Thermal Simulation of a Conductive Fabric Sheet Subjected to a Lightning-like Current

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***Abstract*—A sample of electroconductive fabric subjected to a lightning-like current impulse is analyzed in this contribution. A multiphysics simulation is used to calculate the temperature distribution produced by a lightning-like current flowing through the material sample. A decoupled, electromagnetic (EM) and thermal, simulation was conducted for the analysis and is explained in the paper. The scaling factor calculation to represent the energy presented during current impulse tests is also detailed. Numerical results present patterns that agree with experimental tests reported in the literature and represent an additional tool for the phenomena insight.**

***Keywords*—Conductive fabric, electromagnetic simulation, impulse current, lightning, thermal simulation.**

I. INTRODUCTION

Conductive fabrics have shown promising performance for different applications such as electromagnetic shielding, antennas, sensors, water treatment, and more recently lightning protection [1, 2]. Preliminary tests, in which different kinds of conductive fabrics are tested against lightning-like current impulses [1], show that the textiles can withstand high intense current impulses and provide a conductive path for lightning currents. However, the thermal stress produced in the electroconductive fabric materials during this kind of tests have not been studied in depth.

In this paper, a multiphysics simulation, including electromagnetic and thermal phenomena, is conducted in order to calculate and analyze the temperature produced in a sample of conductive fabric subjected to a high intensity current impulse.

II. SIMULATION SETUP

The characteristics of the excitation signal and the samples under test are the same as the reported ones in previews experimental results [2].

A decoupled, electromagnetic (EM) and thermal, simulation was conducted for the analysis. The general steps for the simulation can be summarized as follows. First, the electromagnetic (EM) simulation is conducted. Then, power losses are calculated from the EM simulation. These losses are the source of the thermal simulation. Finally, thermal simulation is conducted and temperature distribution is obtained.

A. Conductive Fabric Samples

The selected samples of electroconductive fabrics tested in [2] are pieces of 10 cm x 10 cm of non-woven conductive fabrics. The main electrical characteristics of the samples are presented in Table I. Physical characteristics presented in the table are based in the manufacturer data. Simulation parameters, also included in the table, are based on experimental results reported in [2] and typical properties of the fabric's conductive materials.

B. Excitation Signal

The excitation signal used in [2] is a current impulse of 13,7 kA, 4/10 µs. The energy reported for this signal was 104 J with a time to half value of 10 µs. Since the used thermal simulator only imports power losses from EM simulation in frequency domain at one frequency and the excitation signal in the experimental tests is a pulse, different excitation signals were used in EM and thermal simulations. For the EM simulation, the excitation signal corresponds to a current signal injected in the sample. A Gaussian excitation covering the frequencies up to 20 MHz was used.

For the thermal simulation setup, a square pulsed excitation was used. The source in the thermal simulation corresponds to the imported losses from the EM simulation. For this reason, the average power of the pulse signal in the thermal simulations has to be calculated. The average power of a square pulse excitation can be estimated as:

$$P_{ave} = U/\tau, \tag{1}$$

where U is the delivered energy and τ is the pulse duration. In this case, it is assumed that the power is produced by a continuous wave signal. Therefore, if the power P_{ave} is produced by a continuous wave signal, the required current to obtain that power can be obtained from the power dissipated in a resistance. In our case, the conductive fabric is the resistance that dissipate this power into heat,

$$P_{ave} = \frac{I_{peak}^2}{2} R. \tag{2}$$

From (1) and (2), the equivalent current to produce the same energy used in the impulsive tests can be calculated. Using $U = 104$ J, $\tau = 10$ µs, and $R = 0.03\ \Omega$, a peak current of $I_{peak} = 26.3$ kA is obtained. This result provides the scaling factor used in the thermal simulation for the losses 26.3×10^3, which corresponds to the ratio between the desired

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peak current and the peak current used in the EM simulation that in this case was 1 A.

TABLE I. CHARACTERISTICS OF SIMULATED CONDUCTIVE FABRIC

Characteristic	Unit	Fabric	Simulation
Weave pattern	Type	Non-woven	Lossy conductive sheet
Conductive material	Type	Ni-Cu	--
Weight	g/m^2	90±10	--
Sheet resistance	Ω/□	≤ 0.05	0.03
Resistivity	µΩ·m	≤ 4.0	1.17
Density	kg/m3	--	576.92
Thermal conductivity	W/K/m	--	50
Heat capacity	kJ/K/kg	--	0.385

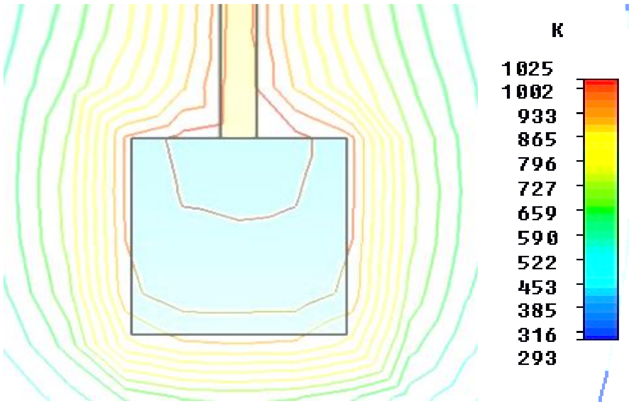


Fig. 1. Constant temperature lines calculated using the EM-thermal simulation.

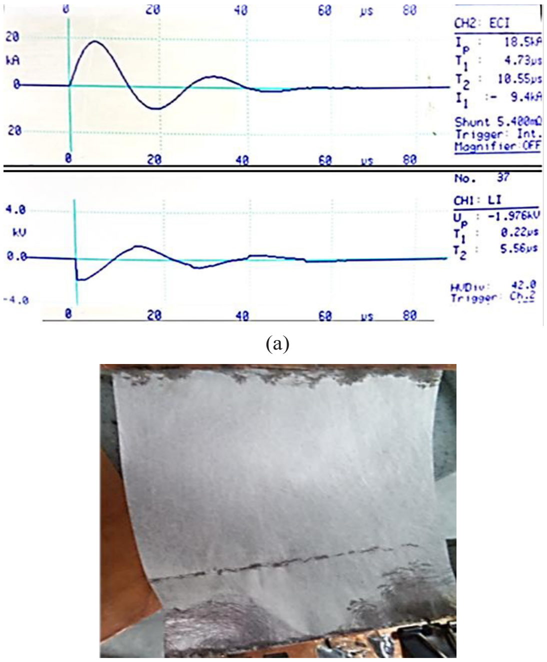
C. *Electromagnetic Simulation*

The electromagnetic (EM) simulation included a box of air (normal) with thermal properties surrounding the conductive fabric, open boundary conditions in all directions, a current port defined in a straight line with a current of 1 A, a straight PEC wire used to connect the current port with the conductive sheet under test, and field monitors (e-field, h-field, loss) for the frequency that represent the desired energy distribution. The conductive fabric was modeled as a lossy conductive sheet with the thermo-electrical characteristics shown in Table I.

The EM simulation was performed using a finite element method (FEM) solver in frequency domain. To estimate the temperature increases, the power losses at 10 MHz were calculated after the EM was completed. At this frequency, the sample is electrically small.

D. *Thermal Simulation*

The thermal simulation included isothermal boundary conditions in all directions, and a boundary temperature fixed at 293.1 K. To import the power dissipated in the sheet to the thermal simulator, the thermal loss distribution was calculated. The scaling factor deduced in the previous section equal to 26.3 $\times 10^3$ was used to represent the energy used in the experimental tests reported in [2]. Due to the small duration of the impulse (i.e., several times lower than the thermal constant of the conductive sheet), heating can be considered adiabatic.



(a)

(b)

Fig. 2. (a) Current and voltage signals measured in the experimental test, and (b) conductive fabric after impulsive test showing marks by overheating. Figure taken from [2].

III. RESULTS

Temperature distribution calculated in the conductive sheet is presented in Fig. 1. The highest temperature is presented around the electrode that injects the current. Similar results are obtained in experimental impulsive tests performed over conductive fabrics [2]. Material overheating produced by the lightning impulse current sublimates metallic layers around the electrodes contact area, as shown in Fig. 2. Particularly, circular patterns are formed around the electrodes, such as the isothermal lines suggested by the numerical simulation results presented in Fig. 1.

IV. CONCLUSIONS

Numerical simulations to calculate the temperature distributions produced by a lightning-like current in a conductive fabric are described in this paper. Numerical results agree with experimental tests previously reported in the literature. Particularly, patterns of melted conductive material observed in the non-woven fabric sheet follows the isothermal lines of high temperature numerically calculated. Work is in progress to numerically estimate thermal effects on conductive fabrics with higher current intensities and higher energy rates.

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