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UCRL-CONF-218103

Lightning Protection Certification for High Explosives Facilities at Lawrence Livermore National Laboratory

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January 12, 2006

2006 IEEE Antennas and Propagation Society Conference
Albuquerque, NM, United States
June 19, 2006 through June 23, 2006

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Introduction

Presented here is an innovation in lighting safety certification, and a description of its implementation for high explosives processing and storage facilities at Lawrence Livermore National Laboratory. Lightning rods have proven useful in the protection of wooden structures; however, modern structures made of rebar, concrete, and the like, require fresh thinking.

Our process involves a rigorous and unique approach to lightning safety for modern buildings, were the internal voltages and currents are quantified and the risk assessed. To follow are the main technical aspects of lightning protection for modern structures and these methods comply with the requirements of the National Fire Protection Association, the National Electrical Code, and the Department of Energy [1][2]. At the date of this release, we have certified over 70 HE processing and storage cells at our Site 300 facility.

The Faraday Cage Method

Lightning and high explosives (HE) don't mix. Many explosives will detonate if too much electrical current passes through them. A typical lightning strike has a peak current of 30 kA, and a very small fraction of this current is enough to fire a detonator. Therefore, it is critical that explosive components be separated from the lightning current.

Lightning rods with down-conductors are more appropriate for wooden structures, to prevent the lightning current from starting a fire. In facilities with rebar and metal frames, it has been shown that most of the current will jump to the lower impedance of the metal structure of the building rather than remain on the down-conductors. Hence, the rod and down-conductor type of lightning protection system has serious limitations with respect to modern facilities.

The preferred method of lightning protection for HE facilities at LLNL is a Faraday cage. If struck by lightning, a perfect cage will distribute charge quickly and evenly, causing the electrical potential inside the cage to fall to zero, thus eliminating the risk of arcing through HE. Surge suppression and step-down transformers are also employed in the certification process, but will not be detailed here.

Our facilities are, of course, not perfect Faraday cages due to the resistance and inductance of the materials, thus voltages develop within the cage. Also, practical cages do not provide 100% optical coverage or symmetry, leading to non-zero potentials within. With respect to practical buildings, good examples employ multiple layers of rebar that are tied together. The maximum voltage inside a good cage occurs near the ceilings, walls, and wall openings, and will likely be less than 10 kV. This residual voltage must be isolated from the explosives by an insulating barrier, in our case an air gap or *standoff*. Thus, explosives are not permitted within a standoff distance of the walls, or other high potential areas. The standoff distance between the explosives and the walls is determined by the quality of the Faraday cage and poor cages result in high internal voltages and large standoff distances. This could be due to inferior materials, or discontinuities within the cage, which could lead to internal arcing and concrete spalling, another danger to HE.

By measuring the transfer impedance of the building/Faraday cage, we can determine its quality and calculate the interior voltage caused by a lightning strike. Metal penetrations such as pipes, conduits, and air vents to name a few, that pass through a wall, floor, or ceiling could increase the interior voltage of the cage at locations that are sometimes difficult to determine. These metal penetrations often originate from outside the facility, and if lightning were to strike them, they will carry current directly into the facility, possibly bypassing the cage. This sneak path must be eliminated by bonding the metal penetrations to the Faraday cage with a short cable or pig tail of a sufficient size.

Lightning Threat Assessment

In this report, we apply a novel technique based on low-power measurements, to assess the vulnerability of HE processing facilities against lightning. This technique is a subset of a more general methodology developed by LLNL to quantify RF vulnerability. The lightning threat assessment technique consists of a site survey, lower-power RF measurement, and computer processing of the data to simulate the effect of a lightning strike. The result is a predictive tool, where voltages and currents in bays and cells can be calculated for different lightning current profiles via a linear transfer function characterized by a transfer impedance.

The accuracy of the predictions depends on, among other factors, the degree to which the relationship between the current and the resulting induced voltage remains linear at lightning energies. A good Faraday cage minimizes electrical arc creation, which is a non-linear response. Further, in a set of rocket-triggered lightning experiments, the non-linearities that did occur actually *reduced* the interior voltages [3]. Therefore, we assume a linear transfer function to be an adequate model of a good Faraday cage.

Measurement Description

The entire measurement process is depicted in Fig. 1. Preliminary setup includes driving ground rods at least 3 ft. in the earth, establishing a sound strike point, and then connecting the rods to this point via cables. The transmission station is established by placing an inductive loop around the ground wires and driving the loop via a function generator. A second inductive loop can be used to measure the induced current. The receiving station is established by connecting a broadband antenna to a spectrum analyzer, and the transmission and receiving stations communicate via a fiber optic link, which minimizes the potential for erroneously coupled energy. The measurement is performed over a frequency band consistent with naturally occurring lightning, 10 khz to 2.5 Mhz.

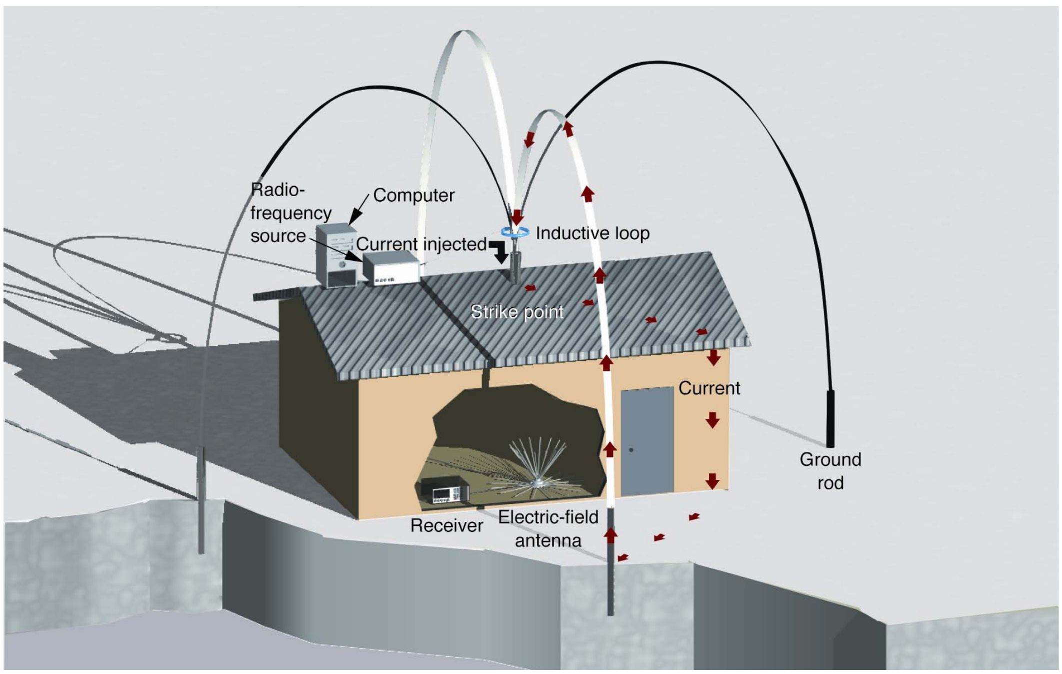

Fig. 1 Experimental Setup.

Transfer Impedance and Extrapolation to Standoff Distance

Safety standoff distances are determined from computer processing of the measurement data, and are accomplished in three main steps. First, we calculate the building transfer impedance from the measurements. Second, we use the transfer impedance and realistic lightning current models to extrapolate the induced interior voltages of the building. Finally, we calculate an appropriate standoff based on the resultant voltage levels, the breakdown thresholds in air, and additional safety factors. The lighting current model we employ is extreme: a peak current of 200 kA and a rise rate of 400 kA/µs [4], which occurs in less than 1% of all lightning strikes nationwide.

Computing the transfer impedance is essentially a system identification process that provides a linear model of the Faraday cage system. Although other more complex system identification methods are available, we compute the transfer impedance by dividing the measured electric field by the low-power injected current and then multiplying by the floor-to-ceiling height of the building, which assumes a properly connected building [5]. This results in magnitude-only floor-to-ceiling transfer impedances, since only the magnitude spectra of the electric field and low-power current are measured.

If the complex magnitude and phase values of the transfer impedance were available, the extrapolated floor-to-ceiling voltage response could be obtained by convolution, or its frequency-domain equivalent. However, the absence of phase information in the transfer impedance complicates matters, such that we utilize multiple methods and models, so that results may be evaluated for consistency and trusted.

Regardless of which method is used, the peak of the absolute value of the extrapolated voltage waveform is used to compute the standoff distance at each location. The dielectric breakdown strength of air is dependent upon pulse duration, among other things, and ranges from 5.5 kV/cm for a resistive-like voltage pulse to 9.0 kV/cm for an inductive-like voltage pulse [6]. We use the more conservative dielectric strength of 5.5 kV/cm. An additional safety factor of 2 is used, thus our formula for calculating the standoff distance, where V_{peak} is in volts and D is in centimeters, is given by $D = 2V_{peak}/5500$.

References:

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This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.