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SURGE PROTECTIVE DEVICES SELECTION FOR TRUE INSTALLATIONS

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ABSTRACT

This paper intends to show how to select SPDs in practical applications when standards only gives general rules. This addresses the selection of voltage protection level Up and the value of current Iimp. Based on these two values an SPD can be determined and appropriate selection of these two parameters is then important. IEC 62305-2 allows to determine the Lightning Protection Level (LPL). Based on this, the current circulating inside an SPD can be determined using simple calculation or a more sophisticated one. Based on the LPL, the probability of protection of the SPD can also be determined and this is related to the current withstand of the SPD and also to its voltage protection level even if this last parameter is less easy to assess in spite of being fundamental.

1 INTRODUCTION

Selection of Surge Protective Devices is based on numerous criteria linked to the electrical installation (short-circuit current, withstand of equipments, surges ...) but also on parameters sometimes more difficult to appreciate.

For example, the risk management as per IEC/EN 62305-2 [1] may lead to lightning level of protection greater than one but the standard remains very vague on the way to select an SPD in such a case.

Surge withstand of equipment (insulation, no dangerous sparking ....) is addressed in the standards but immunity, as important as insulation for the user is not pushed forward except in some standards such as BS EN 62305-2.

Even when selection of SPD based on current is concerned, trend is to select an equal sharing of current between earthing system and the connected lines. However, this is based on the assumption that the earthing impedance is good (conventional earthing impedance) which is not always the case.

62305-1 standard gives in annex E a formula to calculate more accurately the current sharing and the current actually passing through SPDs based on earthing impedance and soil resistivity.

Based on various earth impedance measurements made in field in various soil environment, the SPD current withstand is presented and it can be seen that the needed surge withstand is generally greater than the one given by the simplified formula 50%/50%. In the particular connection scheme of SPD named C2 in the IEC 61643-12 standard (SPD connected between phases and neutral and between neutral and earth) it is even sometimes difficult to find SPDs able to withstand this current requirement between neutral an earth.

2 SELECTION OF SPDS BASED ON VOLTAGE PROTECTION LEVEL AND EQUIPMENT SURGE WITHSTAND

IEC/EN 62305-2 [1] is offering the possibility to provide protection, and thus risk reduction, by using better SPDs than regular SPDs.

But first of all, what is a regular SPD ? At the entrance point of the installation, it is an SPD which has a surge current withstand obtained by calculation based on the lighting protection level. The simplest calculation assumes that 50% of current will flow through the local earth and that 50% will flow through services including power lines and metal pipes. It is assumed that current will share equally between the various path and that inside a single path current split equally between the various conductors.

But, SPDs are defined by current and voltage. Current is then defined based on lightning protection level as presented above but how is defined the voltage ?

The key parameter for selection of an SPD is the voltage protection level Up. Up is, in that standard, related to the rated impulse withstand voltage level Uw of equipment (see [2] for more details). The equipment with the lowest impulse withstand defines the impulse withstand of the zone and is the basis for selection of Up. Values for Uw are defined in various table of [1] and are related to 230/400 V networks : 1,5 kV - 2,5 kV, 4 kV and 6 kV.

In fact, these values are connected to overvoltage categories that are defined within electrical installations for the purpose of insulation coordination and a related classification of equipment with impulse withstand voltages is provided.

Table 1 : Impulse withstand Uw and installation categories.

Nominal voltage of the installation V	Required rated impulse withstand voltage of equipment kV			
	Impulse withstand category IV	Impulse withstand category III	Impulse withstand category II	Impulse withstand category I
230/400 277/480	6	4	2,5	1,5
400/690	8	6	4	2,5

The rated impulse withstand voltage is an impulse withstand voltage assigned by the manufacturer to the equipment or to a part of it, characterizing the specified withstand capability of its insulation against overvoltages.

The impulse withstand voltage (overvoltage category) according to [3] is used to classify equipment energized directly from the low voltage electrical installation. Impulse withstand voltages for equipment selected according to the nominal voltage are provided to distinguish different levels of availability of equipment with regard to continuity of service and an acceptable risk of failure. By selection of equipment with a classified impulse withstand voltage, insulation co-ordination can be achieved in the whole installation, reducing the risk of failure to an acceptable level.

Equipment corresponding to overvoltage category IV is suitable for use at, or in the proximity of, the origin of the installation, for example upstream of the main distribution board. Equipment of category IV has a very high impulse withstand capability providing the required high degree of reliability. Examples of such equipment are electricity meters, primary overcurrent protection devices and ripple control units.

Equipment corresponding to overvoltage category III is for use in the fixed installation downstream of, and including the main distribution board, providing a high degree of availability. Examples of such equipment are distribution boards, circuit-breakers, wiring systems (including cables, bus-bars, junction boxes, switches, socket-outlets) in the fixed installation, and equipment for industrial use and some other equipment, e.g. stationary motors with permanent connection to the fixed installation.

Equipment corresponding to overvoltage category II is suitable for connection to the fixed electrical installation, providing a normal degree of availability normally required for current-using equipment. Examples of such equipment are household appliances and similar loads.

Equipment corresponding to overvoltage category I is only suitable for use in the fixed installation of buildings where protective means are applied outside the equipment – to limit transient overvoltages to the specified level. Examples of such equipment are those containing electronic circuits like computers, appliances with electronic programmes, etc. Equipment with an impulse withstand voltage corresponding to overvoltage category I shall not have direct connection to a public supply system.

Normally, as sensitive equipment should not be directly at the entrance of installation, the Up of the SPD used at entrance for equipotential bonding purpose, should then be compatible with a Uw of 2,5 kV or even in some circumstances of 4 kV, provided another SPD is used downstream to protect equipment. What means "compatible". It is generally assumed that an SPD properly installed as per [4] and [2] needs a 20% margin compared to Uw. This margins could be bigger, if the SPDs is far from equipment to protect (> 10 m), if there is a large loop between SPD and equipment or if lead length is greater than 50 cm. Assuming the installation complies in full with standards and 20% margin will be enough and the "regular" SPD at the entrance will have a Up ≤ 2 kV and a current Iimp defined by the sharing of current.
The standard [1] gives the following table and note.

Table 2 : Extract from IEC 62305-2.

LPL	P_{SPD}
No coordinated SPD protection	1
III – IV	0,03
II	0,02
I	0,01
Note 1	0,005 – 0,001

"*Note 1 : Smaller values of* P_{SPD} *are possible in the case of SPDs having better protection characteristics (higher current withstand capability, lower protective level, etc.) compared with the requirements defined for LPL I at the relevant installation locations."*

It seems reasonably accepted that when a lightning level of protection greater than 1 is needed, surge withstand is no more the relevant parameter. For example at level 1, it already takes into account a 200 kA impulse. What should be the benefit to increase the level of withstand current of SPDs when the installation is already defined for the maximum current ? The voltage level of protection Up becomes then the key parameter and for the 230/400 V network should be below 2 kV : for example a typical value is 1,5 kV for such SPDs. This of course, depends also on the earthing of the system (IT, TN, TT).

The main question is to create a link between the probabilities 0,005 and 0,001 given in [1] and Up of SPDs. It should better than 2 kV. If we link 1,5 kV (almost the bottom value for SPDs Type 1 - tested with 10/350 wave - as per today's technology) to the lowest probability 0,001 at which value of Up should we relate the probability 0,005 ? There is no clear and general answer to this question, so fundamental be it.

The problem is even more complex. Uw is related to surge withstand between active conductor (phase and neutral) and earth so it is a safety concern. But equipment can also be degraded (and not destroyed) by a lack of immunity. This is an EMC concern and value for EMC for the same 230/400 kV system are defined as 4 kV – 2 kV, 1 kV and 0,5 kV. These values are much lower and may apply line/neutral to earth and also line to neutral.

Immunity is generally excluded from lightning protection business as malfunction is excluded from the scope of [3] as can be seen in the introduction of this standard "*Malfunctioning of electrical and electronic systems is not covered by the IEC 62305 series. Reference should be made to IEC 61000-4-5*".

BS version of 62305-2 [5] is proposing a solution, with an extended table and note compared to 62305-2.

Table 3 : Extract from BS EN 62305-2.

LPL	P_{SPD}	P_{SPD}*(see note 2)
No coordinated SPD protection	1	1
III – IV	0,03	0,003
II	0,02	0,002
I	0,01	0,001

"*Note 2 Smaller values of P_{SPD} (P_{SPD}*) are possible where SPD's have lower voltage protection levels (UP) that further reduce the risks of injury to living beings, physical damage and failure of internal systems. Such SPD's are always required to ensure the protection and continuous operation of critical equipment.*

Unless stated, the susceptibility level (of equipment) is assumed to be twice its peak operating voltage. In this respect, SPD's with a UP level greater than the susceptibility level but less than UW, equate to the standard value of P_{SPD}, whereas SPD's with a UP level less than the susceptibility level equate to the enhanced value i.e. P_{SPD}.*

For example, in the case for a 230V mains supply an SPD fitted at the service entrance (for lightning equipotential bonding) should have a voltage protection level of no more than 1000V when tested in accordance with BS 61643 series. Downstream SPD's (those that are located within another lightning protection zone) fitted as part of a coordinated set to ensure operation of critical equipment should have a voltage protection level of no more than 600V when tested in accordance with BS 61643 series."

Thus, BS version of EN 62305-2, is clearly creating a link between the LPL of the installation, Up of the SPD and associated SPD. By this way a "regular" SPD can just be associated with probability 0,01 but SPDs having a Up lower than 1 kV can be associated to a probability as low as 0,001. The note 3 of 62305-2 is expanded and much clearer. However, to find a SPD for a 230/400 V IT system with a Up lower than 1 000 V may be a challenge.

3 SELECTION OF SPDS BASED ON CURRENT SHARING

As already said, the usual rule is to consider that earthing is capable to dissipate 50% of the lightning current and that the remaining current disperse inside the services (power lines, metal pipes ...).

IEC 61643-12 in its latest edition gives a table to give the value of Iimp through SPDs depending on LPL, connection type for SPDs and system earthing (TT, TN and IT). This table is based on the assumption that there is no other service than the power line and thus corresponds to the extreme case.

Table 4 : Extract from IEC 61643-12.

			LV system									
LPL	Max current	No. of conductors	TT			TN-C	TN-S			IT ~~neutral~~	IT neutral	
			Connection mode				Connection mode			Connection mode		
			CT1	CT2			CT1	CT2		CT1	CT2	
			LP-E N-PE	L-N	N-PE	L-PEN	L-PE N-PE	L-N	N-PE	L-PE	L-N	N-PE
			I_{imp} (kA)									
1 or un-know	200 kA	5	NA	NA	NA	NA	20,0	20,0	80,0	NA	NA	NA
		4	25	25	100	25	NA	NA	NA	NA	25	100
		3	NA	NA	NA	NA	33,3	33,3	66,7	33,3	NA	NA
		2	50	50	100	50	NA	NA	NA	NA	50	100
2	150 kA	4	18,8	18,8	75	18,8	NA	NA	Na	NA	18,8	75
		2	37,5	37,5	75	37,5	NA	NA	NA	NA	37,5	75
3 or 4	100 kA	4	12,5	12,5	50	12,5	NA	NA	NA	NA	12,5	50
		2	25	25	50	25	NA	NA	NA	NA	25	50

Connection types 1 and 2 are defined by the following figures 1 and 2.

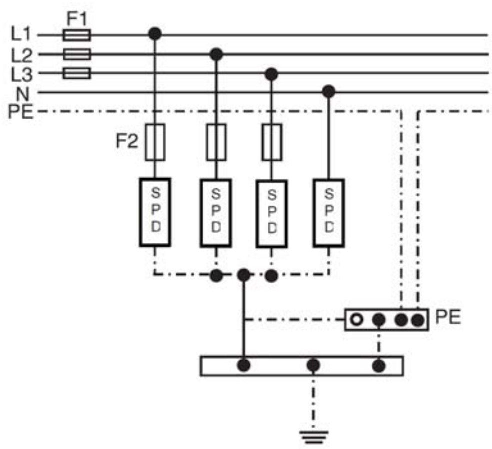

Figure 1. SPD connection Type 1 (CT1)

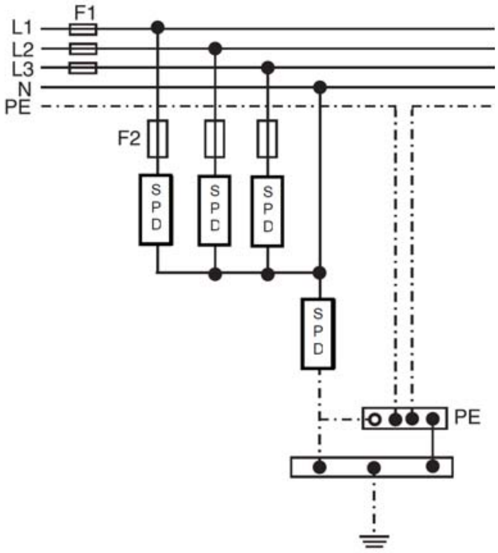

Figure 2. SPD connection Type 2 (CT2)

For example, for the case circled in red in Table 4, the current related to LPL 1 is 200 kA. 100 kA is derived to earth and 100 kA to the sole electrical line. SPD is provided at entrance of the line to avoid a dangerous sparking inside an equipment. For SPD connection type 1, current inside each single pole SPD (or surge protective component inside a multipole SPD), is equal to 100 kA divided by 4 (3 phases + neutral) and is equal to 25 kA. This is more than the minimum value of 12,5 kA generally recommended. In addition, in case of connection type 2, the current in SPDs remains the same except for the SPD between neutral and earth which should be rated to the total current of 100 kA.

IEC 62305-1 in its annex E gives a more detailed calculation for *I*f, being the part of the lightning current relevant to each external conductive part or line.

$$I_f = k_e\, I \quad (1)$$

ke depends on:

– the number of parallel paths;

– their conventional earthing impedance for underground parts, or their earth resistance, where overhead parts connect to underground, for overhead parts,

– the conventional earthing impedance of the earth-termination system.

And formulas are given for underground and overhead installation. The formula, for underground installation is given below.

$$k_e = \frac{Z}{Z_1 + Z(n_1 + n_2 \frac{Z_1}{Z_2})} \quad (2)$$

where

Z is the conventional earthing impedance of the earth-termination system;

*Z*1 is the conventional earthing impedance of the external parts or lines running underground;

*Z*2 is the earth resistance of the earthing arrangement connecting the overhead line to ground. If the earth resistance of the earthing point is not known, the value of *Z*1 may be used (where the resistivity is relevant to the earthing point).

*n*1 is the overall number of external parts or lines running underground;

*n*2 is the overall number of external parts or lines running overhead;

I is the lightning current relevant to the LPS class considered.

Values of Z1 or Z2, when unknown are given in table 5 below.

Table 5 : Extract from IEC 62305-1.

ρ (Ω.m)	Z1 (Ω)
≤ 100	8
200	11
500	16
1 000	22
2 000	28
3 000	35

To show the influence of the earthing of the system to the sharing of current we will take real cases based on previous publications [7]. For all these cases, the services where underground. In some cases, some hypothesis have been done to allow the calculation (number of services, resistivity far away from the structure ...).

Six field measurements are presented below numbered A to F, all of them in various places of France.

Case A : an extended earthing system for a group of office buildings near to Lyon. The soil is rather bad made of a rocky base above which is a layer of high resistivity soil covered by a thin layer of low resistivity soil.

Case B : a factory in Burgundy. The soil is of very bad quality made mainly of rocks. There is only a thin layer of rich soil on the top of it.

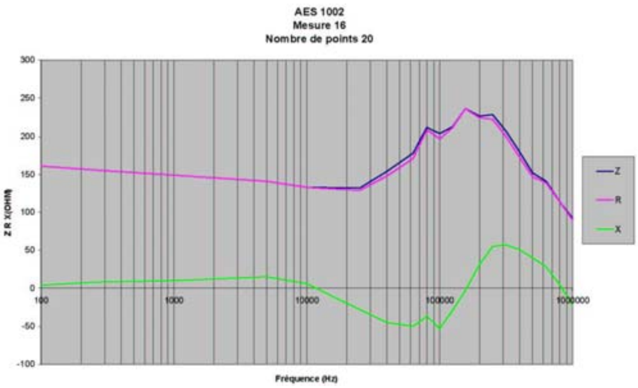

Figure 3. Curve for Case B.

Case C : little silo (3 m diameter). All faces are metallic but the area in contact with the soil is small.

Case D : a large shed built with a metallic frame.

Case E : a group of stainless chimneys. An earthing has been made on each chimney and all of them are connected together to a single earthing system by a long length of copper tape.

Case F : tank (diameter 6 m) near the sea. The concrete base is immersed in a mixture of sand and water.

Figure 4. : Tank near the sea - Case F.

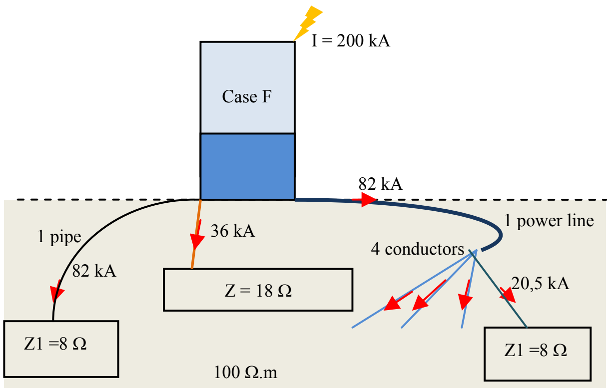

Figure 5 : Iimp current in SPD (connection type CT1, LPL I, using formula 2) - case F

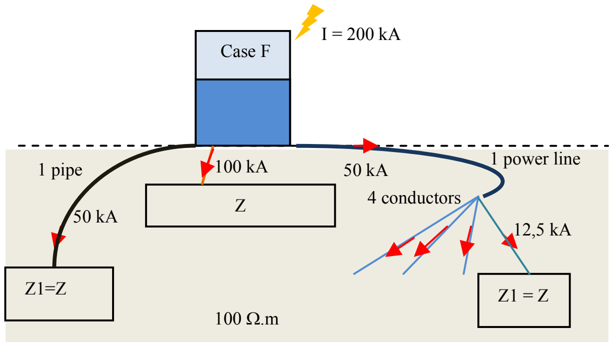

Figure 6 : Iimp current in SPD (connection type CT1, LPL I, using 50/50 rule) - case F

Measured results for Z, values taken into account for calculation as well as calculations results (current sharing in SPDs according to equation 2 and according to the 50/50 simple rule) are as follows :

Table 6 Calculation of current in SPDs

	Case A	Case B	Case C	Case D	Case E	Case F
Average value of Z (63 kHz-1MHz) Ω	47	184	41	23	46	18
Quality of earthing	bad	very bad	acceptable	good	good	very good
Resistivity Ω.m	3000	3000	500	500	500	100
System	TT	TT	TNS	TNS	TNS	TT
Number of power lines connected	2	1	2	1	1	1
Number of conductors per power line	4	4	5	5	5	4
Number of pipes	2	1	3	1	2	1
Z1 - Z2 (Ω)	35	35	16	16	16	8
Iimp current in each SPD (connection type CT1, LPL I, using formula 2) kA	10,5	22,8	7,4	14,8	11,9	20,5
Iimp current in each SPD (connection type CT1, LPL I, using 50/50 rule) kA	6,3	12,5	4,0	10,0	6,7	12,5
Variation in %	*69%*	83%	*86%*	48%	*79%*	64%

It should be noted that in case A, C and E, the value for current Iimp in each SPD is lower than the minimum value of 12,5 kA for both calculations. This means that provided there is enough lines and pipes connected, the calculation is always more optimistic than the bottom line value of 12,5 kA and calculation is not necessary even in harsh soil. But for other cases, the calculated current Iimp taking into account the earthing impedance is higher than what is given by the simple rule (50/50) whatever the earthing impedance is bad, good or even very good. In our calculated cases, the ratio was between 48% and 83%.

4 CONCLUSIONS

This paper intends to show that selection of Up (voltage protection level and Iimp (lightning current withstand) for SPDs is not always as easy as simple rules could let think. Especially, IEC/EN 62305-2 risk method allows to use better SPDs than usual ones but without given simple rule to determine such SPDs. Rules based on withstand level or even on immunity as stated in BS version of the standard can help determining such a better SPD with lower voltage protection level Up. Even, the current withstand , that is limited by values given in standard (200 kA for lightning protection level 1) can lead to various magnitude of current injected in SPDs Iimp depending on earthing conditions of the structure and the resistivity of surrounding soil. As an SPD is almost completely determined with Up and Iimp, suhc parameters should be determined with care and accuracy.

5 REFERENCES

[1] IEC/EN 62305-2, Protection against lightning Part 2 : Risk management

[2] IEC/EN 62305-4 , Protection against lightning Part 4 : Electrical and electronic systems within structures

[3] IEC 60364-4-443: Electrical installations of buildings Part 4: Protection for safety - Protection against overvoltages - Section 443: Protection against overvoltages of atmospheric origin or due to switching (Under revision)

[4] IEC 61643-12 : Low-voltage surge protective devices - Part 12: Surge protective devices connected to low-voltage power distribution systems - Selection and application principles

[5] BS EN 62305-2 : BS version of EN 62305-2

[6] IEC 62305-1 , Protection against lightning Part 1 : General principles

[7] "Practical high frequency measurement of a lightning earthing system ", by Alain Rousseau and Pierre Gruet, ICLP 2004