Proceedings of 2nd International Symposium of Lightning and Storm-Related Phenomena
ISL-SRP 2017 - May 10-11, 2017, Aurillac (Cantal, France)
www.labofoudre.com

# FROM THE IMPORTANCE OF EQUIPOTENTIALITY IN A LIGHTNING PROTECTION SYSTEM

Michael TROUBAT,[1] and Emmanuel PERRIN [2]

[1] *Research Department, FRANCE PARATONNERRES, Limoges, France*
[2] *CISTEME, Limoges, France*
m.troubat@france-paratonnerres.com, http://www.france-paratonnerres.com

Keywords: Equipotentiality, Lightning protection, rising earth potential, dangerous sparks
Thematic area: The study of lightning and its effects

## I/ Introduction

This paper deals with the importance of realizing a complete perfect Lightning Protection System (LPS) and in particular the equipotentiality of conductive parts.

When a lightning discharge occurs, a conductive channel is created from cloud to earth. The LPS aims to be part of the channel and is designed in order to protect the structure and persons from the devastating effects of lightning.

## II/ Lightning Protection System

To realize this protection, the LPS is made of four main parts and each of them is very important in order to be effective in the protection of a structure.

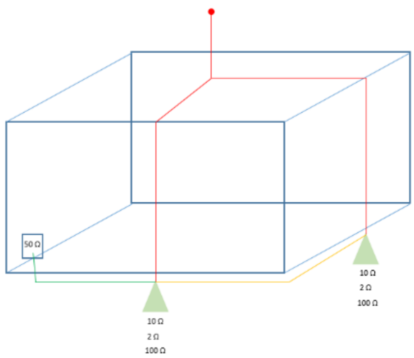
- Capture device
- Down-conductor
- Earthing system
- Equipotentiality (direct or indirect one)

Measurements and modeling [1, 2] show that when an earthing system is well dimensioned (ie with resistance lower than 10 Ohms) the electromagnetic radiated field is reduced.

## III/ Study of the importance of equipotentialities with a simple structure

The studied first case is a simple structure:

- A cube of 10m
- According to field experiences and calculations in this paper, we consider that well positioning the LPS and realizing equipotentialities, have to be considered as the main rules or as the golden rules in lightning protection.




Dangerous secondary sparks can appear between the down-conductors and conductive parts around. The length of the spark that can be created depends of the lightning current, of the distance between the two electrodes and of the earthing system resistance value.
The lightning current will imply more or less current in the down conductor and so a more or less important radiated field. The most important is the electric field (E in V/m), the longer will be the spark.

Moreover, this study enables to show that for an identical lightning current, a very low earthing resistance will reduce this dangerous park.

Then, for the 10Ω standard value, we can consider that 50% of the lightning current flowing to this earthing system is dissipated inside.

The other 50% will go around and will look for conductive parts. Of course, the strength of the current will be reduced along this path. If the lightning earthing system and the main electric earthing are not joined (direct equipotentiality), a potential difference will occur and dangerous rising of the earth potential will occur.

If Surge Protective Device (SPD) are not implemented on main distribution board, critical overvoltage will directly go inside the structure and may cause electric shocks and injuries to person or failure of devices.

## III/ Eiffel Tower simulation with FDTF

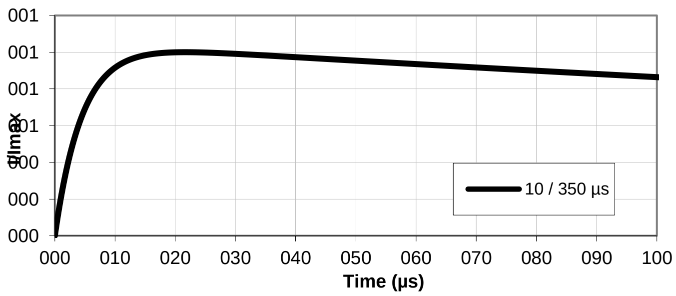
We modelled the Eiffel with the TEMSI-FP software. The study is realized through a rigorous electromagnetic modelling based on the FDTD (Finite Difference Time Domain) method. The modelling tool used is the free software TEMSI-FD developed by the XLIM laboratory [3].

We opt for 3 configurations:
- Case N°1: Initial Configuration
- Case N°2: Configuration in 2015
- Case N°3: Configuration in 2016 after the France Paratonnerres works

The table I below explains the differences between each configuration studied.

| Configurations | NORTH Resistance (Ω) | EAST Resistance (Ω) | SOUTH Resistance (Ω) | WEST Resistance (Ω) | Number of specific down conductors | Equipotential bonding in earthing |
|---|---|---|---|---|---|---|
| **Case 1: 1900** | 10 | 10 | 10 | 10 | 4 | None |
| **Case 2: 2000** | None | 2 | 6 | None | 3 | None |
| **Case 3: 2016** | 7 | 2 | 6 | 6 | 3 | 2 |

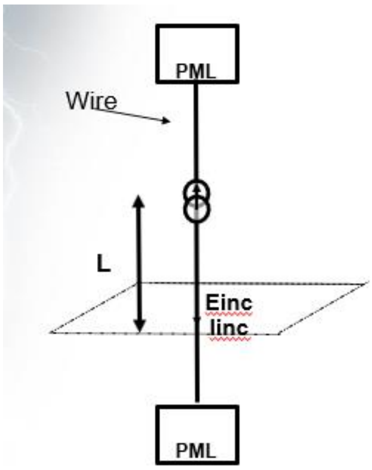
We apply at the top of the tower (directly on the top air-terminal) a bi-exponential lightning current with the following characteristics: 200kA @ 10/350µs waveform.

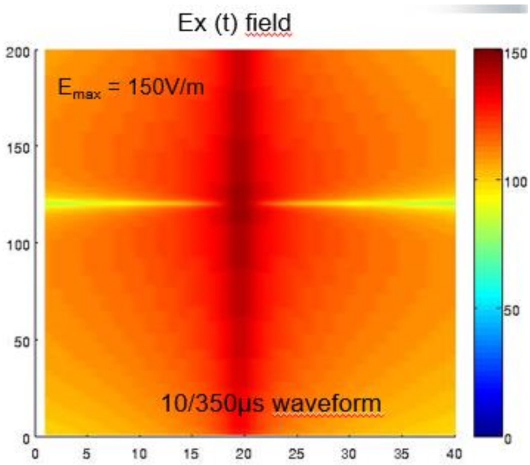



$$f(t) = I_0 \cdot \left(e^{-at} - e^{-bt}\right)$$ Equation n°1

The lightning current is delivered with a perfect current source I0 in parallel with an Impedance Zch.

We can see below the radiated field of the lightning channel. Those data are the reference data wich enable to make comparisons.




PML are Perfect Matched Layer. They enable to simulate an infinite volume of calculation in the FDTD method. It means that there is no reflection of the edge of the calculation volume.

We finally show by comparison of cases the importance of the 4 earthing systems and of the equipotentiality realized between them

Indeed, aside from the risk of direct lightning strikes, it exists secondary risks like dangerous sparks or rising earth potential. Those risk can be simply avoided:

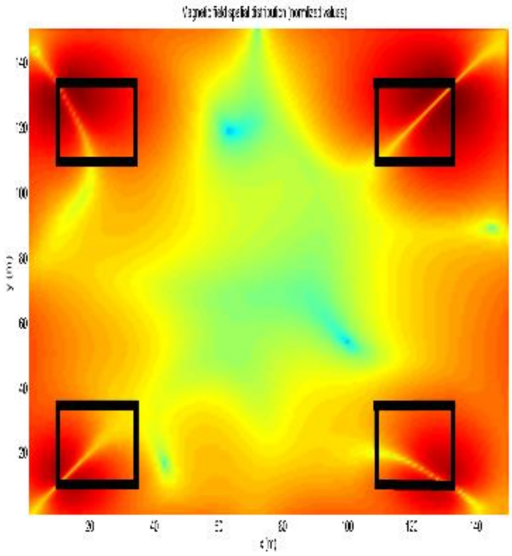
- by well positioning the components of the LPS
- by respecting separation distances between the lightning down-conductors and the conductive object that can be impacted
- by the installation of direct or indirect equipotentiality bonding
- by joining all the earth system

by looking for the lowest earth resistance (both in low and high frequencies) achievable

The studying of the 3 cases shows that, initially, Gustave Eiffel had design a very clever and ahead of his time, Lightning Protection System (LPS).
Indeed, radiated fields were lower in 1900 than in 2000. Moreover, dissipations of the lightning current in earth were more important.

Nevertheless, the LPS in 2016 enables to reach the initial level and is a little bit better because of the equipotential bonding of 3 earthing system (East, West and South).
Indeed, the radiated field is lower at the soil level, thanks to the bonding. This aspect is very important because nowadays, the Eiffel tower is equipped with a lot of sensitive equipment and networks..

The cartography of the case n°3 below, demonstrate that. The radiated field is negligible inside the structure.



This numerical study valid that the Lightning Protection System designed for the Eiffel tower seems efficient. It enables :

- an optimized flowing of the lightning current to earth
- a mastering of the radiated field inside the Eiffel tower

## IV/ Validation in situ with the Eiffel Tower protection realized by France Paratonnerres

Recently the earthing system of the Eiffel Tower has been revised by the France Paratonnerres Company [4].

The Eiffel Tower is protected against lightning with a system which is much more severe that requested in all standard in force.

First, it is composed of various air-terminal:

- 1 Early Streamer Emission (ESE) air-terminal at the top (a)
- 8 multiple rods around the third floor of the tower (b)
- The metallic structure in puddled steel acts as a faraday cage (c)


(a)

(b)

(c)

Then, the wrought iron metallic structure can be considered as a meshed cage.
Three down-conductors are added along the EIFFEL tower structure. They present an equivalent section greater than 200mm$^2$. This section is really greater than nowadays standard requirements. There should probably be four at the realization of the tower.

Those 3 down-conductors are in copper. Their very good conductivity ($\sigma$ = 9,93x106 S/m) enable to conduct a large majority of the lightning current to earth.

Indeed, the 3 down-conductors and the structure are connected to earth via an earthing system. Each pillar of the Eiffel tower is connected to a Type A earthing system.

The table II below give the resistance values of the 4 earthing systems in 2016:

| Pillar of the Eiffel Tower | NORTH | EAST | SOUTH | WEST |
|---|---|---|---|---|
| Case 3: Resistance (Ω) | 7 | 2 | 6 | 6 |
| Equivalent resistance with bonding (Ω) | 7 | 1.2 | | |

*Table II: Earthing system resistance in 2016*

In order to reduced difference of voltage, three of the fourth earthing systems (East, South and West) are connected together.

Some Surge Protective devices installed in all the main Electrical Distribution Board complete the Lightning Protection.

The Lightning Protection System realized has shown its efficiency in front of a natural lightning strike:

The 22nd of May 2016, just after the renovation of the Eiffel Tower Lightning Protection System, a positive upward lightning strike occurs.
The event was pictured by a photograph.
A lightning strike counter installed on the South Pillar registered the event and estimated the peak current at 12kA on the south earthing system.

According to theory and to the distribution of the lightning current, the impact at the top can be estimated above 50kA.

To confirm the simulation and the effectiveness of the Lightning Protection System, no physical, or electrical damage occurs after this event.

Since this date, the Eiffel tower has again been struck by lightning without any damage. Indeed, it is considered that the tower is struck more than 5 times per year and some others pictures can confirm it.

## V/ Conclusion

To conclude, we've realized a numerical approach of the Lightning Protection of the Eiffel Tower. The study has validated a way to design and to realize the Protection System.

Field experience confirms the efficiency of the numerical tools and of the Lightning protection theory developed.

We consider, according to field experiences and calculations in this paper, that well position the LPS and realize bonding, have to be considered as the main rules or as the golden rules in lightning protection.

References
[1] M. Troubat (2015), "Electromagnetic field radiated by the lightning channel and its impacts on a typical building"
[2] M. Troubat, E. Perrin (2012), "Reduction and mastering of electromagnetic field due to lightning in a structure"
[3] C. Guiffaut, "Guide de l'utilisateur TEMSI", 2007.
[4] F. Barriere (2016), "Execution document, n°DOE-NN-160701"