The Sandia Lightning Simulator

Recommissioning and Upgrades

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***Abstract*—The Sandia Lightning Simulator at Sandia National Laboratories can provide up to 200 kA for a simulated single lightning stroke, 100 kA for a subsequent stroke, and hundreds of Amperes of continuing current. It has recently been re-commissioned after a decade of inactivity and the single-stroke capability demonstrated. The simulator capabilities, basic design components, upgrades, and diagnostic capabilities are discussed in this paper.**

Keywords-lightning, full-scale lightning testing

I. Introduction

The Sandia Lightning Simulator (SLS) at Sandia National Laboratories simulates severe lightning strikes. It can produce a maximum peak current of 200 kA for a single stroke, 100 kA for a subsequent stroke, and several hundred Amperes of continuing current for hundreds of milliseconds. The SLS is currently being re-commissioned and refurbished after a decade of non-use. The single-stroke capability has been demonstrated up to 200 kA. The double-stroke and continuing current capabilities have been refurbished but not demonstrated at this time. This paper explains the capabilities and basic design of the SLS, its upgrades, and its diagnostic capabilities.

II. The Sandia Lightning Simulator Capabilities

The SLS can be operated in the single-stroke or double-stroke mode, with or without continuing current. The operating parameters are listed in Table 1, and a SLS single stroke is shown in Fig. 1. Test environments include direct-attachment lightning, (where the simulator is connected to or arcs to the test object), burn-through (which incorporates continuing current), and nearby magnetic fields due to the strokes.

Since the SLS was built largely to qualify nuclear weapon safety components and systems, the operating parameters were chosen to satisfy the more severe nuclear weapon requirements when practical. The parameters were based on a compilation of various nuclear weapon Stockpile-to-Target Sequence (STS) specified lightning environments, which are listed in Table 2. Typical lightning environments known at the time of the original design, also shown in Table 2, were also considered. Because lightning parameters are statistical in nature, the most severe and average values are shown in Table 2.

TABLE I. SLS Operating Parameters

Peak current	200 kA, max
Current rise time	1 to 5 µs
Current rate of rise	200 kA/µs, max
Pulse width (full width half maximum)	50 to 500µs (dependent on load impedance)
Charge transfer of a single pulse	40 C (200 kA peak, 100 µs pulsewidth)
Number of pulses	1 or 2
Interval between pulses	variable
Continuing current	100s A for 100s of ms
Charge transfer of continuing current	250 C (for 500 A @ 500 ms)

TABLE II. Typical STS Requirements and known lightning parameters [1,2]

Lightning parameters	STS requirements		Known parameters	
	Most severe	50% level	2% level	50% level
Peak current[1]	200 kA	20 kA	140 kA	20 kA
Time to peak current	0.2 µs	2.0 µs	12 µs	1.8 µs
Current rate of rise	100 kA/µs	20 kA/µs	100 kA/µs	22 kA/µs
Pulse width (full width half maximum)	200 µs	50 µs	170 µs	45 µs
Continuing current amplitude	700 A	140 A	520 A	140 A
Continuing current duration	500 ms	160 ms	400 ms	160 ms
Number of strokes	1 - 12	2	10 -11	2 - 3

[1] Values for first strokes, subsequent strokes have lower peak currents.

Interval between strokes	500 ms	50 ms	320 ms	60 ms
Total flash duration	1.0 s	0.2 s	850 ms	180 ms
Total charge transfer	300 C	15 C	310 C	41 C
Charge transfer per flash	--------	--------	200 C	15 C
Charge transfer per continuing current	---------	--------	110 C	26 C

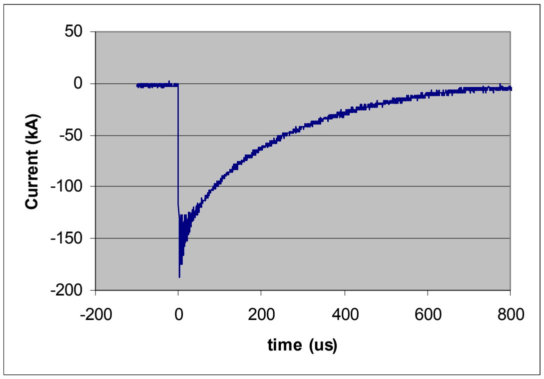

Figure 1. Typical Sandia Lightning Simulator single-stroke output.

III. THE SANDIA LIGHTNING SIMULATOR DESIGN

Fig. 2 shows the major components of the SLS. The left oil tank contains the 200 kA Marx bank and the right oil tank contains the 100 kA Marx bank. Each tank holds approximately 16,000 gallons of transformer oil for high voltage insulation. For a single stroke shot, the 200 kA bank is fired into the center section and through the output terminal into a test object. For a double stroke, the 100 kA bank is fired at some predetermined time after the 200 kA into the center section and output terminal as well. Each tank uses two Marx capacitor banks in parallel. The 200 kA tank has an erected capacitance of 325 nF. The 100 kA tank can be configured in several different ways depending on the amount of current desired. For the maximum peak current of 100 kA, the erected capacitance is 163 nF. When fired, both banks typically erect to approximately 1 MV. At 1 MV, the stored energy is 176 kJ in the 200 kA bank and 88 kJ in the 100 kA bank. The actual energy delivered to a test object is dependent on the timing of the crowbar switch firing and the load characteristics. For continuing current, a motor / generator set is spun up and released, generating hundreds of Amperes for hundreds of milliseconds.

The simulator outputs a unipolar, overdamped waveform to replicate a real lightning stroke. Marx banks are used to generate the high peak current of a lightning stroke. To achieve an overdamped waveform into essentially a short circuit load, a crowbar switch is used to short out the erected capacitance of each tank at approximately the time of peak current, separating the capacitance of the Marx banks from the load circuit. This creates a decaying (instead of oscillating) waveform into the load (or test object), assuming the load is inductive and resistive. The pulse width of the load current is largely determined by the inductance and resistance of the load. The energy delivered to the load is dependent on the load resistance versus the total resistance of the output circuit, including the crowbar switch. The basic simulator circuit for each tank can be seen in Figure 3. In reality, some resistance, capacitance, and inductance are associated with the crowbar switch and its connections. In addition, the crowbar switch is not closed exactly at the peak current, but at some time before. Before the crowbar switch closes, the simulator acts as an underdamped circuit (assuming the load resistance is relatively small) and the Marx voltage is approximately 90º out of phase with the Marx current. At peak current, the output voltages across the Marx banks are zero, or close to it. Some voltage needs to be present across the crowbar switch electrodes to trigger the switch. Therefore, the crowbar switch is typically triggered at a time corresponding to approximately 80% of peak current. This allows sufficient voltage to be present across the crowbar switch to reliably trigger it. Unfortunately, this also causes some energy to be retained in the Marx bank and not delivered to the load. The ringing that can be seen at the current peak in Fig. 1 is due to the discontinuity introduced by the crowbar switching.

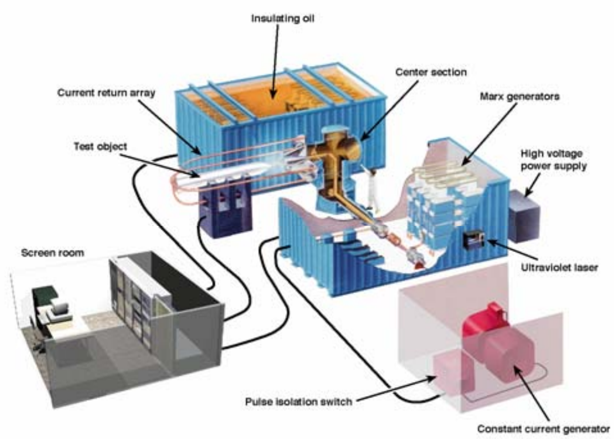

Figure 2. The Sandia Lightning Simulator.

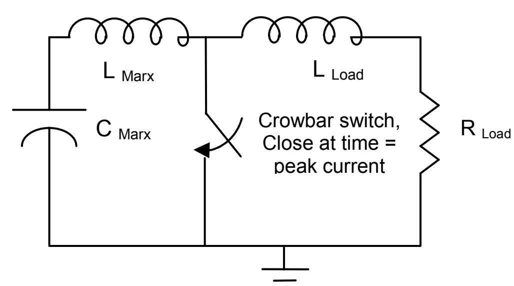

Figure 3. Basic simulator circuit per tank.

IV. RECENT UPGRADES

There are two crowbar switches, one in each oil tank, and they are triggered with lasers. Previously, a large Krypton-Fluoride ultraviolet laser was used to fire both crowbar switches. The laser light was split and routed to each tank with mirrors. This laser was replaced with two much smaller, less hazardous YAG lasers. The previous laser took up a small room, required handling and venting of toxic gas, and routing of exposed high energy laser light. Now, each oil tank has its own laser contained in an electromagnetically shielded box on the side of each tank, without exposed laser light or toxic gas.

The original low-voltage trigger system was replaced with up-to-date trigger generators that are remotely set and adjusted through a custom Labview program. The low-voltage trigger system initiates the firing of the high-voltage Marx banks, the lasers for the crowbar switches, and the continuing current generator. The data acquisition system was modernized to include Tektronix TDS 7054 oscilloscopes that have multi-frame capability for the double-pulse mode and a custom Labview program to set the scopes and retrieve data.

The building that houses the simulator was updated to meet current environmental and safety regulations. Upgrades are planned for the extensive gas system which supplies high-voltage insulating gas to the many switches in the simulator and for automating the high-voltage control console. The high-voltage control console sets and monitors the gas system pressures, the high voltage power and trigger supplies, the continuing current generator operating parameters, and interfaces to building safety interlocks. Future upgrades include replacing the continuing current generator and installing an electromagnetically shielded video system to monitor test objects during testing.

V. DIAGNOSTICS

Current and voltage measurements are taken for each shot to monitor and diagnose the lightning simulator. These signals are sent back to a screen room via shielded coaxial cables. Three current viewing resistors in line with the simulator's return path measure the total current for each shot. The current inside each tank is measured with current viewing resistors. The high-voltage trigger generator signals are monitored with a combination of current transformers and current viewing resistors. The crowbar voltage is measured with a resistive divider, and the trigger signal to the crowbar switch lasers is monitored. It is important to monitor these signals because the timing between the peak Marx bank currents and the triggering of the crowbar switches is critical. If the crowbar switch fires too early into the rising edge of the Marx bank current, less current than desired is transmitted downstream to the test object, resulting in an undertest. If the crowbar switch fires too late or not at all, the Marx bank capacitors may be damaged due to large oscillations in the current pulse.

To minimize the electromagnetic noise generated during a shot from interfering with test object diagnostic data, diagnostics are shielded and fed through a fiber optic system back to the screen room. Typically, the diagnostics are shielded in a metal instrumentation barrel. Within the barrel, fiber optic transmitters convert the analog diagnostic signals into optical signals, which are sent to the screen room via optical fibers. Pictures of the instrumentation barrel, diagnostics, and fiber optic transmitters can be seen in Figs. 4 - 6. In the screen room, the optical signal is converted back to an electrical signal and fed to an oscilloscope channel. Typical diagnostics are current viewing resistors and transformers, Rogoswki coils (for current derivative measurements), and common and differential mode voltage dividers. Other compatible diagnostics are pressure transducers, temperature sensors, and electric and magnetic field sensors (D-Dot and B-Dot, respectively) which may be desired when exposing a test object to indirect lightning electromagnetic fields.

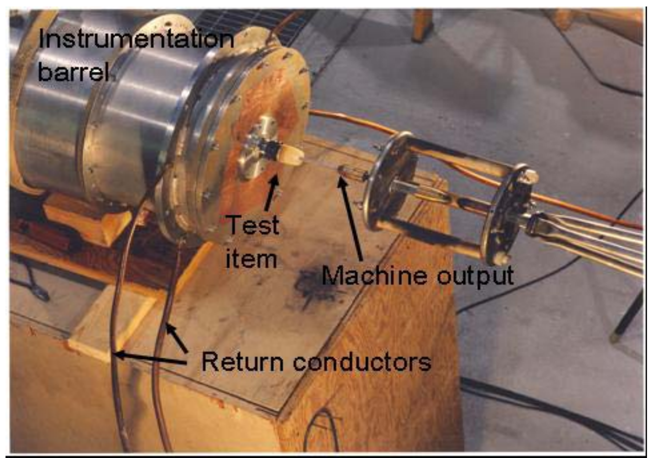

Figure 4. Simulator output and Instrumentation Barrel.

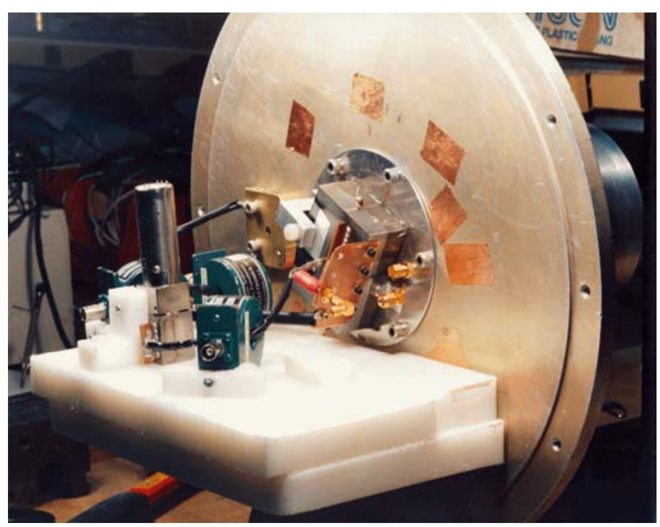

Figure 5. Test object and diagnostics inside Instrumentation Barrel.

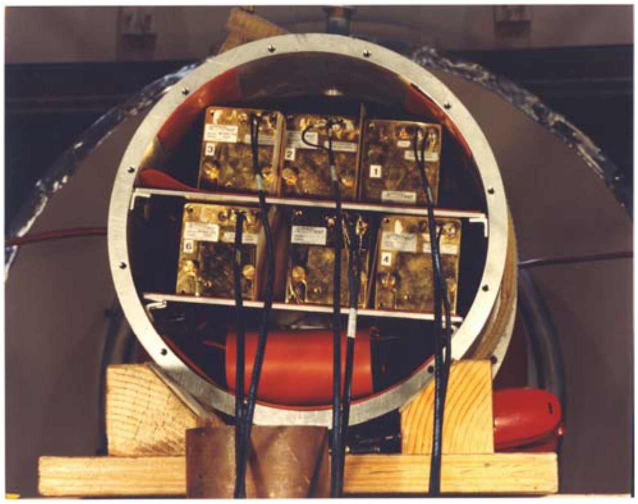

Figure 6. Fiber optic transmitters inside the Insturmentation Barrel.

VI. Typical Test Objects

The Sandia Lightning Simulator can be used to certify or evaluate hardware or to perform research. Historically, it has been mostly used to perform safety qualification testing of nuclear weapon components and weapon systems. However, it has also been used for basic research such as burn-through studies of different materials [3]. The main limitations of the facility are that it is not portable and it is designed to operate essentially into a short circuit. Operating the simulator into an open circuit forces all the current that would be delivered to the test object to oscillate in the Marx banks, risking damage to the simulator. Therefore, if test items are insulating or have a large inductance thereby producing a large inductive voltage drop, care must be exercised in operating the simulator.

The next suite of tests at the Sandia Lightning Simulator include evaluating Lightning Arrestor Connectors, which are safety components used in nuclear weapons. It is also planned in the near future to test hazardous waste containers in a burn-through environment, to evaluate a lightning detection system, and to conduct concrete and rebar behavior research.

VII. Conclusions

In conclusion, the Sandia Lightning Simulator has been refurbished and upgraded after almost a decade of non-use. Currently, the ability to simulate a severe single lightning stroke has been demonstrated. The double-stroke and continuing current capabilities have been refurbished but not yet verified. Test objects can be subjected to direct lightning attachment, burn-through, or coupling of magnetic fields due to nearby strikes. A variety of diagnostics can be used in conjunction with fiber optic transmitting systems, the use of which minimizes electromagnetic noise coupling from firing the simulator.

Acknowledgments

The authors would like to thank and acknowledge the contributions of Parris Holmes and Matthew Kiesling in refurbishing, maintaining, and operating the Sandia Lightning Simulator. Their efforts and dedication have been key elements to the success of this endeavor. We would also like to thank Mike Dinallo for his technical assistance and knowledge.

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