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Article

Lightning Protection Systems Suitable for Stables: A Case Study

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Abstract: The evolution of climate and of electrical devices are raising users' awareness about the protection of structures and plants against common overvoltage phenomena and those ones of atmospheric origin. Therefore, a continuous evolution of thunderstorm phenomena, increasingly concentrated and intense, is occurring. Conversely, electric devices are increasingly being equipped with electronics indispensable for their right functioning and are very sensitive to electromagnetic phenomena of an induced and conducted nature. In Italy, the law concerning work health and safety compels employers to assess the risk raised by lightning and to ensure that buildings, systems, structures, and equipment are protected from the effects of lightning in agreement with national and international technical standards. In the agricultural livestock sector, the new guidelines of agricultural policy in Italy requires farms to re-examine their structures, in particular the compatibility with animal protection requirements. In the event of a fault, the electric circuit must be interrupted in times not higher than expected and, in particular in the agricultural and zootechnical structures, it is necessary to maintain the contact voltages to negligible values by carrying out additional equipotential connections among the masses and with foreign masses that can be touched. Furthermore, particular attention is required in limiting the step voltage to which animals are particularly sensitive to, by connecting the electro-welded metal grids, which are commonly located under the concrete floor of animal shelters, to the earth collector. Taking in mind the aforesaid, the aim of this work was to analyze the technical standard concerning the protection from lightning with reference to the agricultural livestock sector and the study of the salient components to set up a suitable lightning protection system for a medium-sized stable.

Keywords: lightning protection systems; safety; agricultural-livestock sector

1. Introduction

Every year Italy is meanly stroked by about 600,000 lightning strokes (excluding seas), with an average ground lightning density of about 2 strokes per km^2 each year, even if the actual density of lightning depends largely on the geographical conformation [1–3]. Different ways of upward warm air masses with a sufficiently high humidity gives rise to dense masses of clouds (cumulus) having a height ranging from 5 to 12 km and a diameter ranging from 5 to 10 km [4,5]. The drops of water and the ice particles contained in these clouds become electrically charged due to processes of separation of electrostatic charges, such as friction and nebulization [6–8]. In the upper part of the clouds, particles with a positive charge accumulate while, in the lower part, those with a negative charge accumulate.

The obtained charge density can produce electric fields having strengths of several hundred kV/m, thus triggering lightning discharge mechanisms [9–11].

To have complete protection from lightning, a set of devices is needed: Lightning protection system (LPS), which includes the lightning protection equipment itself, the protection measures for electrical and electronic equipment from the electromagnetic pulses connected with lightning (Lightning ElectroMagnetic Pulse, LEMP), protection against overvoltage arising from electromagnetic pulses (Surge Protection Measures, SPM) and, in general, all kinds of protections useful to safeguard fire prevention and technological structures and systems [12–14].

In order to better understand the constitution of an LPS and a SPM, the possible damages that can be caused by lightning need to be considered: (i) Damage to living beings by electrocution; (ii) material damage due to disruptive, high-energy discharges, such as fire, explosions, mechanical damages, release of dangerous substances; and (iii) damage to electrical and electronic equipment and systems, caused by the electromagnetic pulse connected to the lightning, with medium or low energy content, that are conducted and induced by the power lines or due to the radiated electromagnetic field [15–18].

These damages, individually or in combination with each other, can result in the loss (i) of human lives or permanent damages to humans; (ii) of public service; (iii) irreplaceable cultural heritage; and (iv) economic.

Furthermore, it is necessary to consider that the sources of damage are lightning strokes that have as their point of impact: (i) Directly on the structure; (ii) on the field near the structure; (iii) directly on the power lines that feeds the structure; and (iv) on the field near the feeding power lines of the structure [19–21]. The LPS is therefore made up of [22]:

1. The external LPS, which has the aim of intercepting lightning on the structure through a pick-up system and of conducting the lightning current to the ground by mean of a leakage system;

2. The internal LPS, which aims to prevent dangerous shocks inside the structure by means, also, of equipotential connections between the different metal bodies, separation distance among metal bodies, and the insertion of SPD (surge protective device) on the power lines. It should be remembered in this regard that when a lightning protection system is stroked, its parts are interested, even for brief moments, by very high voltages, even of the order of hundreds of kilovolts, depending on the characteristics of the lightning and those of the protection system itself [23]. Under these conditions there are potential differences between the protection system and the protected structure and metal objects close to the LPS conductors, due to the impulses conducted and induced, by a coupling mechanism of a resistive kind (due to the impedance of the leakage system), and inductive (due to the coils inside the circuit) [24–27].

The design of a LPS, once it has the input data, starts from the evaluation of the risk of fulmination [28–31]. If it is higher than the acceptable one, then it is necessary to adopt protective measures, otherwise, the structure is self-protected and it is possible not to proceed with the construction of the LPS [29,30]. The following identification of the acceptable risk includes: (i) Loss of human lives; (ii) loss of public service; and (iii) loss of irreplaceable cultural heritage [30,31].

In regards to agricultural and zootechnical structures, it is required to maintain touch voltages at negligible values and to limit the step voltages to which animals are particularly sensitive to. Starting from these considerations, the purpose of the present work was the analysis of the main topics related to the construction of a LPS for the protection of a stable to be built, in which about 200 animals were to be hosted and 10 employees would work. It should also be noted that, according to the current Italian legislation on lightning protection, the stables were not among the structures for which the construction of a lightning protection system is mandatory, however considering the economic investment in terms of animals and the presence of employees, it could be significant, for safety purposes, the consideration of the construction of a lightning protection system.

2. Materials and Methods

2.1. The Stable

Within an existing farm located near Tursi (Matera Disctrict, Southern Italy—40.24739 N 16.44855 E), a stable suitable to host about 200 beef cattle will be built in which, during the day, about 10 workers will work in order to care and manage the animals. The stable will have a length, L = 20 m and a width, W = 50 m (Figure 1).

Figure 1. Satellite photo of the area in which the stable will be built (Source: Google Earth).

The stable was designed according to technical solutions aimed at reducing, as far as possible, the construction costs and at the same time ensuring the maximum operational functionality for the management of animals and safety and comfort for workers [8,9]. The main construction materials that will be used are:

- Reinforced concrete for foundations, floors, walls and grating in the pit;
- Laminated wood and solid wood for the frame of the walls, decks and the roof frame;
- Wooden boards for wall cladding;
- Glued laminated wood for the roof beams;
- Roof cover with insulated metal roof;
- Partition walls in light brick, plastered;
- Floors and walls of the milk room and toilettes with tiles or synthetic resin;
- Doors and windows in galvanized metal and wood;
- Electrical, sanitary, and lightning protection systems.

The minimum height of the roof will be 5 m with a maximum height, H = 7 m.

2.2. The LPS

The Lightning Protection System will have the aim of protecting the stable from direct lightning and, therefore, from possible fire or from the consequences of the lightning current itself (lightning without ignition). In the following, reference will be made to the following regulations in force: (i) Standard that contains the general principles underlying the "lightning protection systems (LPS)" of structures and connected technical installations [28,29]; (ii) standard for the assessment of risk due to lightning on the ground [28,29]; (iii) standard related to the design, installation, verification, and maintenance criteria of the LPS in order to limit material damage to the structures and danger for people [30]; and (iv) standard concerning the SPM design for the protection of electrical and electronic systems inside the structures against damages arising from the electromagnetic pulse effects of lightning [31].

3. Results and Discussion

According to the legislation, the risk R that lightning damage occurs is the result of the sum of all the R_x risk components relevant for the specific type of loss. The types of losses considered for the stable in question are: (1) Loss of human lives and (2) economic loss.

The R_x risk components for loss of human lives arises from the following equation:

$$R_x = N_x \cdot P_x \cdot L_x \quad (1)$$

where:

N_x is the number of lightning strokes per year on the surface to be evaluated;
P_x is the probability of damage;
L_x is the loss, or the quantitative assessment of damages.

The aim of risk assessment therefore includes the determination of the three parameters N_x, P_x, and L_x for all relevant risk components R_x. The comparison between the risk R, identified in this way and the acceptable risk R_T, provides information on the requirements and the dimensioning of the lightning protection measures.

In order to correctly assess the potential risk associated with lightning strokes, the first step was the determination of the lightning density value on the ground, N_g. This value represents the average number of lightning strokes per km^2 which, on a statistical basis, can fall in a given area in a year and is evaluated by mean of the lightning stroke localization networks (LLS) that cover the Italian national territory [29].

$$N_g = 2.62 \, \frac{\text{lightning}}{\text{km}^2 \cdot \text{year}} \quad (2)$$

To calculate the number N of dangerous events deriving from lightning that affect the stable to be protected, it is necessary to multiply the lightning density on the ground Ng for a collection area equivalent to the stable, taking into account the correction factors for the physical characteristics of this structure [29]. It is necessary to evaluate the lightning frequencies that may affect the stable, considering the direct lightning stroke on the structure (N_D); the lightning stroke near the structure that produce magnetic effects (N_M); the direct lightning stroke on supply power lines (N_L); and the lightning near the supply power lines (N_I).

The characteristics of the stable (type of internal flooring, presence of people, layout of the internal installations, etc.) allowed to identify, for the purpose of risk calculation, a single homogeneous area, based on which they were determined graphically: (a) The equivalent collection area A_D of the isolated structure due to direct lightning stroke (Figure 2); and (b) the A_M collection area due to indirect lightning stroke, which can damage the internal systems due to induced overvoltage (Figure 3) [29].

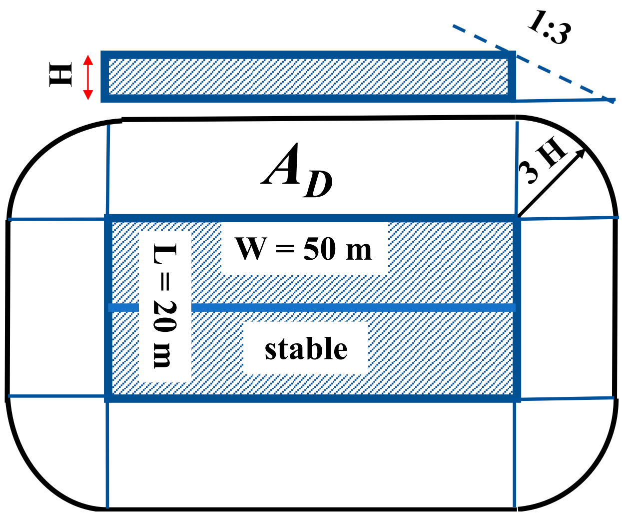

Figure 2. Collection area for direct lightning stroke (A_D).

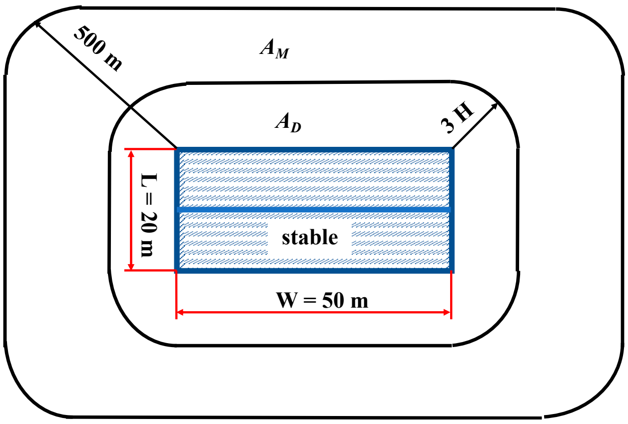

Figure 3. Collection area for both direct (A_D) and indirect (A_M) lightning stroke.

In particular, the following data have been taken into account:

$A_D = 3.22 \times 10^{-3}\ km^2$
$A_M = 4.36 \times 10^{-1}\ km^2$
$A_L = 8.00 \times 10^{-3}\ km^2$
$A_I = 8.00 \times 10^{-1}\ km^2$.

This made it possible to evaluate the corresponding numbers of dangerous events due to direct and indirect lightning strokes on the structure (N_D, N_M) and for direct and indirect lightning strokes on the power supply lines (N_L, N_I) [29–31]:

$N_D = 0.016900/year$
$N_M = 1.140000/year$
$N_L = 0.010480/year$
$N_I = 1.048000/year$,

as well as the probability of damage to living beings (P_A), to the structure (P_B), to the installations (P_C), and the probability of failure of the installations (P_M) that have reached values around 1%.

From the previous values, it was possible to evaluate that the risk deriving from fulmination for the considered structure (R) remains lower than the acceptable risk (R_T) [29–31]. In particular:

$$R = 3.38 \times 10^{-6} < R_T = 1.00 \times 10^{-5} \quad (3)$$

Regarding the assessment of economic losses, it is justified only from an economic point of view. As no data was available for this analysis, the representative value of acceptable risk has been used [28–30]: $R_T = 1.00 \times 10^{-3}$.

The considered structure, therefore, is self-protected and therefore does not require the installation of a lightning protection system. Nevertheless, it is advisable to take some precautions when building the structure with the aim of reducing step voltages and avoiding contact voltages.

In particular, it is necessary to insert an electro-welded steel mesh in the concrete base, make equipotential connections between the reinforcement of the structure and connect all these metal masses to an efficient earth plate made of a bare copper rope buried along the entire external perimeter of the stable, as well as four linear sinks driven into the ground, by drilling, placed at the vertices of the structure at a depth not less than 6 m.

4. Conclusions

Modern agriculture is characterized by increasingly complex computer and electrical systems and, to increase profitability, these systems are used to optimize (and if possible, automate) the most time-consuming processes. In agricultural and livestock plants in particular, lightning can have particularly serious consequences on the structures depending on their geographical location, the type of construction, or their use. It should be remembered that there are now frequent agricultural buildings equipped with robotic milking systems, in which different systems are controlled through different data lines that can often be controlled from remote locations. In such contexts it is recommended to install protective measures against lightning and overvoltages. Even if this is just a case study of a simple stable, it could be considered to be a possible approach that, taking into account the technical standard concerning the protection from lightning with reference to the agricultural-livestock sector, could be used in the design of a medium-sized stable.

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