SAY ?

3.1 Overview

The international standard IEC 62305 (Protection against lightning), published in 2006, in its Part 3 (Physical damage to structures and life hazard, see references), presents an interesting annex D, dedicated to the additional information for lightning protection system (LPS) in the case of structures with a risk of explosion, i.e. for the design, construction, extension and modification of the lighning protection for such structures. It is not a normative annex though an *informative* annex!

As a result of a risk assessment analysis performed according to IEC 62305-2 (Risk management), at least a **class II** LPS should be adopted, but generally a **class I** LPS, or even a **class I+** (class I with supplementary measures), will be required. Indeed, the use of lightning protection level I (or I+) is preferred in oil and gas industrial plants where the environment and contents are exceptionally sensitive to the effects of lightning, unless in such regions where the infrequency of lightning activity is proved.

3.2 Zones: Ex-zones and Lightning Protection Zones (LPZs)

The first problem occurs when the plant must be separated in different zones, as they are defined in ATEX documents (see the European standard EN 60079-10; note that ATEX stands for EXplosive Atmospheres according to the European standardization). What are these zones?

Zone 0 : places in which an explosive atmosphere (ATEX) consisting of a mixture of air and flammable substances in the form of gas, vapour or mist are considered, if it is present continuously or **frequently** or for long periods (> 1000 hours per year);

Zone 1 : places in which an explosive atmosphere (ATEX) consisting of a mixture of air and flammable substances in the form of gas, vapour or mist are considered, if it is likely to occur in normal operation **occasionally** (< 1000 hours per year, but > 10 hours per year);

Zone 2 : places in which an explosive atmosphere (ATEX) consisting of a mixture of air and flammable substances in the form of gas, vapour or mist are considered, if it is not likely to occur in normal operation but, if it does occur, will persist for a **short period only** (< 10 hours per year);

Zone 20 : places in which an explosive atmosphere, in the form of a cloud of combustible dust in air are considered, if it is present continuously, or **frequently**, or for long periods;

Zone 21 : places in which an explosive atmosphere, in the form of a cloud of combustible dust in air are considered, if it is likely to occur in normal operation **occasionally**;

Zone 22 : places in which an explosive atmosphere, in the form of a cloud of combustible dust in air are considered, if it is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Similar to explosion protection methods (Ex-zones), a facility is divided in different lightning protection zones (LPZs; see IEC 62305-4 and figure 3):

- LPZ 0_A : exposed to direct lightning strikes with full lightning current and full lightning electromagnetic field; internal systems may be subjected to full or partial lightning surge current;
- LPZ 0_B : protected against direct lightning strikes with partial lightning or induced current and exposed to full lightning electromagnetic field;

- LPZ 1 : protected against direct lightning strikes; surge current is limited by current sharing and by SPDs at the boundary; spatial shielding may attenuate the lightning electromagnetic field (damped lightning electromagnetic field);

- LPZ 2, ..., n : as LPZ1, surge current is further limited by current sharing and by additional SPDs at the boundary; additional spatial shielding may be used to further attenuate the lightning electromagnetic field.

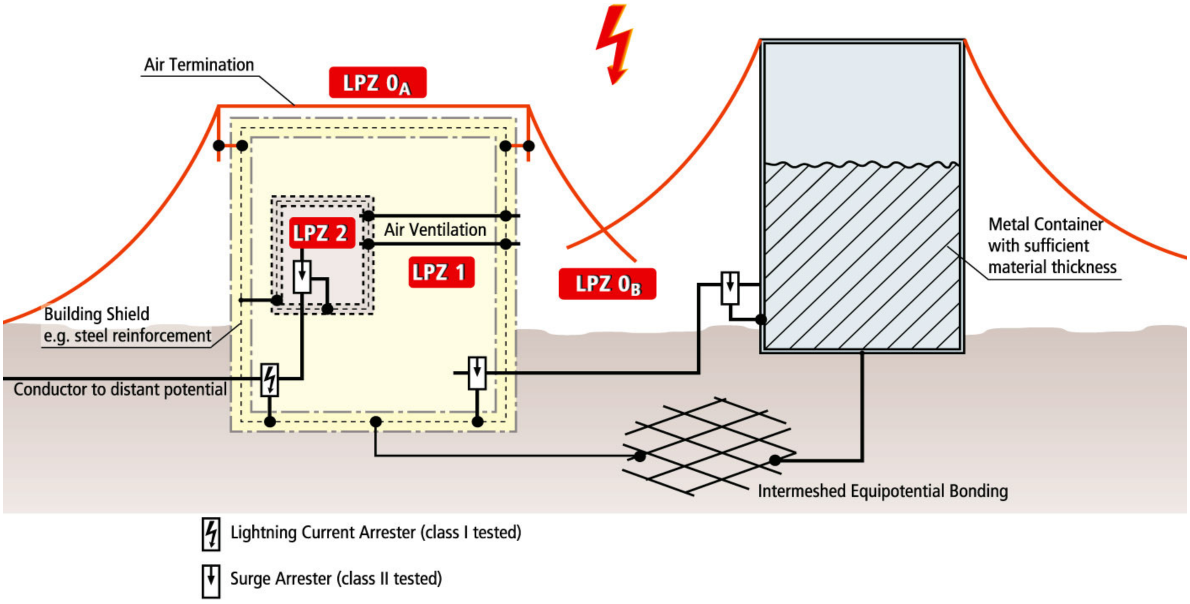

Figure 3. Division of a facility in LPZs

All conductive parts crossing an LPZ have to be taken into consideration:

- metal tubings and conduits as well as conductor shields have to be connected directly with the equipotential bonding at the boundary of the protection zone;
- active lines such as conductors of the power supply or signal lines have to be connected via surge protective devices (SPDs).

3.3 General protection measures

The LPS should be designed and installed in such a manner that, in case of a direct lightning flash, there are no melting or spraying effects except at the striking point. Sparks or damaging impact at the striking point may also be experienced and should be taken into account when determining the *air termination* device locations. *Down conductors* should be installed in such a way that the auto-ignition temperature given by the source of the relative hazardous area will not be exceeded in those applications where it is not possible to install down conductors outside of the hazardous area.

It is recommended to provide appropriate measures already in the planning phase, e.g. the connection of the metal reinforcement of concrete elements or the combination of metal façades with down conductors for the external lightning protection.

The designer and the installor of the lightning protection system should be provided with drawings of the industrial plant to be protected, with the areas in which solid explosive material, i.e. solid chemical compound, mixture or device with explosion as its primary or common purpose, will be handled or stored and hazardous areas according to IEC 60079-10 and IEC 61241-10 appropriately marked.

A so-called *type B arrangement* (binding loop comprising a ring conductor external to the structure to be protected in contact with the soil or a foundation earth electrode generally meshed, see section 2.1) for the **earth termination system** is recommended for structures with danger of explosion and supplementary earth electrodes will be installed so that the earthing resistance will be as low as possible and never larger than 10 ohms.

Let us notice that *metallic storage tanks* provide the effective equivalent of the ring conductor of type B arrangement.

Lightning equipotential bonding between LPS components and other conductive installations, as well as between the components of all conductive installations, should be assured inside hazardous areas and locations where explosive materials may be present, both at ground level and where the distance between the conductive parts is less than the separation distance s as defined in the standard (distance between two conductive parts at which no dangerous sparking can occur) calculated assuming the down conductor coefficient k_c equal to 1; it means that, assuming a selected class I LPS, the separation distance s is such that

$$s = 0.08\, l / k_m \qquad (1)$$

where l is the length along the down conductor from the point where the separation distance is to be considered to the nearest equipotential bonding point and k_m is the electrical insulation material coefficient equal to 1 in air and to 0.5 in concrete or bricks.

Note that, because of dangerous partial discharges, the separation distances s may only be considered in the areas without explosive mixtures; in those areas where a spark may cause ignition of the environment, additional equipotential bonding will be necessary in order to ensure no internal sparking in zone 0 (or zone 20) hazardous areas.

The treatment of cable screens is an important part of the protection concept. Basically all screens have to be earthed at both sides, both at the control unit and at the terminal equipment directly or via SPDs. If they cross a boundary of a lightning protection zone, they also have to be connected with the local equipotential bonding bar.

3.4 Structures containing solid explosive materials

The LPS for strucures containing solid explosive materials should take into consideration the sensitivity of the material in the configuration in which it is used or stored, particularly if these materials are sensitive to rapidly changing electric fields or radiated by lightning impulse electromagnetic fields. In such cases, it is recommended to establish additional bonding or shielding requirements.

Generally, an *isolated* (not attached to the structure) LPS is encouraged. Isolated LPS are achieved either by installing air-termination rods or masts adjacent to the structure to be protected or by suspending overhead wires between the masts in accordance with the separation distance s defined above.

Structures totally contained within a 4 mm-thick steel shell (or equivalent for other metals used, for example 7 mm for aluminium structures) may be considered protected by a natural classical air-termination system. Of course a type B arrangement is required for the earth-termination system.

SPDs (surge protective devices) should be provided as part of the LPS for all locations where explosive material is present. They will be positioned *outside* locations where solid explosive materials are present, otherwise they will be of explosion-proof type or contained within explosion-proof enclosures.

3.5 Structures containing hazardous areas

Where possible, all parts of the external LPS should be at least 1 m away from any hazardous zone. Where this is not possible, conductors passing within 0.5 m of a hazardous zone should be continuous or connections made with compression fittings or by welding.

Where a hazardous area is located directly under a metal sheet that may be punctured by lightning, air-termination shall be provided in accordance with the usual requirements of the IEC 62305-3 standard.

SPDs (surge protective devices) should be positioned outside the hazardous zone. If they were positioned inside the hazardous zone, they should be approved for the hazardous zone in which they are installed or should be contained within an enclosure and the enclosures including surge suppression shall be approved for this service (see IEC 62305-3, point D.5.1.1).

Equipotential bonding should be reinforced. Connections to piping should be provided to avoid any sparking (welded on lugs or bolts or tap holes in the flanges for taking up screws). Connections by clips are only allowed if, in the instance of lightning currents, ignition protection is proved by tests and procedures are utilized to ensure the reliability of the connection. Junctions should be provided for the joining of connection and earthing leads to containers and tanks.

Structures containing zones 2 and 22 do not require supplemental protection measures.

Structures containing zones 1 and 21 require the following two additions:

- protective measures if there are insulation pieces in pipelines (use of explosion-protected devices or isolating spark gaps, i.e. components with discharge distance for isolating electrically-conductive installation sections);
- insertion of isolating spark gaps and insulation pieces outside the explosion endangered areas.

Structures containing zones 0 and 20, requirements for zones 1 and 21 apply with supplemental recommendations:

- lightning equipotential bonding connections between the LPS and other equipments should be carefully made, utilizing spark gaps only if the system operator agrees; such devices shall be suitable for the environment in which they are installed;
- for outdoor facilities, electrical equipment inside tanks containing flammable liquids should be ATEX suitable and closed steel containers with areas defined as zones 0 or 20 inside should have a wall thickness of at least 4 mm at the possible lightning striking points.

3.6 Specific applications

3.6.1 Filling stations

At filling stations for cars, railways, ships... with hazardous areas defined as zones 2 and 22, all the metal pipelines should be carefully earthed. They should be connected with steel constructions and rails, if necessary via isolating spark gaps approved for the hazardous zone in which they are installed, to take into account railway currents, stray currents, electrical train fuses, cathodic-corrosion-protected systems and the like.

3.6.2 Storage tanks

Certain types of structures used for the storage of liquids that can produce flammable vapours or used to store flammable gases are essentially self-protecting, i.e. contained totally within continuous metallic containers having a thickness of not less than 4 mm of steel (or equivalent for other metals: 5 mm of copper or 7 mm of aluminium), with no spark gaps and require no additional protection. Similarly, soil-covered tanks and pipelines do not require the installation of air-termination devices. Nevertheless, instrumentation and electric devices used inside this equipment should be approved for this service. Measures for lightning protection should be taken according to the type of construction. Isolated tanks or containers should be carefully earthed at least every 20 meters.

3.6.3 Floating roof (storage) tanks

In the case of floating roof tanks, the floating roof should be effectively bonded to the main tank shell. The design of the seals and shunts and their relative locations need to be carafully considered so that the risk of any ignition of a possible explosure mixture by incendiary sparking is reduced to the lowest level practicable.

When a rolling ladder is fitted, a flexible bonding conductor of 35 mm width should be applied across the ladder hinges, between the ladder and the top of the tank and between the ladder and the floating roof. When a rolling ladder is not fitted to the floating roof tank, several flexible bonding conductors of 35 mm width (or equivalent) shall be applied between the tank shell and the floating roof. The bonding conductor should either follow the roof drain or be arranged so that they cannot form re-entrant loops.

On floating roof tanks, multiple shunt connections should be provided between the floating roof and the tank shell at about 1.5 m intervals around the roof periphery. Alternative means of providing an adequate conductive connection between the floating roof and tank shell for impulse currents associated with lightning discharges are only allowed if proved by tests and if procedures are utilized to ensure the reliability of the connection.

3.6.4 Pipelines

Overground metal pipelines outside the production facilities should be connected every 30 m to the earthing system.

For the transport of flammable liquids, the following applies for long distance lines:

- in pumping sections, sliding sections and similar facilities, all lead-in piping including the metal sheath pipes should be bridged by conductors with a cross-section of at least 50 mm^2;
- the bridging conductors should be connected with specially welded-on lugs or by screws which are self-loosening, secure to the flanges of the lead-in pipes; insulated pieces should be bridged by spark gaps.

For a pipeline station (see figure 4), lightning protection requires multipole SPDs on the supply in the low-voltage distribution systems, for telecommunication and telecontrol, for intrinsically safe circuits (made of stainless steel for outdoor areas) and explosion-protected ATEX spark gaps in Ex-zones 1 and 2.

3.6.5 Cathodic protection systems

Cathodic protection (CP) systems are generally protected (against surges and lightning currents) by using explosion-protected ATEX spark gaps in Ex-zones 2.

Cables going out of the CP rectifier (measuring cables and anode electrical circuits) are led via SPDs especially adjusted to such installations, so that the partial lightning currents coming from the pipeline as well as surges caused by switching operations cab be safely controlled. It is recommended to install the SPDs into a corresponding separate steel enclosure in order to prevent any threat to the CP installation due to overloads (for example, via overhead lines).

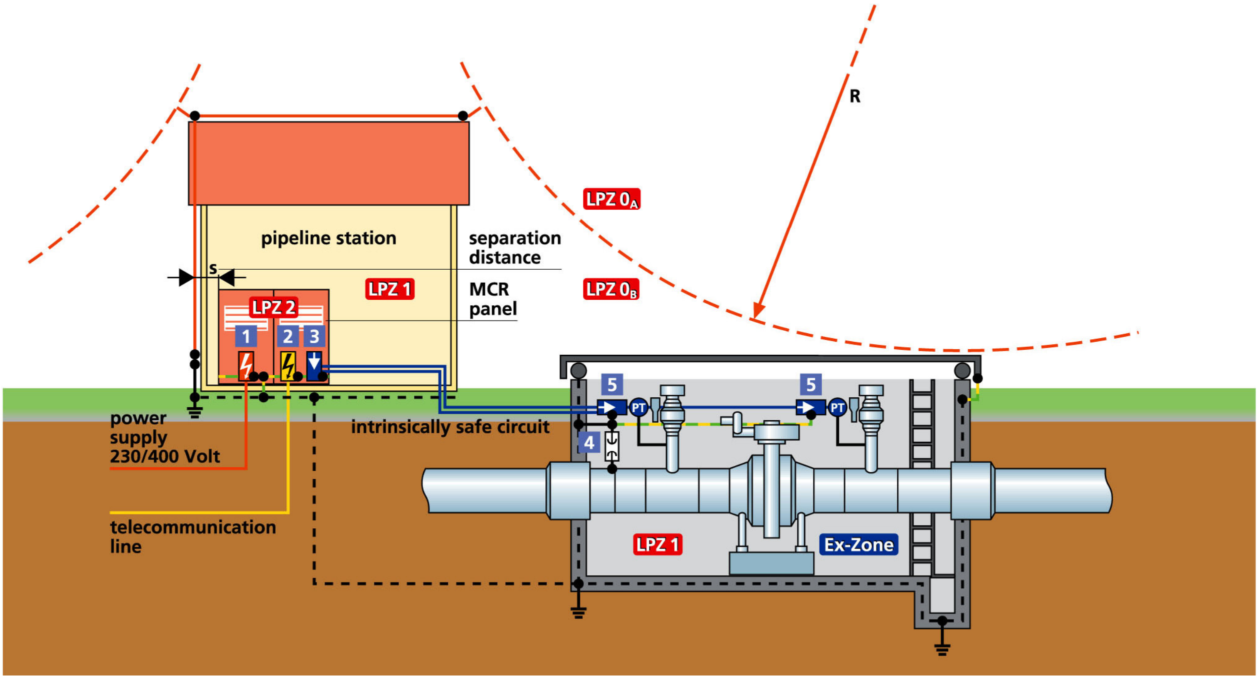

Figure 4. Lightning and surge protection for a pipeline station

3.7 Inspection and maintenance

Especially for oil and gas industrial plants, regular inspections are among the fundamental conditions for reliable maintenance of the lightning protection system.

LPS components tend to loose their effectiveness over the years because of corrosion, weather-related damage, mechanical damage and damage from lightning strokes.

The objective of the inspections is to ascertain that all the components of the LPS are in good condition and capable of performing their designed functions, to check if there is no corrosion and to notice if any recently added services or constructions are incorporated into the LPS.

Inspections should be made

- during the construction of the structure in order to check the embedded electrodes and all components which are concealed in the structure and will become inaccessible;
- after the completion of the LPS;
- periodically at such intervals as determined with regard to the nature of the structure to be protected: *every six months* for a general visual inspection, *every year* for the complete inspection of the critical systems (parts of the LPS exposed to severe mechanical stresses such as flexible bonding straps in high wind areas, SPDs on pipelines, outdoor bonding of cables...), *every second year* for the complete inspection;
- after any significant alteration and repairs;
- right after it is known that the structure has been struck by lightning.

The electrical testing of the installations should be made *each year*. It is sometimes recommended to perform the tests on a 14 to 15 month cycle where it is considered beneficial to conduct earth resistance testing over different times in the year to get an indication of seasonal variations (geographical regions with extreme seasonal changes in temperature and rainfall where the variation of the earthing resistance should be taken into account by measuring the resistivity depth profile in different weather periods).

When the earthing resistance increases steadily between inspections, an improvement of the earthing system should be considered.

During the periodic inspection, it is important to check

- deterioration and corrosion of air-termination elements, conductors and connections;
- corrosion of earth electrodes;
- earthing resistance value for the earth-termination system;
- condition of connections, equipotential bonding and fixings.

The maintenance program should contain provisions for

- the verification of all LPS conductors and system components;
- the verification of the electrical continuity of the LPS installation;
- the measurement of the resistance to earth of the earth termination system;
- the verification of the SPDs;
- the re-fastening of components and conductors;
- the verification to ensure that the effectiveness of the LPS has not been reduced after additions to, or changes in, the structure and its installations.

4 WARNING AND AVOIDANCE

Work that involves hazardous materials such as explosives and flammable gases has a serious potential lightning vulnerability. No universal panacea exists for lightning warning and avoidance.

Large oil and gas industrial plants should be connected to meteorological Lightning Location detection Systems (LLS) for early warning. The anticipation of lightning strikes provides efficient decision-aid information in hazardous weather conditions, particularly for the dynamic lightning protection of sensitive installations and for the protection of the workers staying on some parts of the plant in open air.

In several countries, many sensitive plants are under continuous surveillance and a lightning-warning is sent to the subscriber (by phone, fax or e-mail) with a sufficiently long time in advance, so that he can take the appropriate measures: disconnecting sensitive equipments, stopping dangerous manipulations, encouraging people to enter lightning-protected buildings to avoid hazards due to touch and step voltages...

5 CONCLUSION

Oil and gas industrial plants, product pipelines... belong to the largest and most sophisticated structures to be protected against lightning. We showed that special measures could be taken to avoid any hazards in sensitive ex-zones (explosive zones), by taking great care of the *electrical continuity*, by building an earth termination system with an *earthing resistance as low as possible,* by installing a complete efficient *equipotential bonding* and a *surge protection* of the low voltage installation (including all automatic systems), via the concept of lightning protection zones.

6 REFERENCES

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- 62305-1: General principles;
- 62305-2: Risk management;
- 62305-3: Physical damage to structures and life hazards;
- 62305-4: Electrical and electronic systems within structures.