Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
June 2016, 23(3): 76–88
www.sciencedirect.com/science/journal/10058885
The Journal of China Universities of Posts and Telecommunications
http://jcupt.bupt.edu.cn

Numerical simulation and experiment validation on lightning-induced effects of a special vehicle

Zhou Ping[1] (✉), Lü Yinghua[1], Tao Yong[2], Xu Hongping[2]

1. School of Electronic Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
2. Institute of Astronautic System Engineering, Beijing 100076, China

Abstract

In recent years, with the development of the system integration technology, the outside integrative special vehicles, such as big oil tank, trucks loading with dangerous goods and so on, are becoming more and more important. When the vehicle is under way, it will inevitably encounter the nature environment, including lightning. If the lightning strikes directly or very close to the vehicle, the lightning-induced effects will be very destructive. Therefore, for a better understanding of the lightning-induced effects produced on the special vehicle by the lightning strike, the research on lightning-induced effects of a special vehicle for aerospace system transportation was proposed. In the paper, a numerical simulation model for the special vehicle is established, the lightning-induced effects are analyzed successfully by using tramsmission-line matrix (TLM) algorithm, and the experiment validation example is also implemented. By comparing the numerical simulation with the actual experiment results, the correctness trend of the numerical simulation is validated and a mass of invaluable research data is obtained, which has a deep significance on the lightning research in our country.

Keywords special vehicle, lightning-induced effects, numerical simulation, experiment validation

1 Introduction

In recent years, with the development of the system integration technology, the outside integrative special vehicle with unique function has becoming the emphasis of the vehicular engineering application around the world. When the vehicle is running outside, it will inevitably face to the nature environment, such as the lightning electromagnetic environment. As is known to all, the lightning is a kind of the common nature phenomenon, which can emerge an extraordinary energy accompany with the destructive lightning-induced effects when the lightning strike happened. According to its physical characteristic and the action formation, the lightning-induced effects can defined into two types: lightning direct effects and lightning indirect effects. The lightning direct effects are the effects caused by the lightning directly strike to the vehicle and made the obvious destructive effects on it, such as burning, melting, explosion, or distortion the structure and cables of the vehicle. On the other side, the lightning indirect effects are the harmful effects caused by indirect lightning struck, which often make an indirect influence on the vehicle, in the form of a lightning-induced electromagnetic environment inside the vehicle and produce electromagnetic interferences to electronic equipment and devices of the vehicle [1–6].

National aeronautics and space administration (NASA) may be worthy of special mention for research on lightning-induced effects of special vehicles in the duration from 1970s to 1980s. With the development of applications, many commercial software suits for electromagnetic simulation are developed, some of them have been developing the function of analyzing the lightning-induced effects on the systematic level, such as CST, FEKO, COMSOL, et al [7]. As to the lightning experiment, Clifford reviewed the research progress of the

Received date: 21-04-2016
Corresponding author: Zhou Ping, E-mail: ana0072@163.com
DOI: 10.1016/S1005-8885(16)60036-5

lightning experiment on systematic level in 1982, which was a typical representative review on lightning experiments in the United States [8]. In 1988, the Redstone Technical Test Center (RTTC) was established in the United States, which had implemented many lightning-induced effects experiments on the special vehicles [9]. In 1989, a systemic level lighting-induced effect experiment was implemented by Thiokol Corporation in the United Stated [10]. Moreover in Russia, Ukraine, India or France, the lightning-induced effects experiment research centers for the special vehicles were also established [11]. However, with the quickly development of the system integration technology, the requirement of the special vehicles with unique function is steadily on the increase. Under this situation, a research on the lightning-induced effects of a special vehicle for aerospace system is developed in this paper, in which by establishing the numerical modeling and using an actual vehicle example, the simulation analysis and the experiment validation on the systematic level are implemented. In the numerical simulation, a wholly dimension of special vehicle model is established and the lighting-induced effects produced on it is computed by using TLM algorithms. In order to validate the correctness of simulation results, the systematic level experiments of lightning-induced effects are also implemented. The testing implementation of the lightning-induced effects on the vehicle example is made respectively.

The paper is structured as follows: in Sect. 2 the formation and types of the lightning-induced effects are introduced. Then the coupling channels of lightning-induced effects for the special vehicle are provided in Sect. 3. Numerical simulation and experiment validation on lightning-induced effects of the special vehicle are given in Sect. 4 and Sect. 5, respectively. In the end, conclusions are given in Sect. 6.

2 Lightning-induced effects

2.1 Formation of the lightning-induced effects

The lightning-induced effects are mainly produced by the action of lighting strike mainly focus on the lightning channel. On the moment of lightning strike happened, the extremely high peak current of the lightning channel will directly flow to the lightning connective point of ground or other objects. On the view of antenna theory, the lighting channel can be regarded as a giant dipole antenna, which can radiate a strong electromagnetic field also. When a lightning strike happened, the conductive lightning current and the radiate lightning electromagnetic field are work together, and then make destructive lightning-induced effects are formed.

Typically, the mathematical expression of the lightning channel current $i = i(r,t)$ is a function changed with the duration time of the lightning strike and the altitude from the ground. When $r = 0$, it is defined as the lightning channel-base current, which represents the lightning current in the lightning channel on the ground level, named $i = i(0,t) = i(t)$. In the lightning-induced effects numerical simulation, the lightning channel-base current function is usually used as the initial input excitation. The first methodological attempt to identify a suitable function is the so-called double-exponential function proposed by Beelwy [12], which is the most widely used in lightning research, as follows in Eq. (1). Another often used function is Heidler function [13], which is the defined as the numerical expression of the lightning current in IEC standard [14], as follows in Eq. (2).

$$i(t) = I_0(\mathrm{e}^{-\alpha t} - \mathrm{e}^{-\beta t}) \tag{1}$$

$$i(t) = \frac{I_0}{\eta} \frac{\left(\frac{t}{\tau_1}\right)^n}{1+\left(\frac{t}{\tau_1}\right)^n} \exp\left(\frac{-t}{\tau_2}\right) \tag{2}$$

Where I_0 is donated the peak amplitude of lightning current, in the unit of A. α and β both are time coefficient, in unit of s^{-1}. Where I_0, n, τ_1, τ_2 are constants and $\eta = \exp\left[-(\tau_1/\tau_2)(n\tau_2/\tau_1)^{\eta/n}\right]$ is the peak correction factor.

According to MIL-STD-464A [3], the double-exponential function is defined as the mathematical expression of the lightning current. Considering the different developing stage of a lightning process, the lightning current is divided into six current components with different factors, as lists in Tabel 1.

Table 1 The lightning current components in MIL-STD-464A

Current Component	Description	$i(t) = I_0(\mathrm{e}^{-\alpha t} - \mathrm{e}^{-\beta t})$		
		I_0 /A	α / s^{-1}	β / s^1
I_1	Severe stroke	218 810	11 354	647 265
I_2	Intermediate current	11 300	700	2 000
I_3	Continuing current	400 for 0.5 s	Not applicable	Not applicable
I_4	Restrike	109 405	22 708	1 294 530
$I_4/2$	Multiple stroke	54 703	22 708	1 294 530
I_5	Multiple burst	10 572	187 191	19 105 100

Download English Version:

https://daneshyari.com/en/article/725708

Download Persian Version:

https://daneshyari.com/article/725708

Daneshyari.com