High Voltage Pulses for Surge Protection

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ABSTRACT: *We have provided a detailed analysis of the high voltage pulses to understand the surge protection. We have applied a few metrics such as the frequency and occurrence probability of residual pulses with energy is explained. The probalistic terms based comparison of many protective devices is described in this work.'*

Keywords: Surge Protection, QWS, Random Impulses

Received: 17 May 2022, Revised 29 August 2022, Accepted 7 September 2022

DOI: 10.6025/jitr/2022/13/4/85-91

1. Introduction

In today's world of complex communication systems it is of great importance to closely observe these systems in order to achieve high availability and reliability in the phases of their design and construction. To have robust analytical tools, with which to analyze the processes that pose a threat to the operation of the equipment, is an important element in simulation optimizations of communication devices. There are many processes and each of them requires special methods for its reading.

To a large extent communication equipment is standing on the basis of electronic technologies and therefore a serious threats appear such as electrostatic discharges, switching surges and consequences of lightning strikes. There are numerous standards [1] [2] [3] in this part of the electromagnetic compatibility, which define high-voltage test pulses, conditions for research, etc. However, the search for more precise models for these processes can lead to a better optimization of the devices.

This article reviews a simulation evaluation of the safety features of QWS protective devices. A special methodology is used. It includes generation using a mathematical model of random interference pulses in order to demonstrate the stochastic nature of electrostatic discharges in the nature.

2. Description of the Problem

2.1. Theoretical Basis

High-voltage interference pulses are characterized by a steep climb front and a relatively smooth fading rear edge of the current over time. Standards have been adopted for different types of effects of electrostatic discharges, lightning strikes and switching surges that specify duration of these fronts and the amplitude value of the current over time. Some of them are:

• 200 kA, 10/350 µs – the first positive and negative direct strikes of lightning to the ground;

• 50 kA, 0,25/100 µs – for subsequent strikes;

• 10 kA, 8/20 µs – for secondary lightning strikes and switching surges.

In other studies [4] [5] exponential formulas of a mathematical model are given. These formulas describe the waveforms over time *t*, as:

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

where:

$I(t)$ – current value of the current;

I_m – the amplitude value of the current;

k, α and β – coefficients determining the type of the pulse.

In other publications, the authors of the present article, [6] [7] proposed the following model:

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

in [7] is considered the possibility of using randomly determined values of the parameters *a, b* and *c* to generate high-voltage interference pulses that show the stochastic nature of electrostatic discharges in nature. The generation of random form of pulses leads to a difference in the total charge on each of them, as well as to changes in their spectral composition which can be determined by applying the Fourier transform to the already obtained by (2) disturbing pulse:

$$I(f) = \boldsymbol{F}\{I(t)\} \qquad (3)$$

In most cases, the antenna's QWS protective devices can be considered as filters omitting frequencies of operating signals of the respective radio communication systems, and ground all other frequency components. The input impedance for connection to antenna's feeder is frequency-dependent and can be determined by the relation:

$$Z(f) = \frac{Z_{QWS}(f).Z_c}{Z_{QWS}(f).Z_c}, \qquad (4)$$

Where by Z_c is indicated the nominal wave impedance of the feeder, and by $Z_{QWS}(f)$ – the frequency-dependent impedance of shunt protective device. In consequence $Z_{QWS}(f)$ has significantly bigger values for various frequencies, the flow of disturbing currents $I(f)$ will lead to the emergence of a residual impulse the spectral distribution of voltage of which can be described by the following relation:

$$U_{QWS}(f) = I(f).Z(f), \qquad (5)$$

Quantitative performance of the safety devices can be evaluated by analyzing various parameters of the residual signal, such as its energy, amplitude, etc. The residual impulse can be obtained by using the reverse Fourier transform:

$$U_{QWS}(t) = \boldsymbol{F}^{-1}\{U_{QWS}(f)\} \tag{6}$$

If analysis of a QWS protective device is performed using multiple randomly generated interference pulses, a statistical criteria for evaluating the effectiveness of protection using a residual impulse with a higher energy than a given value, occurrence of pulses with a given energy, etc, can be determined. To define the energy of the residual impulse the following can be used:

$$E = \frac{U_{RMS}^2}{Z_c}.T \tag{7}$$

where U_{RMS} is the effective value of residual voltage impulse $U_{QWS}^{(t)}$ with duration T.

2.2. Test Implementation

Figure 1 shows the block diagram of the algorithm for analytical study of the effectiveness of QWS protective devices with help of random high-voltage pulses. The random number generator sets values for the coefficients b and c of the model (2), with the coefficient a is achieved a normalization of the amplitudes of the interference pulses to the same value, in order to make a comparative analysis of the response of the protective device at different pulse forms. Then on the generated impulses the Fourier transform of (3) is applied and after the application of the impact of protection device according to the relationship (5) is applied a reverse Fourier transform using (6) to determine the type of the residual pulse.

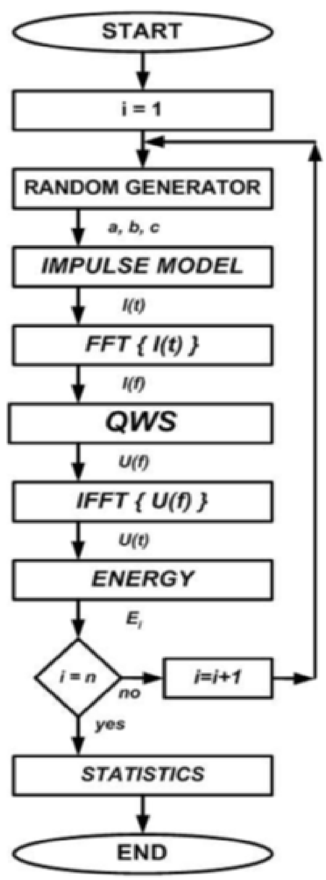

Figure 1. Block Diagram of the Algorithm

The described processes are repeated until a predetermined number of pulses n is reached, and after each iteration the energy of the residual impulse is determined by (7). By performing statistical analysis on the set of values E_i of the energy of the residual impulse, the probability of occurrence of a residual pulse with a given energy can be determined. For this purpose are calculated the mean value, the variance and the coefficient of variation respectively (8), (9) and (10), where n is the number of pulses in the random sample.

$$\overline{E} = \frac{1}{n}\sum_{i=1}^{n} E_i \tag{8}$$

$$\sigma_E = \frac{1}{n}\sum_{i=1}^{n}\left[\left|\left(E_i - \overline{E}\right)\right|\right] \tag{9}$$

$$v_E = \frac{\sigma_E}{\overline{E}} \tag{10}$$

In order to show the actual distribution of occurrences of pulses to their energy correctly, the model should generate random pulses which are asymmetrical with respect to the average distribution. The residual pulse should also have similar distribution. In such cases, the value of the coefficient of variation is much greater than 30%, wherein the normal (Gaussian) distribution cannot be applied. Solution can be found using the Weibull distribution, which can be described by the relation:

$$f(E) = \begin{cases} 0, \quad E < E_{\min} \\ \left(\frac{k_1}{k_2}\right).\left(\frac{E - E_{\min}}{k_2}\right)^{k_1 - 1}.\exp\left[-\left(\frac{E - E_{\min}}{k_2}\right)^{k_1}\right], \quad E > E_{\min} \end{cases} \tag{11}$$

The values of the coefficients k_1 and k_2 are determined by the formulas:

$$k_1 = 0{,}111186 + 0{,}835597\left(\frac{\overline{E}}{\sigma_E}\right) + 0{,}0759898\left(\frac{\overline{E}}{\sigma_E}\right)^2; \tag{12}$$

$$k_2 = \frac{1}{n}\left(\sum_{j=0}^{n} E_j^{k_1}\right)^{1/k_1} \tag{13}$$

The possibility of occurrence of residual pulses with equal or bigger amount of energy can be found using the following:

$$P(E) = \begin{cases} 1, \quad E < E_{\min} \\ \exp\left[-\left(\frac{E - E_{\min}}{k_2}\right)^{k_1}\right], \quad E > E_{\min} \end{cases}; \tag{14}$$

3. Results

Using the MATLAB [8] software, simulations of the probable distribution of residual impulses by using the algorithm specified in Fig. 1 had been made. To set the values of the coefficients b and c during the generation of highvoltage disturbing pulses a random number generator had been used. Table I indicates the intervals of their variation, as they meet the standardized pulses of first positive and negative direct lightning strike to the ground and secondary lightning strike and switching surges. By using the coefficient a of model (2) normalizing of the amplitudes of the pulses to a value 2kA had been made. With such value of the peak current a lot of laboratory data of manufacturers of antenna protective devises around the world can be found, for example refer to [9] [10].

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

Table 1. Coefficient Values

An analytical study of the effectiveness of two types of QWS protective devices had been made:

• Conventional market QWS protective device designed to protect the antenna inputs of base stations of cellular mobile system standard GSM 900;

• QWS protective device with elements of fractal branched structure developed by the participants in this authors team, which is intended to protect the antenna inputs of base stations of cellular mobile systems working simultaneously on standards GSM 900 and GSM 1800.

For achieving a credible evidence from the statistical analysis it is necessary to make a sample with a sufficiently larger number of elements. In Table 2 are listed the values of the average energy of residual pulses, the variance and the coefficient of variation for n = 5000 with the minimum and maximum values for the energy of the residual pulses in the study of both QWS protective devices.

It should be noted that the average values of the energy of the residual pulses of the tested protective devices is different from

Parameter	Value		Unit
	Standard QWS device for GSM 900	Fractal QWS device for GSM 900 & GSM 1800	
Mean Value	3 942,91	727,69	μJ
Standard Deviation	6 460,46	1222,01	μJ
Coefficient of Variation	163,85	167,93	%
Number of impulses	5 000	5 000	-
Minimum value	0,69	0,11	μJ
Maximum value	51 948,26	13 903,54	μJ

Table 2. Statistical Parameters

the values quoted by manufacturers such as [9] and [10] for 8/20μs pulse with amplitude 2kA. Both these companies provide values for the energy of residual impulse, respectively 5μJ and 7μJ, for devices designed to work under the standards GSM 900 and GSM 1800. This is due to the algorithm which generates high-voltage disturbing pulses which have considerably big charges.

Figure 2. shows the density of the probability distribution defined by formula (11) and the values of Table II for the two analysed protective devices.

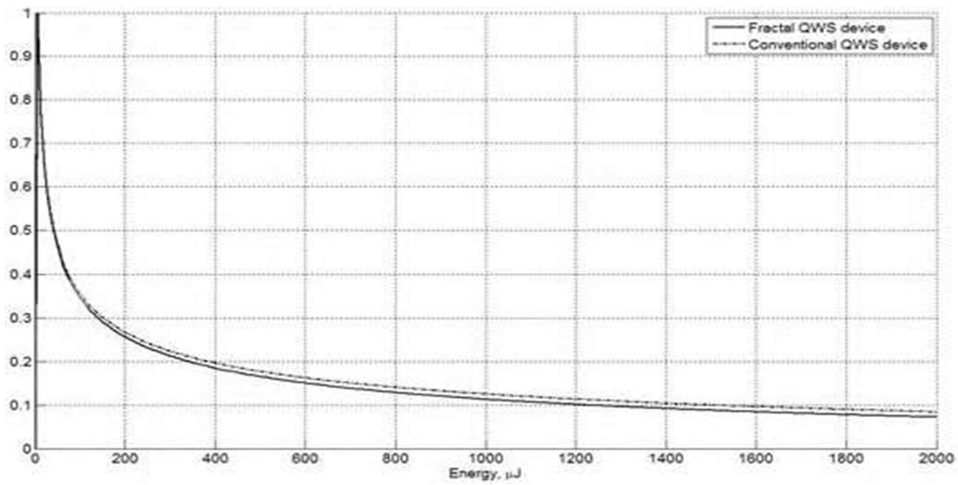

Figure 2. Probability Density Function

Figure 3. gives information about the probability of occurrence of residual pulses with greater energy than the two studied QWS protective devices determined by formula (14).

From the same figure it can be seen that the probability function in a fractal branching QWS protective device is positioned lower than that of the conventional device, which corresponds to a higher efficiency of the protection of highvoltage interference pulses.

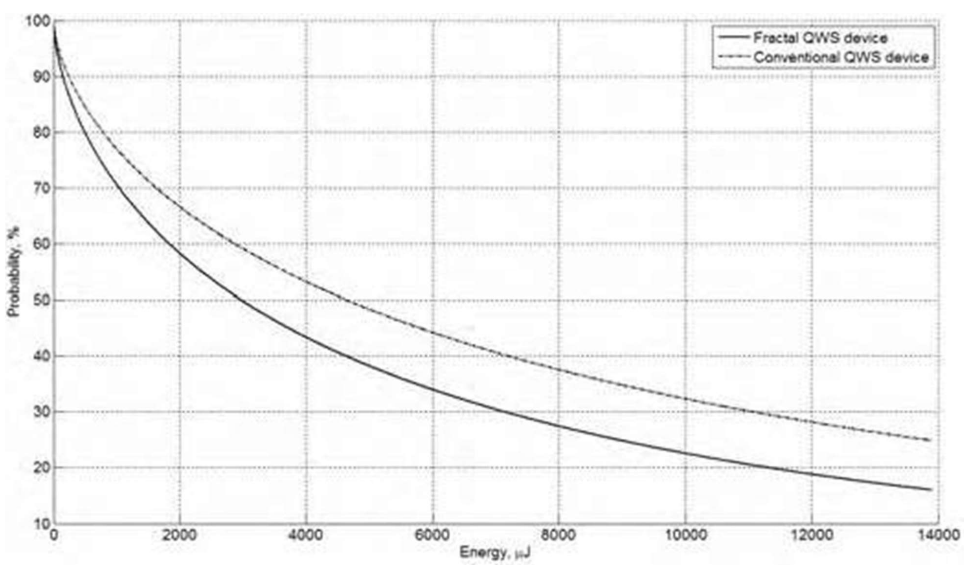

Figure 3. Probability Function

4. Conclusion

From the foregoing, the following conclusions can be drawn:

- The proposed algorithm in this paper used for analysing the QWS protective devices, provides very good results and takes into account the stochastic nature of high-voltage discharges in nature;

- The suggested by the authors branched fractal QWS protective device have high efficiency;

- It is appropriate to make an experiment to confirm the effectiveness of the branched fractal QWS protective device, revealed by the simulation results.

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