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EXPERIENCE IN THE DESIGN OF EXTERNAL PROTECTION SYSTEMS AGAINST LIGHTNING

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Abstract – This paper describes the experience acquired during the revision and determination of external lightning protection systems in some refinery plants, in Argentina. With this purpose a program, developed by IITREE, based on the Monte Carlo statistical technique, was used, among other things, to determine in a period of time the frequency of lightning flashes to structures. International and American standards were used as reference.

1 INTRODUCTION

In Argentina, nowadays and during the last few years people, in a less scale politic leaders and important industries, concern about damage that many technologies and current way of life are causing to the environment. Among industries some refineries are not only concerned about real risk, but loss of social prestige. One agent that could cause high damage (material and life losses) is the lightning phenomena, especially in such plants where flammable products are being manipulated and processed.

2 REVISION OF CURRENT STANDARDS

2.1 Current standards as reference

Standards usually provide information concerning design, construction and materials of Lightning Protection Systems (LPS), however they say nothing about necessity of installation of an LPS. Standards of application in Argentina are: IRAM 2184-1 (1996) [1] and IRAM 2184-1-1 (1997) [2], with the respective modifications and all complementary IRAM standards. Mentioned standards are based on, and equal in contents, IEC 1024-1 (1990) [3] and IEC 1024-1-1 (1993) [4] international standards.

Generally in Argentina and especially in territories where the refineries in study are located, there are no local regulations that oblige the installation of LPS. Only in Buenos Aires City there is an obligatory regulation (N°1411-DGFOC-98) that demands protection by installing LPS in accordance with IRAM 2184-1 and 2184-1-1 standards.

Considering the fact that IRAM standards are based on IEC standards, IEC 1024-1 and its sections (IEC 1024-1-1, IEC 61024-1-2 [5]), as far as the American NFPA-780 [6], were used as current standards of reference.

2.2 Zones of protection

IEC-1024-1 and NFPA-780 standards alter from *protective angle*, and *rolling sphere* criteria when assessing proper locations for air terminals.

IEC defines values for *protective angle*, and *rolling sphere* for each corresponding protection level and regarding structure height, as it can be seen in Table 1, where *h* is height of the structure to be protected in metres, α protective angle and R rolling sphere radius in metres.

As you can see in this table, for structures higher than 20 metres, depending on the desired level of protection, protective angle method is not applicable. On the other hand, rolling sphere method is always applicable, no matter structure size, height, shape, etc.

Table 1: Positioning of air-termination according to the protection levels (IEC 1024-1).

PROTECTION LEVEL	h(m)	20	30	45	60
	R(m)	α(°)	α(°)	α(°)	α(°)
I	20	25	*	*	*
II	30	35	25	*	*
III	45	45	35	25	*
IV	60	55	45	35	25

* In these cases only apply rolling sphere.

As the protective angle method establishes, the zone of protection forms a cone having an apex at the highest point of the air terminal, with walls forming an angle from the vertical.

As the rolling sphere method determines, the zone of protection includes the space not intruded by a rolling sphere when it lays tangent to earth and rests against a lightning protection terminal.

3 ADOPTED CRITERIA FOR PROTECTION

3.1 Classification of typical installations

In order to determine external protection systems against lightning, it was necessary to classify different existing structures into representative types, and adopt some criteria applicable to protection of each one.

The following structure classification was done: TYPE 1) buildings in administrative areas, TYPE 2) buildings immerse in process plants, TYPE 3) recipients containing flammable vapours, flammable gases, or liquids that can give off flammable vapours (tanks and pools).

TYPE 1) Buildings located in non-dangerous areas, usually are made of concrete, or in some cases are made of metal sheets. Almost all of them can be classified as *common structures.*

TYPE 2) In process plants you may accept the presence of explosive atmosphere, because of the flammable substances being manipulated. Strippers, reboilers, columns, reactors, compressors, charge heaters, coolers, condensers, refrigeration towers, motors, etc. are typical equipment in these areas. Also electric substations and other buildings can be found in a process area, usually, not containing flammable substances.

TYPE 3) Storage recipients, containing petroleum and petroleum products are made of metal and the great majority are thick enough not to be punctured by a direct strike and are normally well grounded so that they do not require lightning protection. However, in some of the refineries being analysed metallic tanks, although having enough metal thickness no to be punctured, suffer from lack of maintenance and in some cases show holes where flammable vapours can give off. Consequently, lightning protection will be required in such tanks. In addition, usual open-air pools emanating flammable vapour will require lightning protection.

3.2 Assessment of required efficiency for LPS designs

Once structure classification has been adopted, section 3.1, we assigned a recommended *protection level* for each type of structure. The purpose of selecting a *protection level* is to reduce, below the maximum tolerable level, the risk of damage by direct lightning flash to a structure, or to a volume to be protected.

Applying IRAM 2841-1-1 standard (based on IEC 1024-1-1), we classified refineries as *structures dangerous to their surroundings* where the effects of lightning could be fire and explosion in the plant and its surroundings.

Applying NFPA 780 standard we can classify some of the typical refinery installations as *structures containing flammable vapours, flammable gases, or liquids that can give off flammable vapours.*

In order to determine the proper protection level, we calculate the required efficiency Ec of the LPS, with the following equation:

$$Ec = 1 - \frac{Nc}{Nd} \qquad (1)$$

Where Nd is the average annual frequency of lightning flashes to the structures and Nc is the maximum accepted annual frequency of lightning flashes which can cause damage to each type of structures, estimated in accordance with IRAM 2841-1-1 and ENV 61024-1 (European standard) as follows:

$$Nc = \frac{5.5 \cdot 10^{-3}}{C} \text{ [flashes/year]} \qquad (2)$$

Where C was calculate with the following equation:

$$C = C_2 \cdot C_3 \cdot C_4 \cdot C_5 \qquad (3)$$

C_2 : coefficient that evaluates type of construction of the structure.

C_3 : coefficient that evaluates structure contents.

C_4 : coefficient that evaluates structure occupancy.

C_5 : coefficient that evaluates consequences of a direct stroke to the structure in the surroundings.

Nd is calculated as a product of the local ground stroke density Ng and the equivalent collection area Ae of the structure:

$$Nd = C_1 \cdot Ng \cdot Ae \cdot 10^{-6} \qquad (4)$$

Where C_1 is an environmental coefficient taking into account relative location of the structure.

Table 2: Parameter values used to calculate Efficiency Ec, for each type of structure.

	Common buildings (TYPE 1)	Buildings in process plants (TYPE 2)	Tanks (TYPE 3)	Pools (TYPE 3)
Ae [m^2]	2860	2860	10936	2534
C1	1	0.25	1	0.25
Nd [flsh / year]	0.0088	0.0022	0.0385	0.0022
C2	1	1	0.5	3
C3	0.5	1	3	3
C4	3	1	0.5	0.5
C5	1	10	10	10
C	1.5	10	7.5	45
Nc[flsh / year]	0.0037	0.0006	0.0007	0.0001

Table 3: Calculated efficiency Ec, and efficiency E corresponding with protection levels.

	Common buildings (TYPE 1)	Buildings in process plants (TYPE 2)	Tanks (TYPE 3)	Pools (TYPE 3)
Ec	0.6300	0.7600	0.9817	0.9545
E ≥ Ec	0.80 level IV	0.80 level IV	0.98 Level I*	0.98 Level I

* Level I and additional protection measures

Expressions applied to obtain Ae, given in the standard, are:

Rectangular area $Ae = ab + 6h\,(a+b) + 9\,\pi\,h^2$ (5)

Round area $Ae = \pi\,(\phi/2 + 3h)^2$ (6)

Where a and b are the object length and width respectively, h is the object height, and ϕ is the circle radius.

Typical structure dimensions assumed are as it follows:

- TYPE 1) common building: $a = 20$ m, $b = 20$ m and h = 6 m.
- TYPE 2) building in process plants: $a = 20$ m, $b = 20$ m and $h = 6$ m.
- TYPE 3) tanks: $\phi = 23$ m and $h = 12$ m.
- TYPE 3) open-air pools: $a = 56$ m, $b = 35$ m and $h = 1$ m for railing height rounding the pool.

Quantities indicated in Tables 3 and 4, were used to calculate the required efficiency for each type of structure classified as we proposed in section 3.1.

The adopted value for ground flash density Ng was 3.5 flashes per km^2/year, corresponding to La Plata region, obtained from reference [7].

3.3 Adopted protection method

Considering clients preoccupation in relation with environmental impact and social consequences, protection levels selected were more severe, when possible, than the smaller ones coming from the following equation:

$$E \geq Ec = 1 - \frac{Nc}{Nd} \qquad (7)$$

Rolling sphere method was employed to design alternative LPSs, and the following protection levels were proposed for the previous structure classification:

- *Protection level* I, and additional protection measures (R = 20 m), were applied to Type 3 structures: tanks and pools containing *flammable vapours, flammable gases, or liquids that can give off flammable vapours.*
- *Protection level* II, R = 30 m, was applied to Type 2 structures: buildings located in process plants, such as electric substations, control rooms, dressing rooms, refrigeration towers, etc.
- *Protection level* III, R = 45 m: was applied to Type 1 structures: common buildings located in administrative areas and other non-dangerous areas, such as management, laboratories, medicines, etc.

3.4 Analysis of the selected protection level

Comparing both standards, NFPA 780 defines the zone of protection for common structures with a rolling sphere having a radius of 46 metres (150 ft) in accordance with protection level III as IEC 1024-1-1 defines. This is a good reason for choosing level III for Type 3 structures.

In the same way, NFPA 780 defines the zone of protection for structures containing *flammable vapours, flammable gases, or liquids that can give off flammable vapours* with a rolling sphere having a radius of 30 metres (100 ft), in accordance with protection level II as IEC 1024-1-1 defines. Trying to satisfy client concern, about social impact, level I was recommended for such structures (Type 3).

4 APPLICATION OF THE ANALYSIS TOOL

4.1 The computer program

A computer program developed by IITREE called BLINSUB, assists in determining the objects being struck when a number of lightning flashes moving downward a region are simulated. It employs the Monte Carlo statistical technique to select lightning by means of an external file with an empirical distribution for current amplitude, and chooses flash origin points with a uniform distribution.

It was useful to analyse present lightning performance of refineries. This tool is based on the *electrogeometric model* of the lightning process. According to this model the striking distance of a lightning stroke is expressed as a function of the stroke current, as it is given by the following most frequently accepted expression:

$$R = k I^n \qquad (8)$$

Where:

R: striking distance in metres
I: stroke current in kA
k, n: empirical constants

4.2 Data from installations of the refineries

Significant data research was performed in each refinery. This task turned very large and heavy, as a consequence of data being not available, and because of many difficulties faced especially in some refineries. Characteristics of refinery installations such as dimensions, height, construction materials, thickness, location, contents, and so on, were relevant for the studies. In addition, visual inspection accomplished during several visits to the installations completed missing data.

Once the collection of data was made, each element was represented, for simulations with BLINSUB program, as a parallelepiped with four Cartesian coordinates and height over soil level (Figure 1).

4.3 Protection characteristics

BLINSUB program requires a categorising of all of the elements being represented. This categorising is based upon its characteristics facing a lightning strike. Elements had to be categorised as *objects being self-protecting* or as *objects to be protected.*

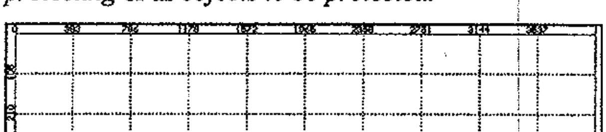

Figure 1: Elements representation from YPF La Plata refinery tanks area

Some of the following considerations were useful to accomplish previous categorising:

- metallic tanks, vessels, and process equipment that contain flammable liquids or gas under pressur normally do not require lightning protection, since suc equipment is well shielded from electrical strikes Equipment of this type is normally well grounded and i thick enough no to be punctured by a direct strike. The can be considered as *objects being self-protecting.*
- metallic tanks that had not been maintained in goo conditions cannot be considered as *self-protectin objects.* Holes over the roof can be responsible fo flammable concentrations of vapour or gas that ca result in a fire or explosion as a consequence of lightning direct stroke.
- metallic tanks used for storage flammable substances a atmospheric pressure, not necessarily have thicknes enough to withstand a direct strike without bein punctured. Hence they were considered as *objects to b protected* in simulations with realistic hypothesis.

4.4 Simulation of different cases

In order to study refinery lightning performance differen conditions were simulated considering, or not, self protecting behaviour of certain installations, an considering, or not, presence of existing lightning rods.

Different hypothesis were assumed, consequently differen cases were analysed. The "most pessimistic" hypothesis i the one that ignores any existing lightning rods and any self protecting object. Then all probable combinations wer made.

Large number of lightning strikes was simulated falling ove every refinery represented, for each determined case. Th proper number of lightning strikes was calculated choosing sufficiently long period of time, and by means of the averag ground flash density Ng.

For lightning stroke current amplitude, the program uses statistical distribution curve based on empirical data.

The adopted values of k and n constants of equation (8) wer 10 and 0.65 respectively.

4.5 Simulation to analyse protection levels

This program was also useful to analyse protection levels. I reproduces the rolling of a sphere over the contour of eac element represented in the simulated area. To perform thi simulation, an external file with one defined value fo current amplitude should be used. According to th electrogeometric model, equation (8), the radius of th sphere, which is correlated with the desired protection level defines the stroke current amplitude.

Such kind of deterministic simulations were accomplishe for the three protection levels selected.

Unfortunately this program do not permit vary strik incidence angle, hence every flash simulated is right vertical.

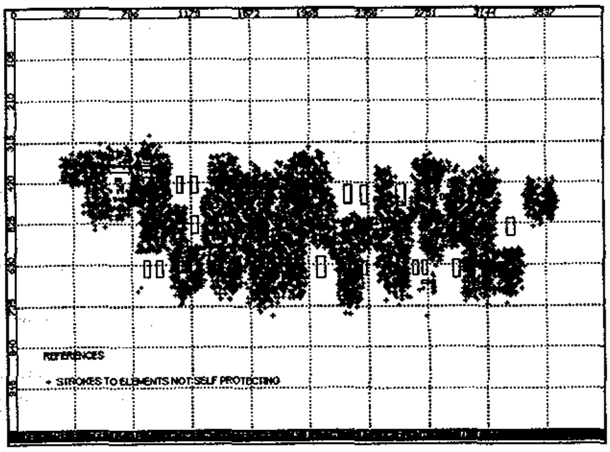

Figure 2: Output from the simulation in the YPF La Plata refinery tanks area

Actually, structures being taller than the sphere radius could be struck if they don't have lateral protection. However, simulations performed with the BLINSUB program, will not declare lateral strokes on them.

4.6 Simulation results

The period being chosen for statistical simulations was 3.000 years. It became enough since changes in the sequence of flashes produce no difference in results.

Results obtained from the simulations were given in two ways. One of them, by means of a map with all the elements being represented and marks indicating lightning strokes to elements categorised as *objects to be protected.* The program was set to omit showing lightning strokes to earth in the map.

By way of illustration, Figure 2 shows the output-map that indicates flashes striking elements categorised as *objects to be protected.* Compare this map with Figure 1, where you can see all the elements being represented.

Another output of the program is a list of each flash striking to *objects to be protected* and ignores either lightning strokes to *self-protecting* elements and lightning strokes to earth. The list indicates for each stroke: origin flash coordinates, stroke current amplitude, and the element being struck.

4.7 LPS proposed designs

Some LPS designs were proposed for either open air pools emanating flammable vapour, and metallic tanks requiring lightning protection, as they appeared to be the most dangerous structures of refinery installations.

Proposed designs consist in two basic types: one performed with overhead ground wires and the another with four single masts. All of these designs were calculated for a protection level I, applying the rolling sphere method. Alternative designs are shown in Figures 3 and 4.

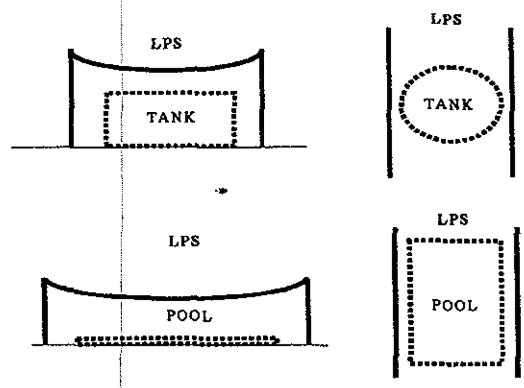

Figure 3: LPS overhead ground wires design for protection of tanks and pools

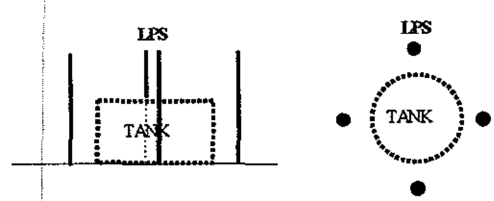

Figure 4: LPS four single masts design for protection of tanks.

All external LPS proposed were isolated from the space to be protected, in order to avoid the ignition of any flammable air-vapour mixture in the tank or pool surroundings, as a consequence of great heat developed along the lightning channel.

In order to verify the protected zone defined by the LPS proposed deterministic simulations with BLINSUB program were performed (rolling sphere method).

5 CONCLUSIONS

- At the moment, great investments in industrial areas such as refineries in order to reduce lightning damage are consequence of lack of lightning considerations during planning and designing periods in the past. As a result concern in prevention against lightning is increasing nowadays.
- Bad or poor maintenance especially in tanks and process plant equipment is another possible cause of future losses associated with lightning strokes.
- An urgent solution is needed to prevent risky consequence in open-air pools containing flammable

products. A different pool design, inherently self-protecting, is recommendable for future installations.

- BLINSUB program resulted an acceptable tool to determine the frequency of lightning flashes to each structure located in the refinery being represented in the simulation. It also allows reproducing a sphere rolling over all exposed surfaces.

6 REFERENCES

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