High Voltage Laboratory
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MISSISSIPPI STATE UNIVERSITY

Study of the Counterpoise Lightning Protection System for a Scale Model Runway

Analysis and Final Report

by
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Executive Summary

This study presents an evaluation of two different configurations of counterpoise Lightning Protection System (LPS) for an airfield runway. In the first configuration, a counterpoise LPS extends 8 inches underground, between the runway pavement edge and the runway edge lights. In the second configuration, the counterpoise LPS is moved close to the light fixtures as allowed due to scale of the model, and the LPS is solidly bonded to light fixtures.

A 100:1 scale model runway is constructed for evaluation in the High Voltage Laboratory at Mississippi State University, and circuit simulations provide evaluation for system response to a first stroke lightning impulse voltage and current.

This study shows that the counterpoise LPS positioned between an airfield runway pavement edge and light system outperforms a counterpoise LPS that is directly bolted to the runway light fixtures. Furthermore, the counterpoise LPS solidly bolted to the light fixtures will likely require a higher cost over-voltage and over-current protection for the runway light system.

Introduction

In order to evaluate the lightning protection system of an airfield runway, a laboratory simulation is required to study multiple lightning stroke attachments to the ground and counterpoise lightning protection system (LPS). Simulation and analysis provides insight into the currents shunted through the ground paths and the peak voltage magnitude near point of lightning stroke attachment. This deliverable provides an analysis and final report for the laboratory testing of 2 lightning protection schemes in a 100:1 scale airfield runway. One configuration of the counterpoise bonds the counterpoise wire to the light fixtures, and the second configuration isolates the counterpoise wire from the light fixtures.

I. Problem Statement

According to the Unified Facilities Criteria (UFC) 3-260-01, page 36, the transverse section of runway shows the centerline as the highest point. Pavement grade may be up to 1.5% for a 196’ wide runway. The paved shoulder grade may be up to 3%, and the unpaved shoulder grade may be up to 4%. An actual runway centerline may be up to 35” above the location of the light fixture. The runway light fixtures will extend 14” above grade, which means the runway centerline remains the highest point.

From the highest attachment points, high currents from lightning stroke attachment may track along the partially conductive surface to a solid ground point. Otherwise the solid ground point may attract a direct lightning stroke attachment. The points of lightning stroke attachment can be observed in laboratory simulation.

For a lightning stroke attachment to a counterpoise LPS, lightning currents will flow through all attached grounding conductors. Conduit insulated ground wire with high current transients will produce high voltage transients near the point of lightning stroke attachment. Therefore, a study of the lightning stroke attachment to a counterpoise LPS, and a study of the LPS network response should provide insight into the proper selected configuration for an airfield counterpoise LPS.

II. Objective

This deliverable presents results from laboratory tests on a 100:1 scale model with two different configurations of the counterpoise LPS. The positions are defined and discussed in chapter 11 of the NFPA 780-2014.

A 3x3 grid of overhead points, aligned by laser, defined the 9 positions for the leader final step, shown in Fig. 1. The overhead final step is 90 cm above the highest point of the model runway. At each overhead position, 5 shots at positive and negative lightning impulse voltage at 900 kV magnitude will simulate the lightning stroke attachment process.

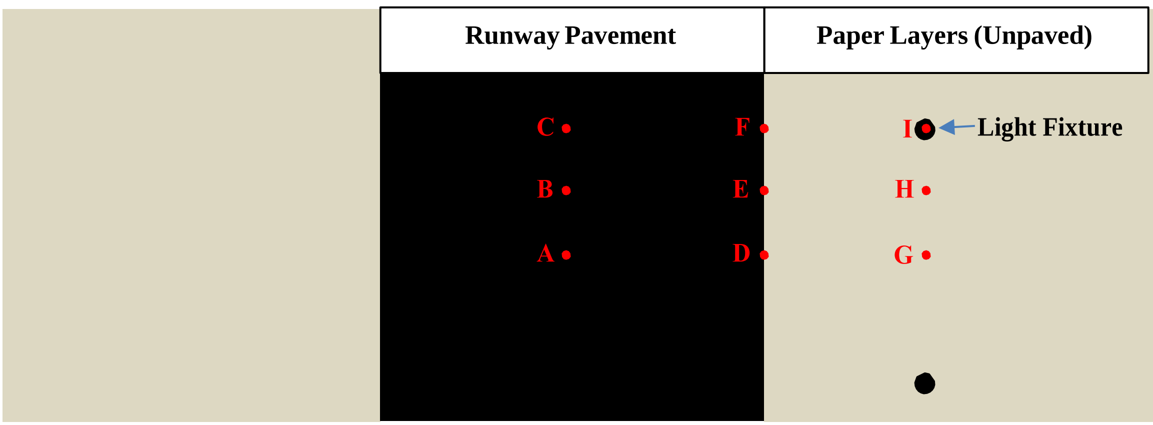

Fig. 1: Overhead Grid Points for Leader Final Step.

Evaluation of the counterpoise LPS in the high voltage laboratory includes high speed camera recording, still images, and multiple strokes from different positions above the runway model.

Following the laboratory measurements, a circuit simulation model developed from the NFPA 780-2014 standard simulates the expected system response to the lightning stroke attachment to the counterpoise LPS.

III. CAD Layout

Construction of the 100:1 scale runway must include an accurate representation of the topology provided in the UFC 3-260-01. In other words, a light fixture must be

140 mils above grade and the runway centerline must be 350 mils above the fixture location. Scale of size 6 AWG wire for 100:1 would be far too small for simulated current, so closest approximation is taken using size 28 AWG wire.

Based on required topology, a CAD layout was completed as shown in Fig. 2. After consideration of scaled downward leader location, a size of 10’ x 10’ was considered sufficient for an equivalent electric field distribution.

Fig. 2: Assembled 100:1 scale runway model.

Fig. 3 shows standoffs that provide a means to accurately “lift” the runway centerline 350 mils above the light fixture location. It also shows additional standoffs located between paved and unpaved sections of the runway shoulder that allow for a removable section of unpaved runway shoulder.

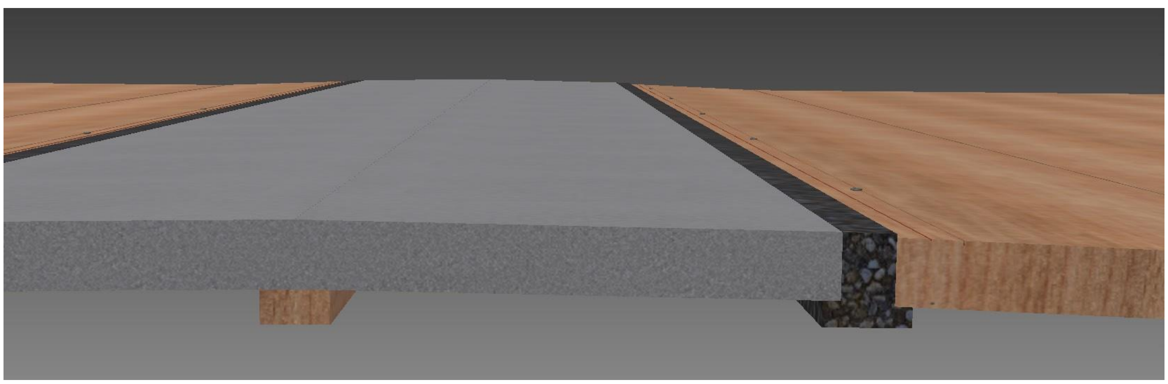

Fig. 3: View of runway model supported by standoffs for accurate position.

The removable section of unpaved shoulder shown in Fig. 4 provides for light system wiring, counterpoise LPS, and the 80 mil-thick layer of paper for ground covering of wires.

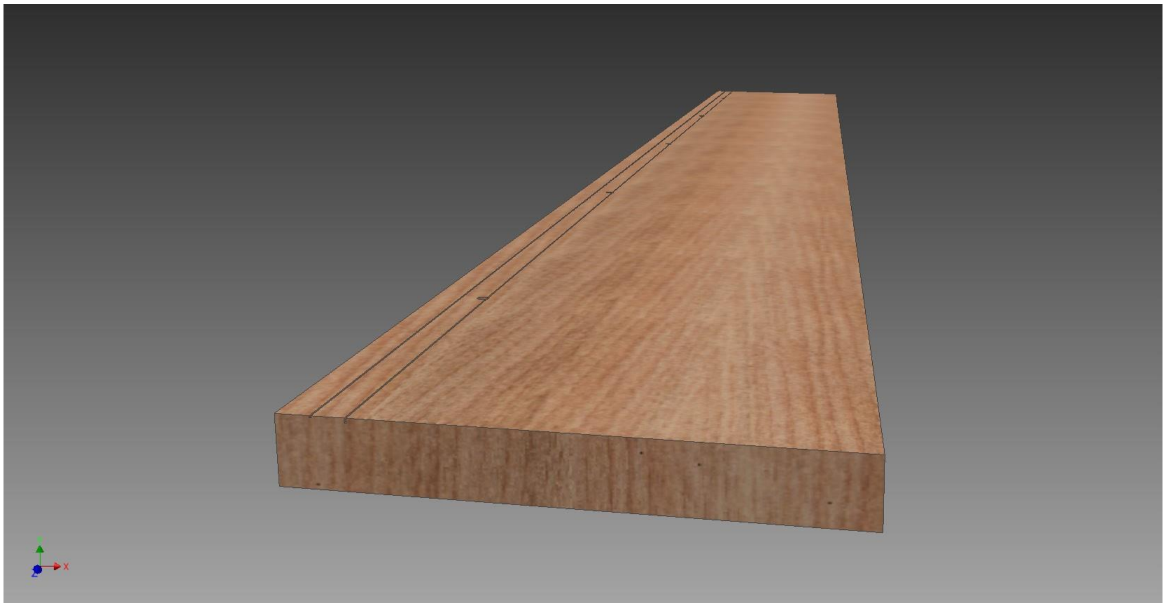

Fig. 4: Removable unpaved shoulder section of runway.

IV. Scale Runway Model Construction

In order to properly model electric fields and simulate the dynamic processes of lightning stroke attachment, material choices were made to provide equivalent electric field conditions. Also, construction materials should be water resistant, in order to allow for wetting of runway between series of lightning stroke attachments.

Treated lumber may be wetted, and it also provides good conductivity to maintain a more uniform electric field across the runway surface. Paper covering of the unpaved section simulates dirt covering of light system wiring and counterpoise LPS that is positioned between light system and shoulder pavement. Blacktop road repair compound is used to simulate paved surface and provide equivalent hydrophobic properties of the paved surface.

The 100:1 scale model runway, 10’ x 10’ in size, is shown in Fig. 5. A slot is cut to provide the wiring for runway lights. Fig. 6 provides a closer view of the model.

Fig. 5: Constructed 100:1 scale runway model.

Fig. 6: Close-up of the constructed 100:1 scale runway model.

V. LPS between Light Fixtures and Runway

The counterpoise between the light fixtures and runway is described in the NFPA 780-2014, Figure 11.4.2.6. The LPS wire is 8 in. below ground, between the paved runway shoulder and the light system. Observations were recorded shown in Table 1. Example of lightning stroke attachment simulation was performed as shown in Fig. 7. A closer view of the attachment is shown in Fig. 8.

Table 1: Lightning Stroke Attachments, Counterpoise between Lights and Runway.

Polarity	Position	Surface Tracking Events	Direct Attachment (no track)	Counterpoise Wire Attachments	Light Fixture Attachments
positive	A	5	0	5	0
	B	5	0	5	0
	C	5	0	5	0
	D	2	3	5	0
	E	3	3	5	0
	F	0	5	5	0
	G	1	4	4	1
	H	2	3	3	0
	I	4	1	0	4
negative	A	1	4	4	0
	B	1	4	4	0
	C	2	3	5	0
	D	2	3	5	0
	E	2	2	5	0
	F	2	3	4	0
	G	2	2	4	0
	H	1	4	3	0
	I	1	4	2	1

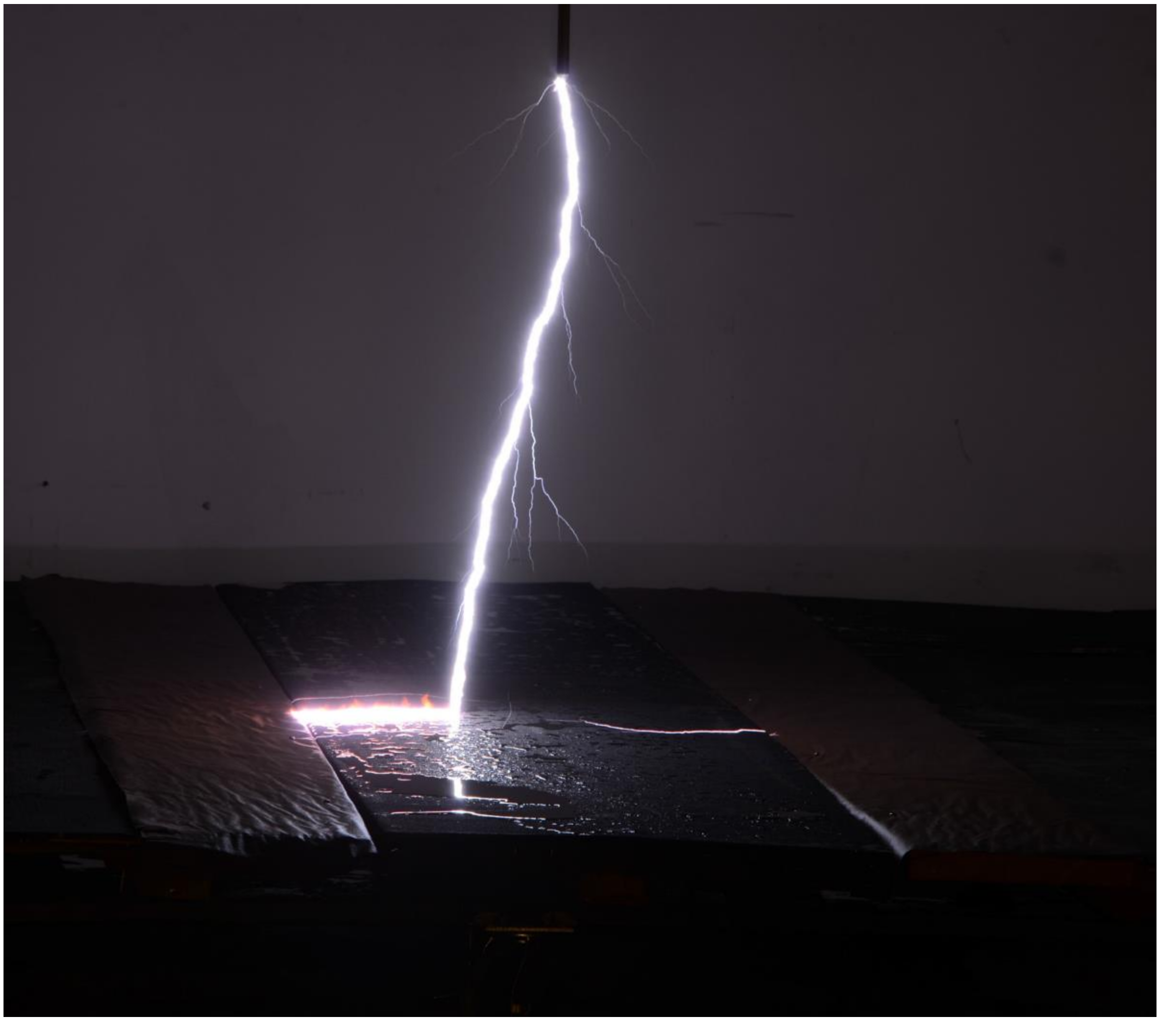

Fig. 7: Lightning Stroke Tracking and Attachment at LPS, Lights Protected.

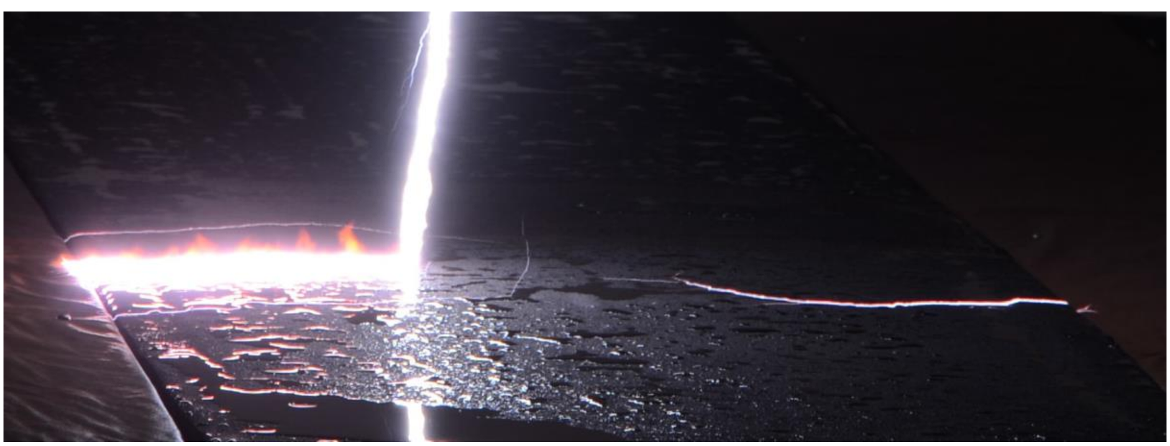

Fig. 8: Lightning Stroke Attachment to Protecting LPS, Expanded View.

VI. LPS Bolted to Light Fixtures

The counterpoise bolted to the light fixtures is described in the NFPA 780-2014, Figure 11.4.2.7. The LPS wire is below ground and bolted to the light fixtures. Observations were recorded shown in Table 2. Lightning stroke attachment simulation was performed as shown in Fig. 9. The closer view is shown in Fig. 10.

Table 2: Lightning Stroke Attachments, LPS Bolted to Light Fixtures.

Polarity	Position	Surface Tracking Events	Direct Attachment (no track)	Counterpoise Wire Attachments	Light Fixture Attachments
positive	A	5	0	5	0
	B	4	1	4	1
	C	3	2	1	2
	D	1	4	5	0
	E	0	5	3	2
	F	0	5	0	5
	G	0	5	4	1
	H	1	4	1	3
	I	3	2	0	4
negative	A	0	5	4	0
	B	1	4	4	1
	C	3	3	2	3
	D	0	5	4	1
	E	2	3	4	1
	F	2	3	3	2
	G	3	2	2	1
	H	1	4	1	1
	I	3	2	4	1

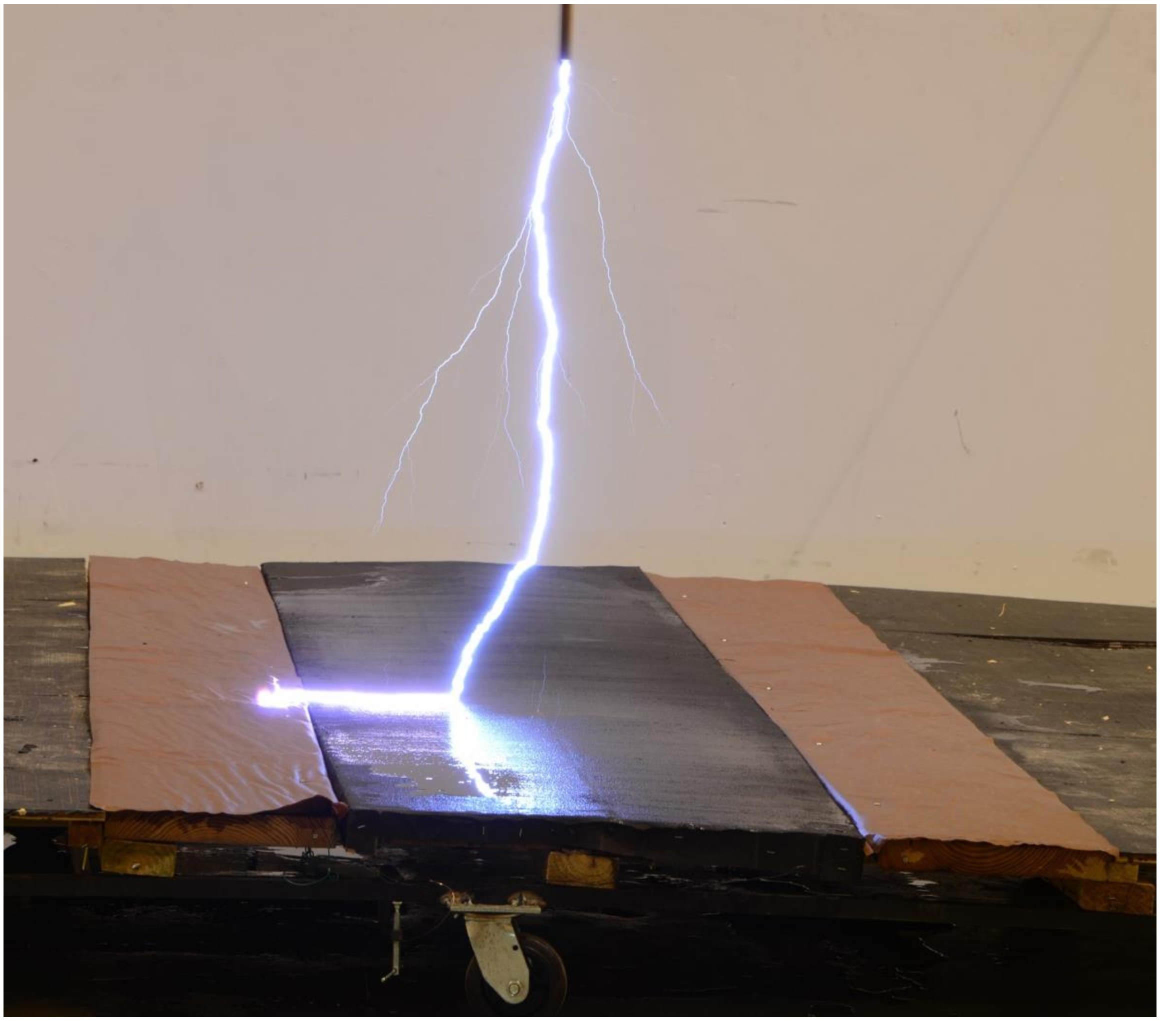

Fig. 9: Lightning Stroke Attachment to Light System and LPS.

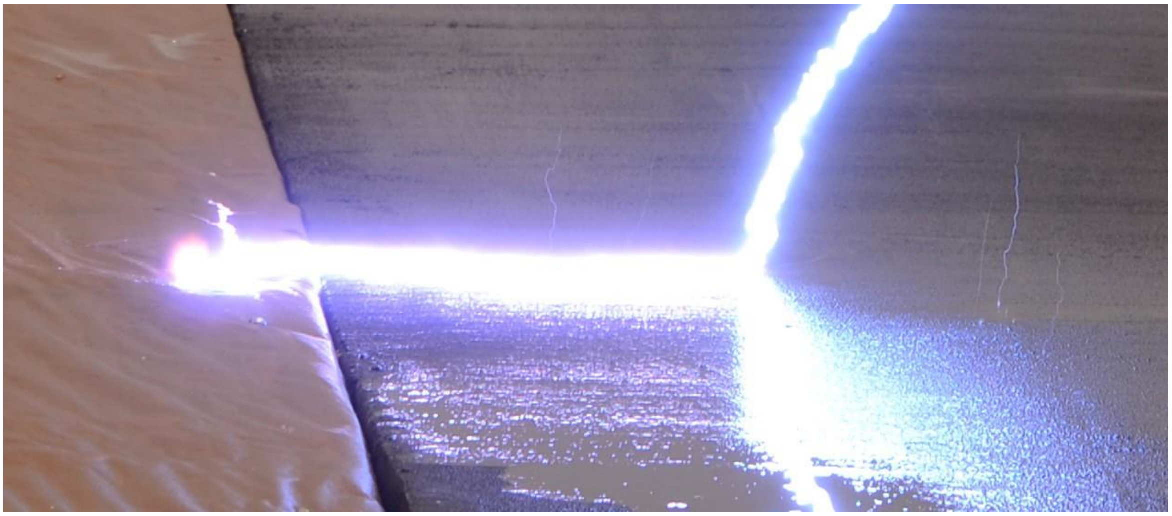

Fig. 10: Lightning Stroke Attachment to Light System and LPS, Zoom View.

VII. High Speed Camera

A high speed camera, recording at 5 million frames per second recorded the attachment process on the model runway. Attachment directly to the LPS is shown in Fig. 11. Attachment to the LPS through tracking is shown in Fig. 12.

(a) **(b)** **(c)**

Fig. 11: Attachment to LPS, Direct Path in Air.

(a) **(b)** **(c)**

Fig. 12: Attachment to LPS, Surface Tracking Path.

VIII. Simulation

Based on laboratory experiments, several SPICE (Simulation Program with Integrated Circuit Emphasis) circuit simulations were performed to present currents and voltages present on the LPS and close-proximity light fixture.

As specified in the NFPA 780-2014 standard, paragraph 11.4.6, impedance of the counterpoise LPS is derived from a single conductor, 6 AWG wire in good conducting earth. The resulting per-foot lumped impedance of the wire is shown in Fig. 13.

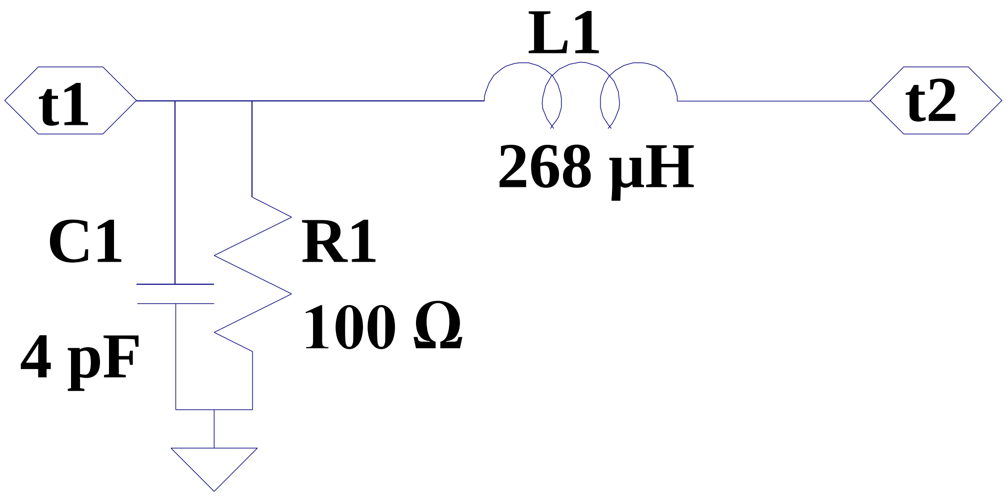

Fig. 13: Per-Foot Lumped Element for the Underground 6 AWG Wire.

The safety grounding wire in the light system conduit must remain at equipotential with all other ground, as stated in the NFPA 780-2014 standard, paragraph A.11.2.1. Furthermore the ground wire must be in the conduit as specified in paragraph A.11.2.2. From these specifications, a per-foot lumped element model is derived shown in Fig. 14.

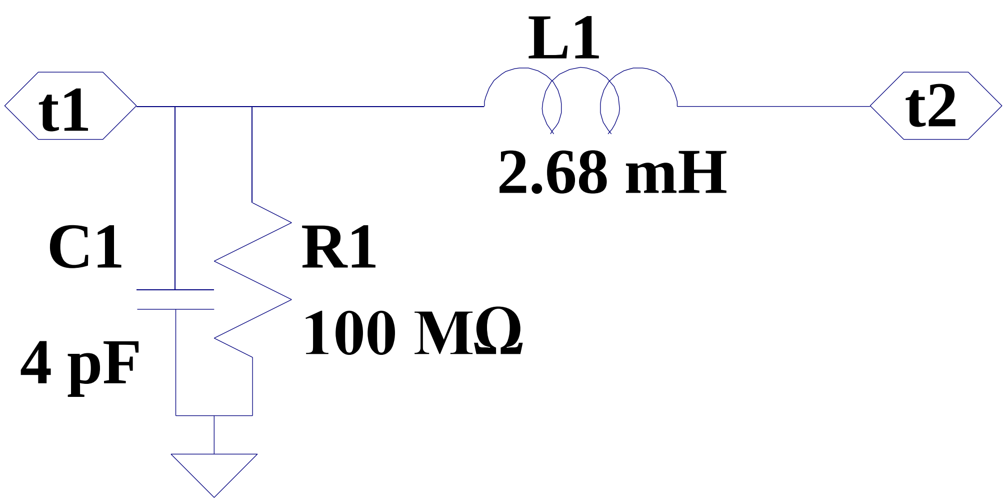

Fig. 14: Per-Foot Lumped Element for the Light System Ground Wire.

When considering an average 100 Ω per foot ground impedance, Fig. 15 shows the counterpoise LPS centered between the runway pavement edge and light fixtures. If the counterpoise LPS is directly bonded to the light fixtures, Fig. 16 shows the adjustment to the model.

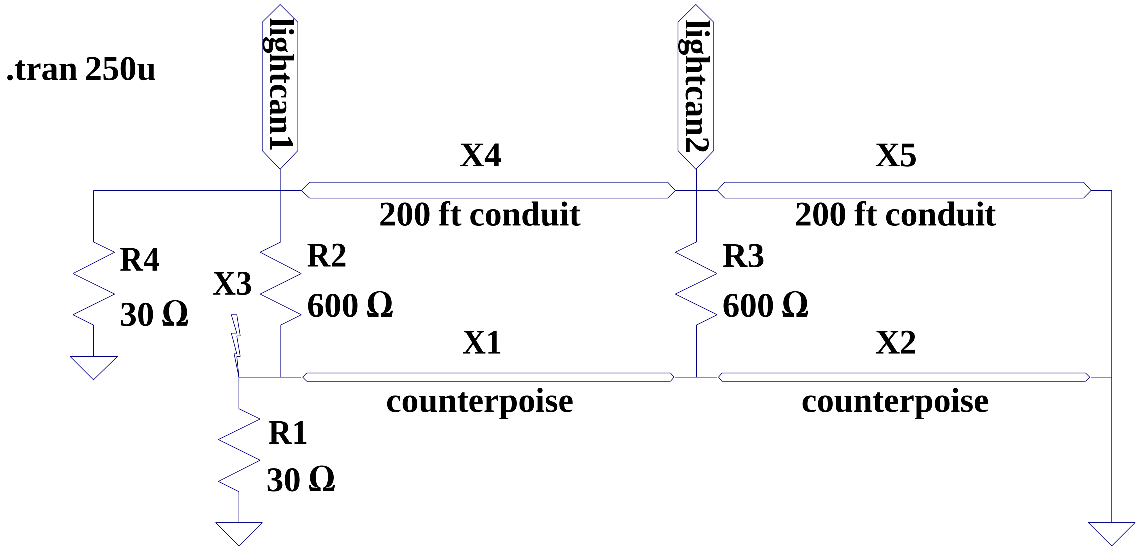

Fig. 15: SPICE Simulation Model for the Counterpoise LPS between the Runway and Light Fixtures.

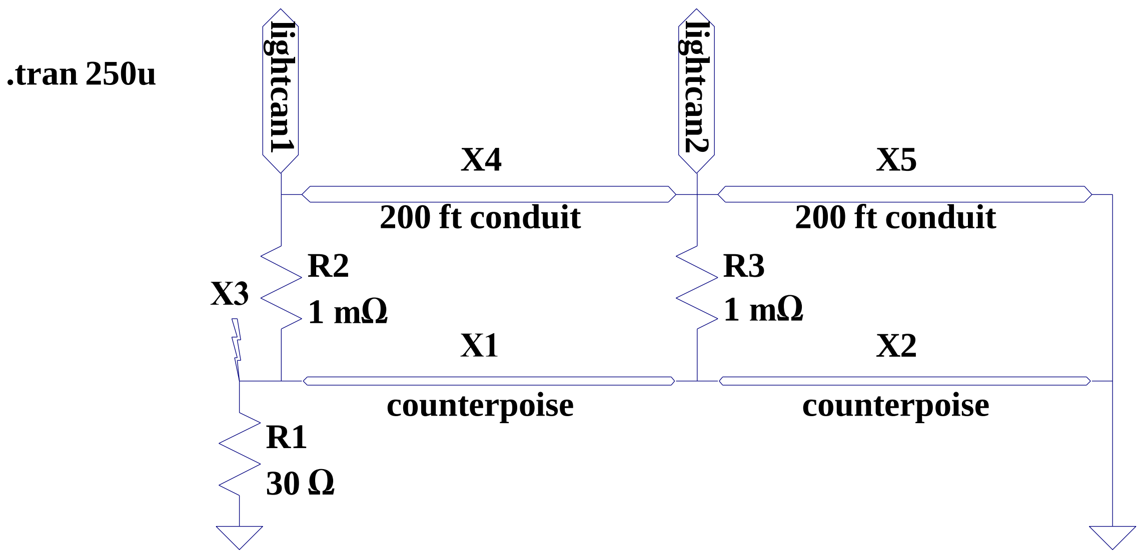

Fig. 16: SPICE Simulation Model for the Counterpoise LPS Bolted to the Light Fixtures.

IX. Results

Table 3 shows the observed for simulated cloud-to-ground lightning scaled from a maximum 90 m air gap between the final step and ground, for a counterpoise LPS between the light fixtures and the runway pavement edge. This tabulation shows the highest probability of lightning stroke attachment to the counterpoise LPS.

Table 3: Lightning Stroke Attachment, Counterpoise between Lights and Runway.

Polarity	Surface Tracking During Stroke	Direct Attachment During Stroke	Counterpoise Wire Attachment	Light Fixture Attachment
positive	**64.3%**	**45.2%**	**88.1%**	**11.9%**
negative	**37.8%**	**78.4%**	**97.3%**	**2.7%**
total	**51.9%**	**60.76%**	**92.4%**	**7.6%**

Considering the most common situation, with lightning stroke attachment to the counterpoise LPS, a SPICE simulation can reveal transient activity during the first stroke. Simulation results shown in Fig. 17 show lightning current and voltage at the entry point on the counterpoise LPS.

Fig. 18 presents the highest lightning current and voltage magnitudes coupled to the light system through the ground impedance. Ground impedance greatly attenuates the voltage and current, and an easily protected current oscillation appears at the light fixture. Current and voltage magnitudes approach zero through the length of the conduit.

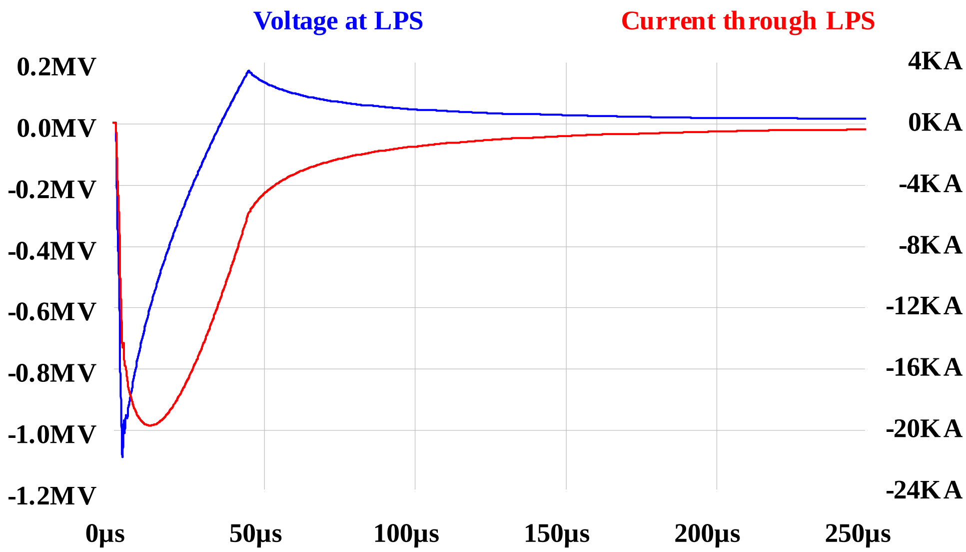

Fig. 17: SPICE Simulation Results for the Lightning Voltage and Current at the Node of Lightning Stroke Attachment, Counterpoise LPS between Light Fixtures and Runway.

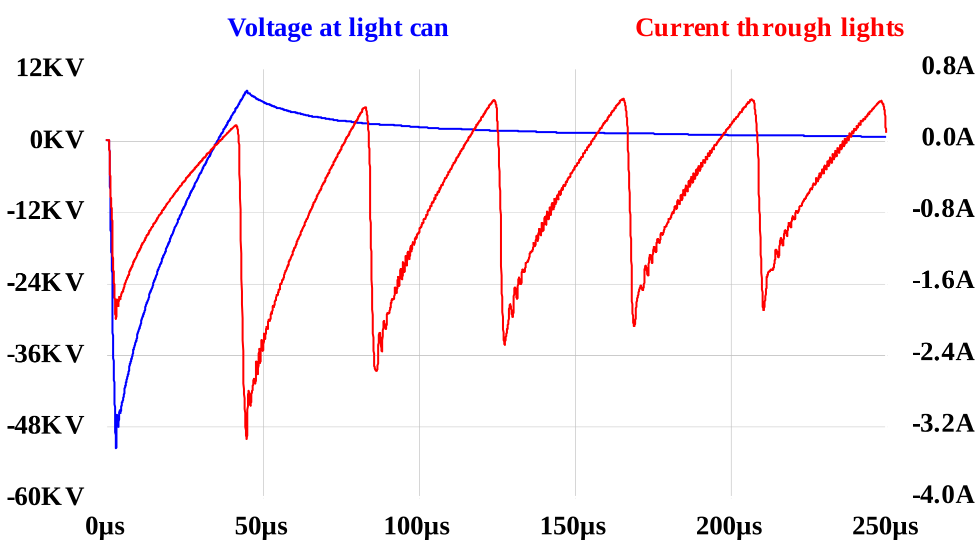

Fig. 18: SPICE Simulation Results for the Lightning Voltage and Current at the Node of Nearest Light Fixture, Counterpoise LPS between Light Fixtures and Runway.

Table 4 shows the observed for simulated cloud-to-ground lightning scaled from a maximum 90 m air gap between the final step and ground, for a counterpoise LPS bonded to the light fixtures. In the worst case, the most common form of cloud-to-ground lightning has nearly 50% chance to strike the LPS or the light fixture.

Table 4: Lightning Stroke Attachment, LPS Bolted to Light Fixtures.

Polarity	Surface Tracking Duing Stroke	Direct Attachment During Stroke	Counterpoise Wire Attachments	Light Fixture Attachments
positive	41.5%	68.3%	56.1%	43.9%
negative	38.5%	79.5%	71.8%	28.2%
total	40%	73.75%	63.75%	36.25%

Considering the most common situation, with lightning stroke attachment to the counterpoise LPS, a SPICE simulation can reveal transient activity during the first stroke. Simulation results shown in Fig. 19 show lightning current and voltage at the entry point on the counterpoise LPS, similar values in both counterpoise configurations.

Fig. 20 presents the highest lightning current and voltage magnitudes coupled directly to the light system through a low impedance, bolted connection. The full voltage magnitude is incident at the nearest light fixture, and a high current oscillates through the conduit.

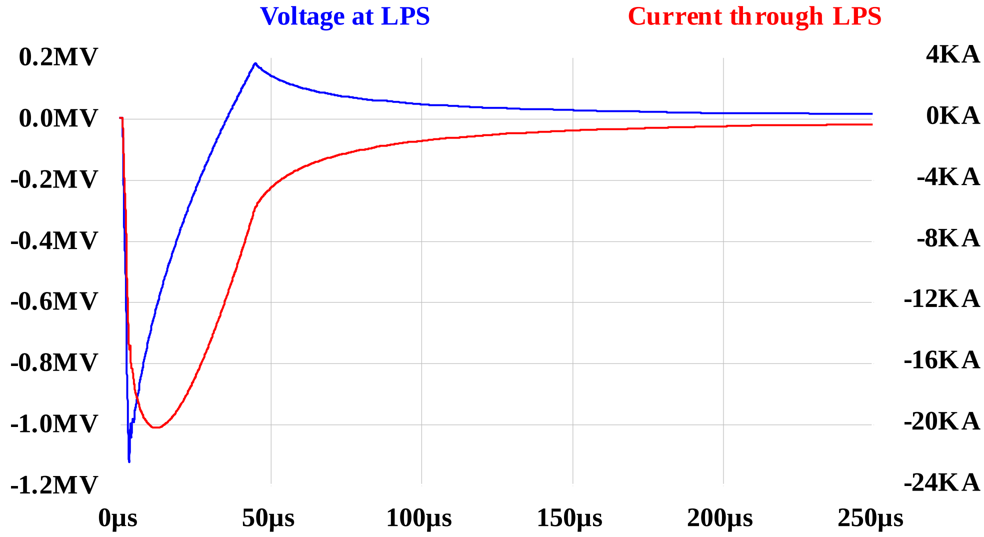

Fig. 19: SPICE Simulation Results for the Lightning Voltage and Current at the Node of Lightning Stroke Attachment, Counterpoise LPS Bolted to the Light Fixtures.

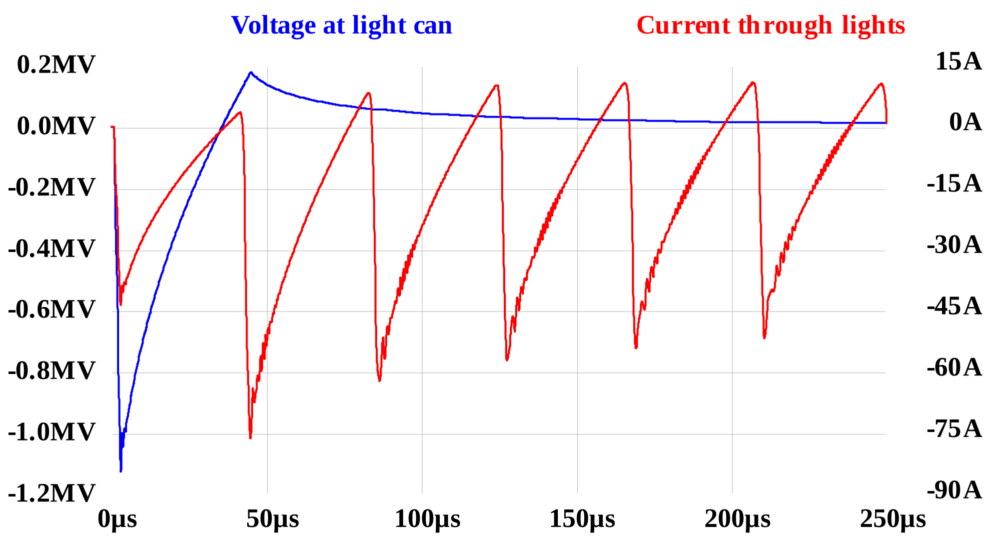

Fig. 20: SPICE Simulation Results for the Lightning Voltage and Current at the Node of Nearest Light Fixture, Counterpoise LPS Bolted to the Light Fixtures.

X. Conclusion

For the worst-case scenarios in the laboratory test, cloud-to-ground first stroke attachment at positive polarity, some positions of final stepped leader show a possibility of lightning stroke attachment to a light fixture. Additionally, circuit simulation results show ground impedance attenuates lightning currents and voltage. In every recorded case of lightning stroke attachment, both configurations of counterpoise LPS attracted lightning stroke attachment.

According to NOAA (http://www.srh.noaa.gov/jetstream/lightning/positive.htm), positive lightning makes up less than 5% of all strikes. Therefore, the focus of the conclusion is on the data obtained from the applied negative strikes. From Table 1, for the counterpoise between the light circuit and runway edge, there was one attachment to the light circuit. From Table 2, for the bolted counterpoise-to-light circuit, there were 11 attachments to the light circuit.

For the laboratory experiment and simulation of the counterpoise LPS aligned between the light fixtures of an airfield runway and the pavement edge of the runway:

- Lightning stroke attachment to the counterpoise LPS attenuates to low magnitudes before reaching the runway light system.
- Lightning voltage magnitude coupled to the lighting circuit through ground impedance is significant enough to require some protection from over-voltage transients for high voltage-magnitude strikes.
- Small lightning currents may oscillate through the runway light system, requiring some protection from over-current transients.
- At least 97% of the initial lightning strokes attached to the counterpoise LPS, protecting the light system from negative cloud-to-ground lightning, the most common form of lightning for an airfield runway.

For the laboratory experiment and simulation of the counterpoise LPS bolted to the light fixtures of an airfield runway:

- High magnitude lightning current and voltage is directly coupled to the runway light system in every case of lightning stroke attachment.
- Without expensive over-current protection, high lightning currents may oscillate through the runway light system.
- 28% of the most common form of airfield lightning strokes attached directly to the runway light fixture.
- For lightning stroke attachment to the LPS, circuit simulation show airfield light systems are not protected by this configuration of counterpoise LPS.

This study shows that the counterpoise LPS positioned between an airfield runway pavement edge and light system outperforms a counterpoise LPS that is directly bolted to the runway light fixtures. Even in the case with additional protective devices installed in the light system, fewer lightning transients in the light system extend the effective life of the protective devices.

XI. References

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