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Assessment of probability of damage of an apparatus protected by a surge protective devices system

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ABSTRACT

This paper deals with the efficiency of a coordinated system of surge protective devices (SPD), which is indicated by the IEC standard 62305 as typical protection measure for electrical and electronic apparatus against surges due to lightning. For practical applications, the probability of a given SPD system to reduce the risk of failure of apparatus is a key point for its proper selection and installation. The paper aims to give the rationale for the evaluation of such probability and shows application examples of different types of SPD systems in the case of direct lightning stroke to the structure (source of damage S1).

Introduction

Failure of electrical and electronic systems within a structure can be caused by surges arising from different sources of damage [1], namely: direct flashes to the structure (source of damage S1), flashes to ground nearby the structure (source of damage S2), flashes to power and communication lines connected to the structure due to flashes to and near the lines (sources of damage S3 and S4).

The typical protection measure suggested by the standard [2] is a coordinated system of surge protective devices (SPD). The probability of a given SPD system to reduce the risk of failure of apparatus is a key point for their proper selection and installations within a structure.

In this subject, it is essential to know the stress, in terms of energy and current, which an SPD will experience under surge conditions at its installation point.

In fact the probability P_{SPD} that a surge will damage an apparatus protected by an SPD system, is associated to the probability that, at the installation point, the expected charge overcome the one tolerable by the SPD system and to the probability that the SPD system protection level is lower than or equal to the impulse withstand voltage level of apparatus.

The expected stresses, which an SPD system will experience, have been evaluated in [3,4].

Aim of the paper is to give the rationale for evaluating the coordinated SPD system characteristics in order to reduce the probability of damage of electrical and electronic equipment within a structure against lightning surges.

Types of SPD systems

As known, two main types of SPD are used for the protection against lightning surges of electrical and electronic equipment within a structure, namely switching type SPD (spark gap) and limiting type SPD (varistors).

Advantages and disadvantages of both types of SPD are well known; the limiting type SPD are typically used alone (SPD1) for the protection of equipment, or as a system with SPD1 switching type and SPD2 limiting type or as a system with both SPD1 and SPD2 limiting type.

Therefore, three cases of SPD systems may be considered:

- SPD system type L – Consists of only one SPD, typically a limiting type SPD;
- SPD system type SL – Consists of SPD1 switching type + SPD2 limiting type;
- SPD system type LL– Consists of SPD1 limiting type + SPD2 limiting type.

The types of SPD system that can be used depend on the source of damage against which protection is required; in particular:

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– Type L SPD system is suitable for sources S2, and S4, but it can also be used for source S3 in some cases.
– Type SL or type LL SPD system is to be used for sources S1 and, in many cases, for source of damage S3.

Terms and definitions

For the purposes of this paper the following terms and definitions apply:

– I_{SPD} is the expected current flowing through SPD at its installation point of SPD.
– I_{imp} is the rated current (10/350 μs waveshape) for class I test SPD.
– I_n is the nominal current (8/20 μs waveshape) for class II test SPD.
– I_{max} is the maximum discharge current (8/20 μs waveshape) for class II test SPD.
– Q_{SPD} is the charge associated to I_{SPD}.
– Q_{imp} is the charge associated to the current I_{imp}.
– Q_{max} is the charge associated to the current I_{max}.
– U_{SPD} is the voltage across SPD when the current I_{SPD} is discharged.
– U_p is the voltage across SPD when the current I_{imp} or I_n is discharged (SPD protection level).
– U_l is the voltage at the terminals of the apparatus to be protected.
– U_w is the rated impulse withstand voltage of the apparatus to be protected.

Probability P_{SPD} evaluation

Failure of an apparatus protected by an SPD system can occur either if:

(a) the protection voltage U_{SPD} is exceeding the required protection level U_{pr} of the SPD; or
(b) the energy associated to the current I_{SPD} is exceeding the value tolerated by the SPD.

The probability P_{SPD} that an overvoltage will damage an apparatus protected by an SPD system is the probability that both condition (a) and condition (b) will occur, being:

– P_{SPDa} the probability associated to condition (a).
– P_{SPDb} the probability associated to condition (b).

Condition (a) will occur if the value of U_{SPD} exceeds the protection level U_{pr} of the SPD, required to limit the voltage U_l at the terminals of the apparatus to be protected at values not higher than its rated impulse withstand voltage U_w, taking into account:

– the inductive voltage drop ΔU on the leads/connections of the SPD,
– the effects of surge traveling along the protected circuit,
– the overvoltage U_i induced by lightning current in the protected circuit.

Condition (a) may be expressed by:

$$U_{SPD} > U_{pr} \tag{1}$$

or in terms of currents:

$$I_{SPD} > I_{pr} \tag{2}$$

being I_{pr} the current relevant to required protection level U_{pr}. If the value of current I_{pr} is equal to the nominal current I_n of SPD ($I_{pr} = I_n$), then the required protection level U_{pr} is equal to the nominal protection level U_p of the SPD ($U_{pr} = U_p$).

The needed protection level U_{pr} of an SPD can be evaluated as reported in [2,5].

Condition (a) should be verified with reference to the subsequent strokes of negative flashes, which represent the most severe case, as discussed in [5].

Condition (b) will occur if the charge Q_{SPD} associated to I_{SPD} exceeds the tolerable one by the SPD.

Consider that the charge for unit of current associated to the standard current 10/350 μs is $Q_{imp} = 0.5$ C/kA and that the one associated to the standard current 8/20 μs is $Q_n = 0.027$ C/kA, condition (b) becomes:

– ***for SPD tested with I_{imp} (class I test)***

$$Q_{SPD} > Q_{imp} = I_{imp}/2 \tag{3}$$

– ***for SPD tested with I_n (class II test)***

$$Q_{SPD} > Q_{max} = I_{max}/37 \tag{4}$$

Because typically $I_{max} = 2 \times I_n$, Eq. (4) could be written as follows:

$$Q_{SPD} > Q_{max} = I_n/18.5 \tag{5}$$

Condition (b) should be verified with reference to the positive strokes, which represent the most severe case, as discussed in [5].

Therefore the probability P_{SPD} is given by:

$$P_{SPD} = 1 - (1 - P_{SPDa}) \cdot (1 - P_{SPDb}) \tag{6}$$

The probability P_{SPDa} that the value of U_{SPD} exceeds the required protection level U_{pr}, relevant to the current I_{SPD} of the SPD, is the probability that, for the subsequent stroke of negative flashes, I_{SPD} exceed I_{pr}.

Assuming that P_{SPDar} is the probability relevant to an SPD with $I_{pr} = I_{SPD}$, SPD with $I_{pr} > I_{SPD}$ will have P_{SPDa} values lower than P_{SPDar}; SPD with $I_{pr} < I_{SPD}$ will have P_{SPDa} values higher than P_{SPDar}.

The value of P_{SPDa} relevant to SPD is obtained from cumulative frequency distribution of lightning current relevant to the subsequent stroke of negative flashes, as shown in Fig. 1 (IEC 62305-1), in correspondence to the values of the current I which makes $U_p = U_{pr}$ taking into account:

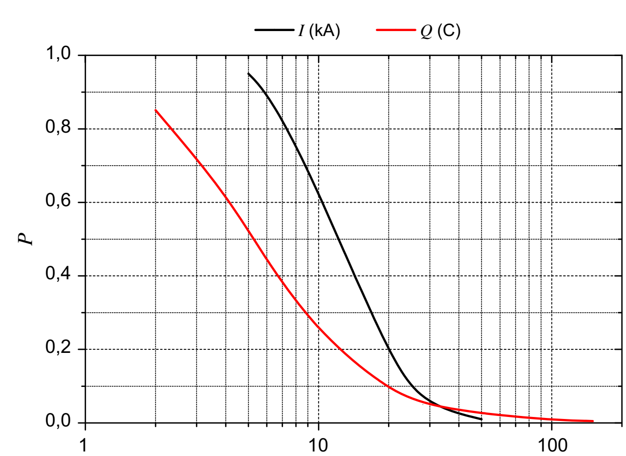

Fig. 1. Cumulative frequency distribution of lightning current I relevant to subsequent stroke of negative flashes and of lightning charge Q relevant to positive and negative first stroke.