Random High Voltage Impulses Modeling for EMC Testing

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Abstract – **In this paper an analytic method for random high voltage impulses generating for EMC testing has been described. A statistical assessment of their distribution toward the electrical charge has been made in order to compare with the real physical surges and electric discharges.**

Keywords – **EMC, LEMP, Surge Protection.**

I. INTRODUCTION

Achieving high reliability of modern communication systems imposes the requirement for trouble-free operation in harsh environmental conditions. Much of this environment is dependent on natural factors. For example, a condition is imposed to ensure a device temperature is maintained by air conditioning systems or in certain cases, to take measures against damage from moisture, strong wind, icing, earthquakes etc. For analytical studies of such processes is appropriate to create relevant models and to implement and comply with standards to integrate as well as technical implementation and operation of the apparatus, and in simulating the processes of change resulting from natural factors, especially in construction phase.

When it comes to protection of electronic communication equipment from high voltage disturbances and effects of lightning strikes requirements are also established. Such are, for example, standards of the IEC [1] [2]. Different mathematical models of high disturbing pulses are considered [3] [4], in order to correctly simulate the processes "in case of LEMP" and achieve higher level of protection of electronic communication devices [5].

The purpose of this article is to evaluate the statistical ability to generate random high disturbing pulses with a specific mathematical model. The model could be used to simulate the behavior of communication equipment in situations when taking into account the stochastic nature of the parameters of this type of interference.

II. DESCRIPTION OF THE PROBLEM

A. Theoretical basis

High-voltage disturbing pulses are characterized by very steep climbing forefront and gradually fading rear front of the current in time. Standards have been adopted for different types of effects of lightning strikes, specifying the time duration of these fronts and amplitude value of current. Some of these are:

- 200 kA, 10/350 μs – for the first positive and negative direct hit of lightning to the ground;
- 50 kA, 0,25/100 μs – for subsequent hits;
- 10 kA, 8/20 μs – for secondary lightning strikes and switching surges.

For mathematical models describing the shapes of pulses exponential dependencies can be used. In work [3] the following formula is quoted:

$$I(t) = I_m k\left(e^{-\alpha t} - e^{-\beta t}\right) \tag{1}$$

where:

$I(t)$ – current value of the current;
I_m – amplitude value of the current;
k – normalized (scaled in amplitude) coefficient.

The shape of the curve is determined by the coefficients α and β.

In this study an attempt is made to achieve the modeling of the stochastic nature of high-voltage disturbing pulses, as using a step-exponential function of the type [6]:

$$I(t) = I_m.a.t^b.e^{-c.t} \tag{2}$$

In this case the shape of the curve depends on the coefficients b and c, and as using the coefficient a the amplitude of the pulse can be scaled. By changing these coefficients is possible to obtain the shapes of the curves of the current corresponding to the standard 10/350 μs, 0,25/100 μs and 8/20 μs, which is discussed in other publications of this team [7].

To take into account the random nature of high-voltage phenomena in nature a random number generators can be used. These generators set values to the coefficients of the mathematical models. Changing the form of pulses, on one hand leads to a difference in overall charges of each one, and on the other hand shifts the spectral distribution of the harmonic composition.

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B. Test Implementation

Ability to generate random pulses can be used in cases of simulation study of the behavior of the electronic communication equipment under close-to-real conditions. In such case it is necessary pulses to be generated with a maximum close distribution as occurred in nature.

To check whether the model (2) is able to generate trustworthy random pulses a statistical methods applied to the sample of the generated pulses can be used. Preliminary studies performed on model (1) showed that it doesn't give good results in a similar direction.

The generated pulses can be compared in their charge, which can be determined by the following relation:

$$Q = \int_{t=0}^{\infty} I(t).dt \,, \qquad (3)$$

as obtained by (3) charge is in coulombs. For the purpose of comparative study we can work with normalized charge, so the amplitudes of all pulses are equal. It can be assumed that:

$$I(t)_{\max} = 1 \,, \qquad (4)$$

which can be achieved by using the coefficient ***a***. In this case the unit charge will be for 1 coulomb per ampere (***C/A***), but it can be denoted ***q***.

A statistical evaluation of the resulting set of normalized charges has to be made. For this purpose we calculate the average value, the dispersion (variation) and the coefficient of variation respectively on dependencies (5) (6) and (7), where ***n*** is the number of random pulses in the sample.

$$\overline{q} = \frac{1}{n}\sum_{i=1}^{n} q_i \qquad (5)$$

$$\sigma_q = \frac{1}{n}\sum_{i=1}^{n}\left[\left|\left(q_i - \overline{q}\right)\right|\right] \qquad (6)$$

$$v_q = \frac{\sigma_q}{\overline{q}} \qquad (7)$$

To reflect plausible the actual distribution of occurrence of impulses to their charge, the model should generate random pulses that are unsymmetrically distributed to the mean value. In such cases the value of the coefficient of variation is significantly greater than 30%, so the normal (Gaussian) distribution is not applicable. Solution can be obtained by using the distribution of Veybul, which can be described as:

$$f(q) = \begin{cases} 0, & q < q_{\min} \\ \left(\frac{k_1}{k_2}\right).\left(\frac{q - q_{\min}}{k_2}\right)^{k_1 - 1}.\exp\left[-\left(\frac{q - q_{\min}}{k_2}\right)^{k_1}\right], & q > q_{\min} \end{cases} . \qquad (8)$$

The values of coefficients ***k₁*** and ***k₂*** are determined by the following formulas:

$$k_1 = 0{,}111186 + 0{,}835597\left(\frac{\overline{q}}{\sigma_q}\right) + 0{,}0759898\left(\frac{\overline{q}}{\sigma_q}\right)^2 ; \qquad (9)$$

$$k_2 = \frac{1}{n}\left(\sum_{j=0}^{n} q_j^{k_1}\right)^{1/k_1} . \qquad (10)$$

The probability of occurrence of pulses defined or greater amount of charge can be given with the dependency:

$$P(q) = \begin{cases} 1, & q < q_{\min} \\ \exp\left[-\left(\frac{q - q_{\min}}{k_2}\right)^{k_1}\right], & q > q_{\min} \end{cases} ; \qquad (11)$$

III. Results

Using the software environment MATLAB [8] simulations of the probability distribution obtained with the dependence (2) models of high-voltage disturbing impulses were made. Using a random number generator values are given to the coefficients ***b*** and ***c***, as Table I indicates the intervals of their variation.

TABLE I
COEFFICIENT VALUES

Coefficient	**10/350 µs**	**8/20 µs**	**Random**
b	0,145	2,78	0,145 ÷ 2,78
c	0,00325	0,26	0,00325 ÷ 0,26

In Table I the values of the coefficients ***b*** and ***c***, in case of pulses corresponding to the standard 10/350 μs and 8/20 μs, are shown. They are the boundary and the distribution of random values in these intervals is given by equal probability law.

Fig. 1 shows a family of randomly generated curves, for clarity of the image their number was reduced to 10. There are variously shaped pulses with different slope of the forefront and rear front respectively integrand area, respectively, different relative charge.

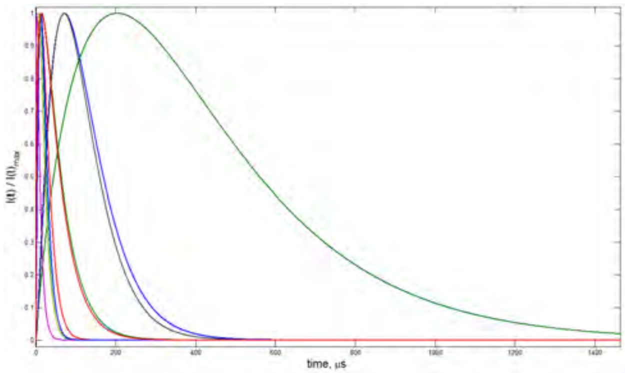

Fig. 1. Random Generated Impulses

To achieve credible data on the statistical analysis is necessary to sample a sufficiently large number of elements. In Table II are given values of average relative charge, dispersion (variation) and coefficient of variation when ***n = 10 000***, and minimum and maximum value of the relative charges.

TABLE II
STATISTICAL PARAMETERS

Parameter	**Value**	**Unit**
Mean Value	5,27	$x10^{-5}$, C/A
Standard Deviation	4,73	$x10^{-5}$, C/A
Coefficient of Variation	89,7	%
Number of impulses	10 000	-
Minimum value	5,46	$x10^{-6}$, C/A
Maximum value	1,09	$x10^{-3}$, C/A

Figure 2. shows the density of the probability distribution determined by formula (8) and the values of Table II. There is a minimum threshold of the relative charge below where no pulses are generated. From the perspective of a real physical process, this can be explained by the nature of the occurrence of disturbing impulses. In most cases they are the product of electrostatic discharge, that breakthrough occurs when they reach a certain critical value of the charge.

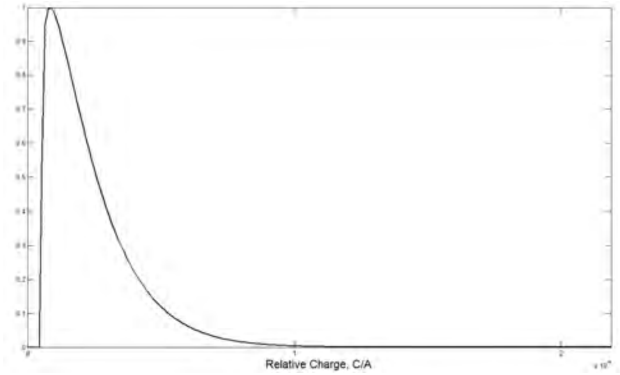

Fig. 2. Probability Density Function

There is a cluster of pulses with relative charges in a specific area, fairly close to the minimum, but there are a few others with significantly higher charges than average. This corresponds to the actual distribution of the disruptive signals in nature - in most cases disturbing impulses are relatively weak, but there also are extremely strong discharges (e.g. direct hit by lightning), under which the charge is significant.

Fig. 3 shows a graph of the probability distribution function of the relative charges. It can determine the probability of occurrence of disturbing impulse with relative charge greater than or equal to a certain value.

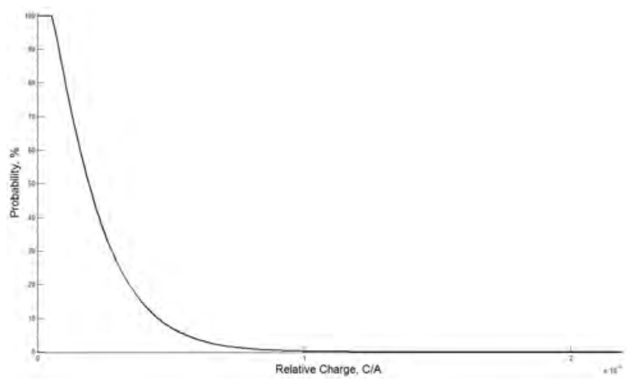

Fig. 3. Distribution Function

By using these results a pattern of disruptive impulses generated by lightning activity in certain geographic areas can be obtained. In Fig. 4. is presented a map showing the density of lightning activity worldwide, which was published in George M. Kauffman's [9] work about similar topic . A similar map is shown in the corporate material of SPINNER GmbH [10]. It shows the frequency of lightning falling, measured in number of lightenings per square kilometer per year. It is seen that the highest density regions are Central Africa, the Himalayas, the Caribbean and Indochina, where the density of lightning hits is in the range 50 ÷ 70 lightnings.km^{-2}.year^{-1}. For Bulgaria, this density is in the range 6 ÷ 10 lightnings.km^{-2}.year^{-1}.

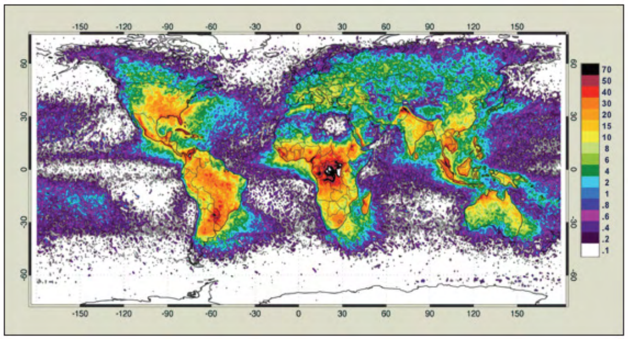

Fig. 4. Worlds Lightning Strike Density

Using the diagram of Fig. 3 the number of pulses with a relative charge greater than or equal to a value per square kilometer within one year can be determined. In Table III are given the relative charges of the three main types of disturbing impulses. The same table gives the average number of impulses exceeding that charge per square kilometer within one year and the average time between the occurrence of two pulses with exceeding relative charges per square kilometer. These values are calculated for Bulgaria.

TABLE III
YEAR LIGHTNING ACTIVITY

	10/350 µs	**0,25/100 µs**	**8/20 µs**
Relative charge, x10^{-4} C/A	4,399	1,326	0,166
Number of impulses for 1 km^2 per year	0,002	0,7	5,8
Time between impulses for 1 km^2, days	182 500	521	62

It is noted that the values for the period of occurrence of the disturbing pulses is large. On one hand, due to the fact that the probability of strong interference (e.g. direct hit by lightning) is significantly less than that of the weaker ones. On the other hand these Thunderstorms data have very general nature. It strongly depends on topography, soil and other factors and for more accurately determine the probabilities of occurrence of a specific impulse with relative charge more accurate statistics on lightning activity at the site should be used.

IV. CONCLUSION

From the foregoing it can be drawn:

- The mathematical model of high-voltage disturbing pulse described by dependence (2) can be used to generate random pulses to take into account stochastic character in nature;
- The probability distribution of occurrence of disturbing pulses to a particular relative charge meets the reality;
- It is appropriate to experimentally confirm the simulation results, and compared with actual statistics on lightning activity and its consequences.

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