Determination of discharge current equation parameters of ESD using genetic algorithms

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In the literature there is an absence of an accurate equation describing the current of the electrostatic discharge (ESD) phenomenon. Reported, is a method that is a genetic algorithm, which having as input data current measurements from ESD generators optimises the parameters of the discharge current's equation.

Introduction: The IEC 61000-4-2 Standard [1] has an aberration between the typical waveform of the output current of the electrostatic discharge (ESD) generator and the discharge current that the ESD generator of the Standard produces in reality. This fact has as a result computer simulations for the circuit defined in the Standard to insert an error in the calculated voltages and currents. This problem can be solved by introducing either a new circuit of the ESD generator or an ESD current source, where the produced current waveform is a function of a number of parameters. In the work reported in this Letter the second way has been followed and the minimisation of the parameters of the current discharge equation is obtained, using genetic algorithms (GA). The GA is applied on four different types of equations.

A well-known equation, which does not correspond to the discharge current, but is used in the further analysis for the application of the GA, is the equation of the lightning current given by the following equation:

$$i(t) = i_0 \cdot \left(e^{-t/t_1} - e^{-t/t_2}\right) \tag{1}$$

where i_0 is current in amperes, and t_1, t_2 are time constants in nanoseconds.

A first approximate equation of the discharge current for commercial simulators was first introduced by [2] using a double exponential function:

$$i(t) = i_1 \cdot e^{-t/t_1} - i_2 \cdot e^{-t/t_2} \tag{2}$$

where i_1, i_2 are current in amperes, and t_1, t_2 are time constants in nanoseconds. The reference waveform for the discharge current according to [3] is:

$$i(t) = A \cdot e^{-(t-t_1/\sigma_1)^2} + B \cdot t \cdot e^{-(t-t_2/\sigma_2)^2} \tag{3}$$

The factors $A \cdot e^{-(t-t_1/\sigma_1)^2}$ and $B \cdot t \cdot e^{-(t-t_2/\sigma_2)}$ represent the narrow and broad Gaussian, respectively.

In [4] the referred waveform is given by the formula:

$$\begin{aligned} i(t) = {} & i_1 \cdot \frac{(t/\tau_1)^n}{1+(t/\tau_1)^n} \cdot e^{1/\tau_2\left[\tau_1(n\tau_2/\tau_1)^{1/n}-t\right]} \\ & + i_2 \cdot \frac{(t/\tau_3)^n}{1+(t/\tau_3)^n} \cdot e^{1/\tau_4\left[\tau_3\left(n\tau_4/\tau_3\right)^{1/n}-t\right]} \end{aligned} \tag{4}$$

where i_1, i_2 are currents in amperes, T_1, T_2, T_3, T_4 are time constants in nanoseconds and n signifies how many times the equation can be differentiated with respect to time. Here we assume that $n = 3$.

Experimental setup: The measurement system used was in accordance with the Standard [1] and provides high fidelity data. The current for a charging voltage of 4 kV was measured by a four-channel Tektronix oscilloscope model TDS 7254B. An ESD generator, model NSG-438 of Schaffner, was producing contact discharges and it was grounded to the earth via a ground strap. To measure the current a resistive load known as the Pellegrini target (MD 101 of Schaffner) was placed in the centre of a grounded metal plane with dimensions 1.5 × 1.5 m. The Pellegrini target was connected to the oscilloscope by a HF coaxial cable and an attenuator. The measurements were conducted in an anechoic chamber so that the measurement system was unaffected by the surrounding equipment and the cables were set away from the discharge point. To minimise the uncertainty of the position of the ground strap into the GA application the ground strap was at a distance 1 m from the target as the Standard defines and the loop was as large as possible.

Application of GA: The GA has been used in the past and produces excellent results for computation of parameters of the earth structure [5]. A careful selection of the experimental data has to be made. In this application, the use of the GA does not require the use of the whole measured data; this would be not only a time consuming procedure, but does not give more accurate solutions than using properly selected measured data and applying a greater number of parents and iterations. For computation of the parameters for each equation the minimisation of the function F_g is necessary. F_g is given by the following equation:

$$F_g = \sum_{i=1}^{N} \frac{\left|I_i^m - I_i^c\right|}{I_i^m} \tag{5}$$

where I_i^m is the ith measured value of the discharge current. I_i^c is the computed value of the discharge current for the unknown parameters of (1)–(4)

The waveforms' points have been selected as follows: from 0 to 5 ns all the measured points (51 points) have been used, while for 5 to 100 ns the stepwidth was equal to $3(1 + \text{round}(\exp(j/N))$ (92 points), where j is the jth point of the measured data of 1000 points. This was done in order that the GA takes all the measured points at the first 5 ns, and in order that the initial nanoseconds of the discharge current be treated as the most important part of the waveform owing to the fact that most of the radiation and the largest values of the current derivative occur during this period.

Results: In Fig. 1 common graphs of the experimental data of the discharge current and the discharge current for the optimised parameter values for (1)–(4) are depicted.

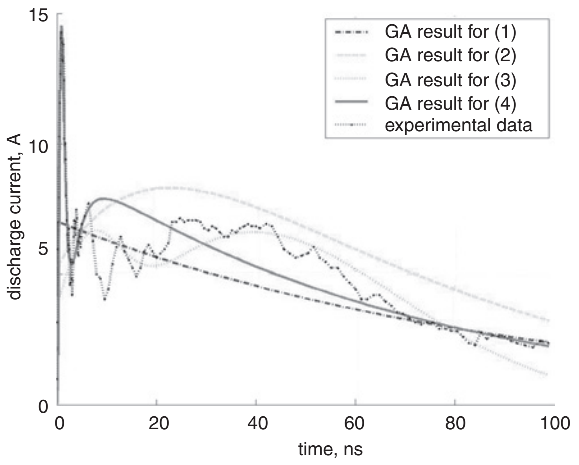

Fig. 1 *Curve comparison between experimental data of discharge current and discharge current for optimised parameter values of (1)–(4)*

The optimised parameters for each equation are as follows: for (1) $i_0 = 7.03$ A, $t_1 = 91.80$ ns, $t_2 = 0.12$ ns and $F_g = 28.24$; for (2) $i_1 = 21.17$ A, $i_2 = 15.93$ A, $t_1 = 53.97$ ns, $t_2 = 21.71$ ns and $F_g = 27.21$; for (3) $A = 4.95$ A, $B = 0.27$ A, $t_1 = 5.18$ ns, $t_2 = 1.62$ ns, $\sigma_1 = 9.78$, $\sigma_2 = 54.72$ and $F_g = 28.87$; and for (4) $i_1 = 17.46$ A, $i_2 = 7.81$ A, $t_1 = 0.75$ ns, $t_2 = 0.82$ ns, $t_3 = 3.43$ ns, $t_4 = 68.70$ ns and $F_g = 22.91$. Comparing the error (F_g) for each equation it can be concluded that the equations can be sorted as follows: (4) → (2) → (1) → (3), with (4) giving the best result.

Comparing the curves of Fig. 1 it is obvious that the equation which has the best fitting to the experimental data is (4). This is the most suitable of all the examined equations since it simulates the discharge current in the best way. The second more suitable equation, (2), cannot simulate the first peak of the discharge current, however it can calculate accurately the parameters of the double exponential function. Equation (3) has a shape similar to the experimental results, but inserts a higher error.

Conclusions: A methodology based on a GA is proposed to calculate the parameters of the discharge current, produced by an ESD generator. The calculated discharge current is very close to the current that is measured. Evaluation of the equations and the sampling rates has shown that they can be sorted as follows: (4) → (2) → (1) → (3). Equation (4) has the best behaviour. Therefore, a current source, which produces the ESD current of (4), is better for use than the ESD generator circuit described by IEC 61000-4-2. This equation could be included in the next revision of the Standard.

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References

1 International Standard IEC 61000-4-2: ‘Electromagnetic Compatibility (EMC), Part 4: Testing and measurement techniques, Section 2: Electrostatic discharge immunity test – Basic EMC Publication’, 1995

2 Cerri, G., Leo, R., and Primiani, V.M.: ‘ESD indirect coupling modelling’, *IEEE Trans. Electromagn. Compat.*, 1996, **38**, (3), pp. 274–281

3 Berghe, S.V., and Zutter, D.: ‘Study of ESD signal entry through coaxial cable shields’, *J. Electrost.*, 1998, **44**, pp. 135–148

4 Wang, K., Pommerenke, D., Chundru, R., Doren, T.V., Drewniak, J.L., and Shashindranath, A.: ‘Numerical modeling of electrostatic discharge generators’, *IEEE Trans. Electromagn. Compat.*, 2003, **45**, (2), pp. 258–270

5 Gonos, I.F., and Stathopulos, I.A.: ‘Estimation of multi-layer soil parameters using genetic algorithms’, *IEEE Trans. Power Deliv.*, 2005, **20**, (1), pp. 100–106