Reality Check Initiative on the Equivalency of 8/20 versus 10/350 Waveforms for Testing Surge-Protective Devices

Task Force Report sponsored by the Surge-Protective Devices Committee [1]

***Abstract*—A Reality Check Initiative was launched to assess the merit and possible pitfall consequences of accepting that the parameter of charge transfer (*Q*) associated with a lightning flash, stipulated in IEC 61643-1, might be the sole significant parameter. Reverse computations were performed to determine the other parameters associated with the classical 8/20 waveform and the more recently introduced 10/350 waveform. These computations demonstrated that the consensus-derived compromise "equivalency" of the two waveforms, via a simple multiplying factor, was not a realistic endeavor.**

***Index Terms*--Impulse testing, Power system protection, Surge protection, Test equipment, Varistors**

I. Introduction

The purpose of launching this Reality Check Initiative in 2004 was to assess the merit and possible pitfall consequences of accepting that the parameter of charge transfer (Q) stipulated in IEC 61643-1 [1] ("*Surge protective devices connected to low-voltage power systems – Part 1: Performance requirements and testing methods"*) is the basic parameter for a Class I test to be applied on surge-protective devices (SPDs), and then deriving the peak amplitude I_{peak} of any waveform that will deliver that stipulated charge transfer to an SPD under test, specifically the familiar 8/20 and 10/350 waveforms.

Table 3 of IEC 61643-1 from which TABLE I of this report is derived, includes a note stating that a 10/350 impulse is one of the possible waveforms that meets the parameters shown in the table published in IEC 61312-1 [2] *(Protection against lightning electromagnetic pulse – Part 1: General principles")*, which was used as reference source. This note, when it first appeared in an amendment under circulation within the IEC committee, was interpreted at the IEEE as a possible compromise to resolve the difference of perceptions between the North American community, the IEC Lightning Protection Community (TC81) and the IEC SPD community (SC37A).

For many years, as reflected in the many standards that are concerned with SPD applications, an 8/20 surge current waveform was considered to be a representative test [2], but later on, as the IEC TC81 began its series of publications describing or stipulating the lightning parameters, a 10/350 waveform arose as being the IEC-recommended SPD test waveform for the most severe test, the Class I test.

II. Lightning Flash Parameters

TABLE I shows the parameters of an impulse as described in IEC 61643-1 for a "Class I test": the peak impulse current, I_{imp} the charge transfer Q, and the specific energy W/R – also expressed as $\int i^2 dt$ (Goedbloed, 1987) [3]. Values shown in the IEC Table 3 were given with several rows of decreasing levels, presumably to allow users to select a level appropriate to their application.

TABLE I
PARAMETERS OF THE TEST IMPULSE FOR IEC CLASS I TEST

I_{peak} Within 50 µs (kA)	Q Within 10 ms (A.s)	W/R Within 10 ms kJ/Ω
20	10	100
10	5	25
5	2.5	6.25
2	1	1
1	0.5	0.25

In the absence of guidance on using that IEC Table 3, one could presume that since a cloud-to-earth lightning event is the rushing of earthbound charges up into the ionized leader channel, the charge transfer (Q) would be the dominant parameter, and miss the implied but not explicit point that all three must be used at the same time. There was no mention of the fact that for any given row of the table, the numerical values of the three parameters are consistent only if a 10/350 waveform is

[1] This report has been developed by a Task Force of the Surge-Protective Devices Committee – Working Group 3.6.4 on Surge Characterization, and recommended for presentation at the PES General Meeting, July 2006. Members of and contributors to the Task Force included: T. Conrad, J. Funke, M. Gerlach, W. Goldbach, R. Goodrich , D. Kladar, J. Koepfinger, M. Maytum , A. Rousseau, A. Surtees, and J. Wosgien with F. Martzloff serving as initiator and editor. Graphics were formatted to template specifications thanks to the support of Nanette Jones.

[2] The term "representative test" has sometimes been interpreted as an exact duplication of a waveform observed or presumed to occur in the real world. A more accurate interpretation introduces the concept that any test waveform is an arbitrary choice among the quasi-infinite variety of waveforms that have been observed or conjectured. The key criterion of such a choice is the pragmatic observation that the field performance of equipment designed and successfully tested according to the selected waveform is better than the performance of equipment that ignores that choice.

postulated, in contradiction with the interpretation of the table note that any waveform which meets the parameters may be acceptable. The computations made by several volunteer contributors to this report revealed that hidden postulate.

When preliminary results of the computations launched by the initiative were disseminated among stakeholders, feedback from two experts who had participated in the IEC work indicated that the intent of that table note was not to allow any waveform, but only to allow some tolerances for the waveforms that actual generators can deliver when attempting a 10/350 discharge, and further feedback that the intention was to obtain all three parameters delivered by the test generator.

With the benefit of that late information in mind, three stages and findings of this initiative are described in this report, together with two additional contributions submitted in 2005 commenting on the initiative. The additional contributions are reproduced as Annexes A and B. The resulting Task Force conclusions are presented in this report.

III. Computations based on interpreation that Q is the dominant parameter of a lightning flash

In the absence of guidance on how the three parameters of the IEC Table 3 should be selected, one approach was to consider that in a lightning event, the charge transfer would be the key parameter and that the two other parameters would be the response of the environment (relatively high ionized column impedance, compared to relatively low ground impedance) to that imposed charge transfer.

In an Informative Annex of IEEE Std C62.41.2™-2002 [4], Table A.2, which is reproduced below as TABLE II, shows a tentative compromise "equivalency" of the 10/350 and 8/20 waveforms for stresses to be applied to MOV-based SPDs, but also includes a remark that researchers have shown that failure modes of MOVs are also influenced by other factors, not just the total deposited energy (Bartkowiak et al., 1999 [5]).

TABLE II
SCENARIO II TESTS FOR SPDS INVOLVED IN EXIT PATHS

Exposure	All SPD Technologies 10/350 µs	Alternative for MOVs 8/20 µs
1	2 kA	20 kA
2	5 kA	50 kA
3	10 kA	100 kA
X	Lower or higher by agreement between parties	

By using the equations provided in IEEE Std C62.45™-2002 [6], one can then compute the corresponding values of I_{peak} for an 8/20 and for a 10/350 waveform that will deliver that charge transfer $Q = \int i dt$. These equations are provided in IEEE C62.45 to enable numerical computations based on "textbook waveforms," which the contributors used to make the computations if this initiative. However, it has been recognized by experimenters that practical surge generators do not deliver textbook waveforms. That is one of the reasons for allowing generous tolerances on the Class I test waveform parameters of IEC Table 3.

Some manufacturers have offered specially designed undershoot-free generators but many others deliver a damped sine wave with an undershoot, a fact recognized by imposing a 20 % limit to the amplitude of the undershoot.

This reality should be kept in mind when computing charge transfers from a waveform that involves a reversal of current polarity, adding a negative part to the total integration, but which still deposits cumulative energy in a varistor.

Phase I – Compute I_{peak} values for a given charge transfer

The following steps were performed in this first phase of the computations:

1. Using any appropriate math software, plot the two 10/350 and 8/20 waveforms by using the equations given in IEEE Std C62.45™-2002 [6] to verify that the correct equation has been entered in the software.
2. For each of the waveforms, write the equation $\int i dt = 10$ C (max value of Q in IEC Table 3) with i as defined in the IEEE Std C62.45™-2002 equations where Ip is the peak value of the waveform.
3. Solve the equations by any appropriate method, including graphic approximations, to obtain the value of Ip that will satisfy the equation for each of the two waveforms, for a time interval consistent with the decay rate of the waveform.

Intuitively, one might expect that to obtain the same charge transfer, the peak current in the case of the 8/20 waveform would be much higher than that of the 10/350, roughly by the ratio of the durations, that is 350/20 = 17. Consequently, stipulating a very high value of an 8/20 peak (a factor of 10, not 17, was proposed in Table A.2 of IEEE C62.41.2) for the purpose of demonstrating very large charge transfer capability might then appear to be a justifiable conservative requirement (with an expectation of enhanced durability that still has to be demonstrated). However, three reservations lingered on accepting this equivalency:

1. A real-world installation cannot accept transferring the postulated charge with the very high I_{peak} values computed from the Class I test parameters in the case of an 8/20 waveform. This limitation was discussed in (Mansoor & Martzloff, 1997 [7]).
2. As previously mentioned, parameters other than simply the total energy do influence the limit capability of MOVs
3. The high currents imposed on a disconnector integrated with the SPD (as it should) act upon the disconnector on the basis of the specific energy – proportional to the square of the current – and therefore are not representative of the disconnector duty in a real-world environment; hence a second phase of the initiative to compute the specific energy levels based on the current peak found necessary to obtain the stipulated charge transfer.

The computation results for peak impulse currents, from nine volunteers, are summarized in TABLE III. Three levels of the postulated charge, 10 C, 5 C, and 1 C were selected as a cross-check of the presumption that the peak current is simply proportional to the level of charge transfer, $Q = \int i^2 dt$.

TABLE III

COMPUTED I_{PEAK} VALUES FOR THREE CHARGE TRANSFER LEVELS PER TABLE 3 OF IEC 61643-1

Range of I_{peak} for Q = 10 C (kA) *(IEC 61643 Table 3 shows 20 kA)*		Range of I_{peak} for Q = 5 C (kA) *(IEC 61643 Table 3 shows 10 kA)*		Range of I_{peak} for Q = 1 C (kA) *(IEC 61643 Table 3 shows 2 kA)*	
10/350	8/20	10/350	8/20	10/350	8/20
20 to 22	410 to 573	10 to 10.8	205 to 287	2.0 to 2.17	41 to 57

Note: The low values in the range of the 8/20 results reflect computations based on the current waveform delivered by a generator delivering a damped sine wave with a 20 % undershoot.

Different approximations used in the computations account for the range of values rather than a unique value. These results show: that indeed, the current peak and the charge transfer values for a 10/350 match the IEC parameters, revealing the hidden postulate of validity for only the 10/350 wave mentioned above.

For an 8/20 wave, the multiplying factor is greater than the value of 17 – let alone 10 – predicted by the crude intuitive notion. This multiplying factor is on the order of 20 to 25, again depending on the waveform approximations used by the volunteers.

Phase II – Implications on disconnector duty

Concerns about the implications for the duty imposed upon the disconnector when subjected to the high current peaks associated with an inflated 8/20 test associated with the concept of equivalency based on the same charge transfer, Q, needed to be reviewed. Hence, a Phase II in the computations performed under this initiative addressed the issue of what stress would be imposed on the disconnector by either wave.

1. Compute the specific energy $\int i^2 dt$ associated with the two values of I_{peak} for their durations, respectively for the 10/350 and the 8/20 waveform.
2. Then, consider and assess the likelihood that a disconnector capable of ensuring acceptable failure mode under TOV with moderate fault currents could also carry that specific energy without opening (a requirement implied in the NEC® 280.2 definition of an arrester)

The computation results for specific energy, from seven volunteers are summarized in TABLE VI, below.

TABLE VI

COMPUTED SPECIFIC ENERGY VALUES FOR THREE CHARGE TRANSFER LEVELS PER TABLE 3 OF IEC 61643-1

Range of $\int i^2 dt$ for Q = 10 C (A^2.s x 1000)		Range of $\int i^2 dt$ for Q = 5 C (A^2.s x 1000)		Range of $\int i^2 dt$ for Q = 1 C (A^2.s x 1000)	
10/350	8/20	10/350	8/20	10/350	8/20
100 to 112	2400 to 4000	25 to 28	600 to 1000	1.0 to 1.1	24 to 40

Again, note in this table that the computed values of the specific energy for the 10/350 waveform closely match the values given in Table 3 of IEC 61643-1, revealing the hidden postulate that the IEC Table 3 was developed while thinking solely 10/350.

IV. DISCUSSION

The calculations performed during Phase II of this Initiative indicate that the specific energies for the 8/20 and the 10/350 waves have a ratio of approximately 30:1. To achieve the same energy in a 8/20 current waveshape as is obtained in a 10/350 current waveshape, it would be necessary to have a peak current that is approximated 17.5 times that of the current in a 10/350 current waveshape. The problem is that an SPD stress is impacted both by the amount of energy that has to be dissipated and by the rate-of-rise of the discharge current. Although the deposited energy can be made the same in an 8/20 current waveshape as that in a 10/350 current waveshape by increasing the peak current by a factor of at least 17.5, the stress to the SPD will be much greater due to the rate-of-rise of the current front, and it is not appropriate to compare dynamic forces under such different test conditions.

These results indeed show that attempting to test an SPD with an 8/20 current to demonstrate a declared charge transfer capability as defined in the Table 3 of IEC 61643-1 leads to "stratospheric" values of the I_{peak}, which in turn lead to values of specific energy that a disconnector might have difficulty reconciling with proper operation during TOV-induced failures. Therefore, if for some reason the decision is made to perform a test with those high "equivalent values" of I_{peak}, one should not require the disconnector to be left in the circuit but rather by-pass it – in other words, open the black box! [3]

It would be unrealistic to require, for example under a "*Black Box Test is the only fair method*" posture, or in compliance with the Introduction of IEC 61643-1 ("*All SPDs are tested on a 'black box' basis*.") that the disconnector be left in the circuit when performing a Class I test and then declare failure of the SPD to pass because the disconnector opened. The desire to have the disconnector remain intact with inflated 8/20 surge current tests can lead to problems if a disconnector designed to survive these high currents might then fail to disconnect in case of an SPD failure caused by a moderate TOV occurrence.

A further reason for not leaving the disconnector involved during an inflated high-current 8/20 surge test is that if the disconnector were to open during the surge, the behavior of the SPD would be affected in an unpredictable and difficult to interpret manner – in other words a wasted specimen in a series of tests.

[3] Based on these findings, a paper "*Black boxes, Blind spots, and Disconnectors: How not to test SPDs*" [8] was presented at the International Conference on Lightning Protection (ICLP), discussing the need to reconcile satisfactory operation of the disconnector over the range of possible TOVs against the unrealistic stresses imposed by an "equivalent" high 8/20 current waveform, i.e., do not demand black-box testing that could lead to blind spots.

The NEC stipulation, implied in its definition of an arrester, that the SPD emerge unchanged from a lightning event, if interpreted as meaning that a Class I equivalent test is required to simulate a lightning event, ***would be inappropriate.***

The requirement for performing a Class I test has been the subject of much debate among North American stakeholders. In the recent restructuring of the IEC TC81 documents, a clear distinction is made between low-lying buildings being impacted mostly by cloud-to-earth flashes, on the one hand, and on the other hand tall structures that can generate earth-to-cloud flashes, which have greater peak currents.

The TC81 documents also present texts and figures that seem to imply that the threat is an impinging surge appearing at the service entrance. IEC 62066 [9] and ICLP papers (Birkl et al., 1996) [10]), (Martzloff & Mansoor, 2002; [11]) identify the scenario of a direct flash to the building as the most severe stress imposed on service-entrance SPDs. Paper [11] goes one step beyond, identifying SPDs installed downstream of the service entrance as being also involved in the dispersion of the lightning current toward the power supply connection from the energy service provider. That involvement is implied in the title and associated narrative of Table A.2 of IEEE C62.41.2™-2002, which carefully avoided referring to these exclusively as the "Service Entrance SPD."

V. CONCLUSIONS

The initiative was launched on the assumption that an equivalency might be developed for electing to test an SPD with either an 8/20 waveform or a 10/350 waveform. That interpretation was encouraged by the publication of the "Consensus Compromise" of Table A.2 in IEEE Std C62.41.2 as well as by the footnote of Table 3 of IEC 61643-1, even as no rationale or explanation was offered for that footnote.

The computations performed in this initiative revealed that fundamental differences exist between the two waveforms, with misleading test proposals attempting to allow drawing conclusions based on "pass" results from one test and apply them to the other test. Thus, in the updating process of IEEE C62.41-2™-2002, serious reconsideration of the Consensus Compromise appears necessary.

To the extent that recommendations from this report might be considered by all standards-developing groups in the development of their standards, these standards would gain more credibility, acceptance, and avoid misinterpretation if clear and specific rationales for required tests were included. "Notes" inserted in the text, footnotes, or references to Informative Annexes could accomplish this goal without falling in the trap of becoming excessively tutorial.

VI. BIBLIOGRAPHY

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Annex A
The 10/350 Sweet Spot that isn't

M.J. Maytum

A.I. Introduction

THE Class I impulse current test in 37A/169/FDIS (IEC 61643-1 Ed. 2: *Low-voltage surge protective devices – Part 1: Surge protective devices connected to low-voltage power distribution systems – Requirements and tests*) [A1] uses a waveform having defined peak current I_{peak}, charge Q and specific energy W/R (i^2t to normal circuit people) in a 10 ms period. This Class I test tries to simulate a coupled high-energy positive lightning stroke. A 10/350 waveform is stated as being a wave shape that can meet the given I_{peak}, Q and i^2t relationship.

A.II. Relationship between I_{peak}, Q, and I^2T

The IEC 37A/169/FDIS gives the parameter relationship in terms of I_{peak}:

$Q = 0.5 \times I_{peak}$ C
$I^2t = 0.25 \times I_{peak}{}^2$ kA^2.s
where I_{peak} is in kA

The derivation of this relationship comes from IEC Std 61312-1, *Protection against lightning electromagnetic impulse - Part 1: General principles,* 1995-03-13 [A2].

A. IEC 61312-1

Annex A (informative) of IEC 61312-1 gives the background of fixed lightning parameters. The IEC 61312-1 Figure A.1, stripped of non-essential lines is shown here as Fig. A1. In the first section it is stated, "*In Fig. A.1 the probabilities of several lightning stroke parameters are shown.* ***Probabilities are substantially independent of each other***" The last sentence means you can't assume things like the 10 % value of I_{peak} also occurs at the same time as the 10 % values of Q and i^2t. Yet this sound advice is ignored when formulating the positive lightning parameters (stacked disaster concept), which result in the 10/350 justifications!

The first thing to notice is that the IEC 61312-1 values of 200 kA, 100 C and 10 kA^2.s, shown as circled points in Fig. A1, are not all done at the same probability level. Tactfully, this is referred to in the IEC text as "*the following rounded values with probabilities somewhat below 10 %.* " In fact, if the values were all done at the same 6.5 % probability the parameter set would be 200 kA, 120 C and 10 kA^2.s This is a 20 % increase in charge. Force-fitting the 200 kA, 100 C and 10 kA^{2}s parameter set into an exponential with a decay time t_D gives:

Decay from Q $\qquad \tau_{DQ} = Q/(1.43 I_{peak}) = 350$ µs
Decay from i^2t $\qquad \tau_{Di2t} = i^2t/(0.725(I_{peak})^2) = 345$ µs
…*QED*

However the equal probability Q of 120 C gives:
Decay from Q $\qquad \tau_{DQ120} = Q/(1.43 I_{peak}) = 420$ µs

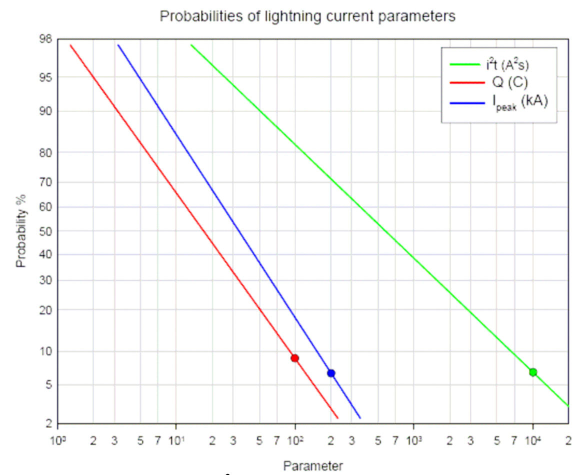

Fig. A1 *I*peak, Q and i^2t probabilities according to 61312-1

Could it be that the 200 kA, 100 C and 10 kA^{2}s values were selected to give a "sweet spot" that gave the same resultant decay time from Q and i^2t?

B. Waveshape tolerance

The tolerances for the 37A/169/FDIS Class I test waveform are I_{peak} ±10 %, Q ±20 % and i^2t ±35 %. Table 3 – Parameters for Class I test of 37A/169/FDIS notes "*One of the possible test impulses which meets the above parameters is the 10/350 waveshape proposed in IEC 61312-1*". Calculating the tolerance matrix for an exponential decay waveshape shows that this statement is misleading.

Table A.I
Exponential decay time (µs) for Class I test tolerances

I_{peak} Tolerance (%)	Q Tolerance (%)		
	-20	0	+20
+10	253	316	379
0	278	347	417
-10	309	386	463

The allowed i^2t variation is not exceeded by any combination of the limit tolerance values of Q and I_{peak} in the above table. The range of exponential decay times is 253 µs to 463 µs. Allowing for a 5 % error margin on measurement and control of I_{peak} and Q gives a target decay time variation of 350 µs ±70 µs.

The 37A/169/FDIS Table should have comprehended the original IEC 61312-1 statement intent with a note of: "*An approximately exponentially decaying current can achieve these parameters with a decay time in the range of 350 µs.*"

A.III. Parameter Correlation

There is an excellent review paper entitled Parameters of Lightning Strokes: A Review, *IEEE Transactions on Power Delivery, Vol. 20*, No. 1, January 2005 by the Lightning and Insulator Subcommittee of the T&D Committee.

This review paper includes the correlation factors between the various lightning parameters. The last table in the review paper lists the correlation coefficients between the various lightning stroke parameters. Extracting the I_{peak}, Q_{flash} and i^2t_{flash} parameters from that table gives TABLE A.II, as follows.

TABLE A.II
CORRELATION COEFFICIENTS AMONG LIGHTNING STROKE PARAMETERS

Conditional Median	Correlation Coefficient †	a	d
Q_{flash} / I_{peak}, (C)	0.62	15.5	0.461
I^2t_{flash} / I_{peak}, (kA^2.s)	0.84	5.83	1.33

† Correlation relationship equation is $y = aI_{peak}^{d}$ where I_{peak} is in kA

It can be seen that the strongest correlation (0.84) exists between the flash energy (i^2t_{flash}) and the peak current (I_{peak}). Far less reliable is the relationship (0.62) between the peak current (I_{peak}) and the charge (Q_{flash}). This result is somewhat counter-intuitive on the basis of a certain amount of charge to be discharged.

It is a pity that only the total flash values were quoted as IEC 61312 uses stroke values, which are smaller as only the first 10 ms of current flow are considered. The review gives the charge probabilities for the flash, Q_{flash}, and the charge in the first 2 ms, Q_{short}. Fig. A2 plots the probabilities for Q (IEC 61312), Q_{flash} and Q_{short}. Although the Class I waveform is meant to be integrated over 10 ms, the charge line used (Q) often shows less charge than the 2 ms charge (Q_{short}) line. In the critical area below 10 % probability, there is a substantial difference. At the 6.5 % probability level the 2 ms charge is 140 C. The equivalent exponential decay equation now gives:

Decay from Q_{short}

$\tau_{DQ140} = Q/(1.43 I_{peak}) = 490$ µs

This result further re-enforces that the 10/350 waveshape is contrived rather than the result of scientific analysis.

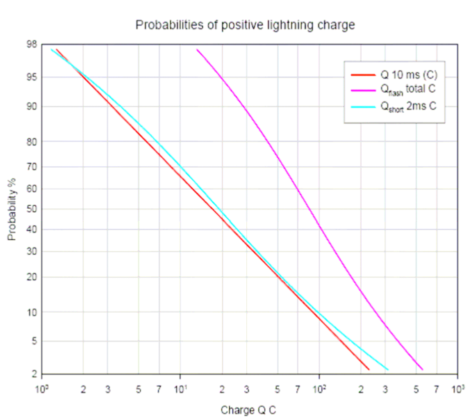

Fig. A2 Comparison of positive lightning charges

However, the i^2t_{flash} value will be close to i^2t as most of the value will be developed in the first few milliseconds. Using the i^2t_{flash} equation from TABLE A.II, the values of i^2t for an I_{peak} range of 5 kA to 250 kA can be calculated . Using i^2t exponential decay equation ($\tau_{Di2t} = i^2t/(0.725(I_{peak})^2)$, the equivalent time decay, τ_{Di2t}, for the i^2t values can be calculated. Based on I_{peak} and τ_{Di2t} values, the charge equivalent, $Q_{equivalent}$, of the exponential waveform can be calculated. The results are plotted in Fig. A3.

A.IV. DISCUSSION

The analysis of a 1997 Telcordia field trial failure returns showed that the predominant waveshape causing the failure of telecommunication line primary protectors was about 10/200 [A3]. This value is similar to the 230 µs decay time from the review paper in TABLE A.III. The TABLE A.III value is also similar to the 10/250 waveshape used by Telcordia GR documents for extreme environments. Further, the longitudinal current waveshape produced by the ITU-T 10/700 impulse generator is 4/245, again in the 230 µs area.

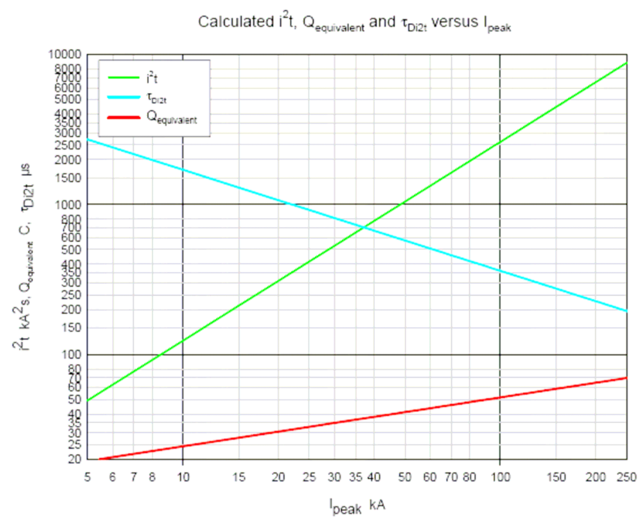

Fig. A3 Calculated i2t, Qequivalent and □Di2t versus Ipeak

TABLE A.III shows the IEC 61312-1 and review paper values of i^2t, Q and t_D for an I_{peak} of 200 kA.

TABLE A.III
200 KA I_{PEAK} POSITIVE LIGHTNING PARAMETER COMPARISON

Source	I^2t (kA^{2}s)	Q (C)	τ_D (µs)
IEC 61312-1	10 000	100	350
Review Paper	6500	65	230
Difference	3500	35	120

There cannot be a single waveshape to characterize the lightning environment. One needs at least two waveshapes; one to emulate the high energy positive lightning stroke and a rapidly-rising short-duration waveshape to emulate the subsequent negative strokes of a negative flash.

The above analysis indicates the formulation of the 10/350 is flawed and a better choice is something like a 10/230 for a 200 kA positive stroke.

A.V. ANNEX A REFERENCES

[A1] IEC 61643-1 Ed. 2: *Low-voltage surge protective devices – Part 1: Surge protective devices connected to low-voltage power distribution systems – Requirements and tests.*

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Annex B
A review of some of the differences between IEC and IEEE standards on surge ratings and test waveshapes

A.J. Surtees

Abstract: -- *This Annex serves to provide a companion to the main body of the report. It seeks to support the primary conclusion that it is not a trivial matter to correlate the behavior of an SPD by simply equating the action integral (charge transfer) of different test waveshapes.*

In so doing, it goes beyond this assertion to provide some background to the often conflicting values of surge current which appear between various IEC and ANSI standards, and attempts to justify why these are often orders of magnitude different, by educating the reader as to the assumptions which are often made in coming up with such values – in a way performing its own reality check on these assumptions and the conclusions which result.

The parameters I_{imp}, I_{max} and their submultiples are test parameters used in IEC 61643-1 [B1] for the operating duty test for Class I and Class II tested SPDs, respectively. They are related to the maximum values of discharge currents, which are expected to occur only very rarely at the location of the SPD in the system. The parameter I_{max} is associated with Class II tests and I_{imp} is associated with Class I tests. The preferred values for I_{imp} (I_{peak}, Q, W/R), according to IEC 61643-1 are shown in TABLE I of the main body of this report.

B.I. STRESSES IMPOSED ON SPDS

The stress which an SPD will experience under surge conditions is a function of many complex and interrelated parameters. These include:

- ***Location of the SPD(s) within the structure*** – are they located at the main distribution board or within the facility at secondary board, or even in front of the end-user equipment?
- ***Nature of coupling the lighting strike to the facility*** – for example, is this via a direct strike to the lightning protection system (LPS) of the structure, or via induction onto building wiring from a nearby strike?
- ***Distribution of lightning currents*** within the structure for example, what portion of the lightning current enters the earthing (grounding) system, and what remaining portion seeks a path to remote grounds via the power distribution system and equipotential bonding SPDs?
- ***Type of power distribution system*** – the distribution of lightning current on a power distribution system is strongly influenced by the grounding practice for the neutral conductor. For example, in the TN-C system with its multiple earthed neutral, a more direct and lower impedance path to ground is provided for lightning currents than in a TT system.
- ***Additional conductive services*** connected to the facility – these will carry a portion of the direct lightning current and therefore reduce the portion which flows through the power distribution system via the lightning equipotential bonding SPDs. Attention should be paid to permanence of such services due to possible replacement by non-conductive parts).
- ***Type of waveshape being considered*** – it is not possible to simply consider the peak current which the SPD will have to conduct under surge conditions; one also has to consider the waveshape of this surge. In addition, it is not possible to simply equate the areas under the current-time curves (also referred to as the action integral) for SPDs under different waveshapes.

For example, if an assumption is made that for the same value of *I*max the action integral of a 10/350 waveshape is approximately 10 times that of an 8/20 waveshape (MOV based SPD), it would be incorrect to assume that an SPD which can handle 10 kA 10/350 could handle 100 kA 8/20. This is because the mechanical stresses exhibited in the 100 kA 8/20 waveshape are very much greater than in the 10 kA 10/350 waveshape, even though the action integrals may be the same.

B.II. QUANTIFYING THE SURGE ENVIRONMENT

Many attempts have been made to quantify the electrical environment and "threat level" which an SPD will experience at different locations within a facility. IEC 62305-4 [B2] has sought to address this issue by considering the *highest surge magnitude* which may be presented to an SPD based on the lightning protection level (LPL) being considered. For example, this standard postulates that for an LPL level I the magnitude of a direct strike to the LPS of the structure may be as high as 200 kA 10/350. While this level is possible, its statistical probability of occurrence is only 1 %. In other words, 99 % of discharges will be less than this postulated 200 kA peak current level.

In addition, an assumption is made that 50 % of this current is conducted via the earthing (grounding) system of the building, and that 50 % returns via the four equipotential bonding SPDs connected to a three wire plus neutral power distribution system. It is also assumed that no additional conductive service exists. This assumption implies that the portion of the initial 200 kA discharge experienced by each SPD is 25 kA.

Simplified assumptions of current dispersion are useful in considering the possible threat level, which the SPD(s) may experience, but it is important to keep in context the assumptions being made. In the example above, a lightning discharge of 200 kA has been considered. It follows that the threat level to the equipotential bonding SPDs will be less that 25 kA for 99 % of the time.

In addition, it has been assumed that the waveshape of this current component through the SPD(s) will be of the same waveshape as the initial discharge, namely 10/350, while in reality the waveshape can be altered by the impedance of building wiring etc.

If one further considers the fact that direct strikes to structures are far less frequent than the effects of less severe indirect strikes and the resulting couplings of current via induction, one soon realizes that the likelihood of an SPD at the service entrance to a facility experiencing currents as high as 25 kA 10/350, while not impossible, are statistically fairly infrequent.

Many standards have rather sought to base their considerations of the threat level which the SPD may experience during service on field experience collected over time.

For example, the IEEE Guide on the surge environment C62.41.1™-2002 [B3] and the IEEE Recommended Practice on surge characterization C62.41.2™-2002 [B4] describe two scenarios of lightning discharge (Scenario II: a direct strike to the structure, and Scenario I: nearby strikes), and suggest different exposure levels under each of these, depending on the location where the SPD is installed.

TABLE B.I below, transcribed from the Recommended Practice (Table A.2. in IEEE C62.41.2), details this for the case of Scenario II:

TABLE B.I
SCENARIO II TESTS FOR SPDS INVOLVED IN EXIT PATHS

Exposure	All SPD Technologies 10/350 µs	Alternative for MOVs 8/20 µs
1	2 kA	20 kA
2	5 kA	50 kA
3	10 kA	100 kA
X	Lower or higher by agreement between parties	

Note that the table shows several exposure levels which might be considered as applicable to a particular situation, with the additional flexibility of a negotiated level for those applications where the parties would have mutual acceptance of different conditions

B.III. CONCLUSIONS

From the above, it is apparent that the selection of the appropriate I_{max} or I_{imp} of an SPD depends on many complex and interconnected parameters. The user not only needs to consider how the injection current will distribute within the structure and its power distribution system, but also needs to take into account the statistical probabilities associated with the magnitude of this discharge and the waveshapes involved.

When addressing such complexities, one needs to keep in mind that the most important aspect in selecting an SPD is its limiting voltage performance during the expected surge event, and not the energy withstand (I_{imp}, I_{max}, U_{oc}) which it can handle. An SPD with a low limiting voltage will ensure adequate protection of the equipment, while an SPD with a high energy withstand might only result in a longer operating life.

B.IV. ANNEX B REFERENCES

[B1] IEC 61643-1: *Surge protective devices connected to low-voltage power systems – Part 1: Performance requirements and testing methods.*
[B2] IEC 62305-4: *Protection against lightning – Part 4: Electrical and electronic systems within structures.*
[B3] IEEE Std C62.41.1™-2002 – *IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) Power circuits.*
[B4] C62.41.2 – IEEE Std C62.41.2™-2002 – *IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.*