THE IEC 63205 LIGHTNING PROTECTION SERIES
UNDER THE MICROSCOPE

Bruce Glushakow
MCG Electronics Inc., IEEE
12 Burt Drive, Deer Park, New York, 11729, USA

Abstract: In January 2006, the IEC released its 62305 Series, a revised and reordered family of lightning protection standards. This series bases itself upon a lightning model attributed to two articles written in the 1970s. To give credibility to this lightning model, both articles were included in 62305-1's bibliography. (2 of only 7 citations considered worthy of inclusion by the standard writers.)

The articles are CIGRE reports entitled "Parameters of lightning flashes" (1975) and "Lightning parameters for engineering application." (1980) The writers were Berger, Anderson, Eriksson, and Kröninger, respected researchers, but writing about measurements performed with the limited methods available to them at the time.

Core data concerning the above-mentioned 2 articles has been unearthed and presented here which had heretofore been clouded in abstruse language and in some cases purposefully hidden. The facts cast a horribly deep shadow over the IEC 62305 standards and the lightning model upon which they are based.

Keywords: IEC 62305, Class I Test, 10/350 µs waveform, 8/20 µs waveform, W/R, Q, SPD test procedure.

1. THE QUEST FOR A LIGHTNING MODEL

For over 30 years scientists and researchers have sought to improve their understanding of lightning. Uncountable studies have resulted in tens of thousands of articles written on this subject. Both the quantity of these studies and their quality have increased exponentially in the past 15 years, due in part to technological breakthroughs that have permitted a more accurate recording of the phenomena and also driven by the discovery of the deleterious effects lightning has on electronic equipment.

You'd think after all this time a workable model that reflected the amount of lightning in a lightning strike would have been worked out and agreed upon by the academic community. But it has not.

IEC 61312-1 first postulated an IEC lightning model in 1995 based on two studies from the 1970s. This model has occasioned a seemingly unending debate from scholars and researchers around the world who have claimed it to be based on incomplete data. [1, 2]

The most fundamental element of any lightning standard is the lightning model on which it is based. Just as no house can stand without a reliable foundation, no lightning protection standard can stand without a scientifically-based lightning model. Even a small defect in such a model can have serious repercussions in terms of loss of life and damage to structures and equipment.

That is why it was a surprise, in light of the volume and intensity of dispute surrounding the earlier IEC 61312-1 lightning model, for the IEC 62305 series to have been released without addressing any of the existing concerns.

One expected to find somewhere sandwiched in between its 1,000 pages, an updated and compelling, well-referenced, reality-based lightning model.

Instead of that, and without offering any further reason or justification, IEC 62305-1 summarily announced that the 62305 lightning standards would preserve the lightning standard based on those two studies from the 1970s on which the 61312-1 lightning standard had been based.

The authors of the two articles under examination (Berger, Anderson, Eriksson, and Kröninger) are all shining stars in the sky of lightning research. Although this paper will point out some imperfections in their studies, one can't help venerate them for their courage and hard work in the face of often daunting obstacles. To be especially applauded is their intellectual integrity.
But work that might have been considered state-of-the-art 30 years ago must sometimes be made to step aside in favor of data provided by new science which enable us to see phenomena more clearly. That is called progress.

The question before us is: Do these 30-year old studies merit the weight of responsibility that has been singularly thrust upon them in the IEC 62305 series of documents? It is the purpose of this paper to answer that question.

2. THE ORIGIN OF THE 63205 LIGHTNING MODEL

Since 1995, all IEC lightning standards referenced the lightning model promoted in IEC 61312-1.[3] In its turn, 61312-1 gave as the sole source of its lightning model: "the results of CIGRE given in Electra Magazine Issue 41 (1975) and Issue 69 (1980)." [4] This is confirmed by Prof. Peter Hasse, world's leading proponent of the 10/350 waveform and the 61312-1 lightning model. [5]

In 2006, the 62305 series announced that all ***new*** IEC standards shall continue to be based on parameters from these same two articles and indeed these are the only references cited in the 62305-1 bibliography relating to the parameters of lightning flashes. [6]

These are the articles:

- Berger K., Anderson R.B., Kröninger H., *Parameters of lightning flashes.* CIGRE Electra No 41 (1975), p. 23 – 37
- Anderson R.B., Eriksson A.J., *Lightning parameters for engineering application*. CIGRE Electra No 69(1980), p. 65 – 102

K. Berger, a pioneer in lightning research did the major part of his work in 1960s and 1970s. It was his studies at a small station on a mountain above Lake Lugano in Switzerland that was the basis of these two CIGRE articles. The fact that 62305-1 cited both of the above Electra articles is the first misconception to be cleared up. Lightning has been divided into several categories. IEC 61312-1 clearly stated that the ONLY interest it had in these two Electra articles was the data they contained pertaining to **positively-charged cloud-to-ground lightning**.[7]

It should be noted that all data relating to positively-charged cloud-to-ground lightning comes from Berger's findings presented in Electra 41. Electra 69 data focused on negatively-charged cloud-to-ground lightning for the reason, as explained by Anderson: "The downward negative flash is considered to be the most important discharge process for practical engineering systems."

There was no additional data pertaining to positively-charged cloud-to-ground lightning in Electra 69, for the simple reason, that no new data existed to be added. As Anderson notes on p. 72 of Electra 69: "the **only** comprehensive study of positive flash current impulse shape characteristics is that carried out (in the earlier studies) by Berger."

For that reason, in this paper when we refer to Electra 41 and Electra 69, we will simply cite "Berger" as he is the actual source of the data under discussion.

That having been cleared up, we ask the question: Is there something so special about the 30-year-old data in Berger's article that would warrant us placing such implicit faith in it?

3. QUANTITY OF BERGER'S DATA: WAS THERE ENOUGH OF IT?

3.1 The last 15 years has seen a dramatic increase in the accuracy and precision in detecting and recording lightning phenomena. In Uman/Rakov's landmark textbook "*Lightning: Physics and Effects*" published by the Cambridge University Press in 2003 the two Electra articles are of course duly noted in the chapter covering positively-charged cloud-to-ground lightning. But they are merely the earliest 2 of 239 references expressly covering that subject.

3.2 IEC 62305-1- Annex A Table A-1 produces a table out of the above-mentioned Electra 41 article. [8] The table omits a key column--where Berger disclosed **the number of lightning flashes studied** from which he was forced to draw his conclusions.[9] This is an unfortunate omission as this data helps put in perspective one of the key concerns over the advisability of blind reliance upon Berger's results: the question of whether it was based on incomplete data. **In fact, Berger had measured only 26 positively-charged flashes of which only 4 were found to have any similarity in wave shape.** [10]

3.3 Over the world, there are 100 lightning flashes hitting earth every second. If only 5% of those are positively-charged, then over 7 billion positively-charged CG flashes have hit the earth since the aforementioned Electra articles were written. In one study in the USA by the National Lightning Detection Network, using advanced gated wide-band magnetic direction finders, over **1 million positively-charged lightning flashes** were measured. Here is a map that shows only the ones with I-peaks between 75kA and 200 kA.

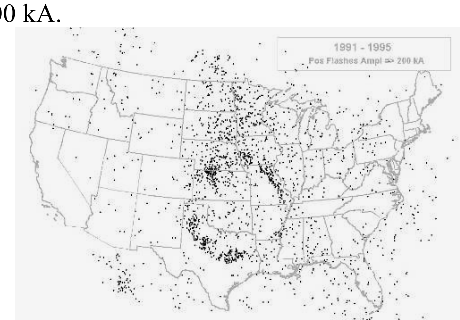

Fig. 1. NLDN study of positively charged CG lightning >75kA

With modern methods and equipment providing us such abundant data, don't you think that standards written in 2006 do themselves a disservice by limiting their scope of data to 26 positively-charged lightning flashes recorded in the 1970s?

4. QUALITY OF BERGER'S DATA: WAS IT ACCURATE ENOUGH?

What follows are a selection of data reported by Berger in 1975 that displays significant deviations with results of more modern studies.

4.1 Methodology & Equipment.

Historically, the observed skill of a lightning network has been measured by its accuracy in locating a lightning flash and by the percentage of these lightning flashes it was able to observe out of the total number produced by a storm. The technical term for this is DE (detection efficiency). DE measurements are tough to validate and often have been the source of considerable scientific debate. There is no way to rate Berger's DE because there was no means of corroborative verification available to him.

For the last 15 years, ground-based CG lightning observing systems have used one of two basic technologies, Time of Arrival (TOA) or Magnetic Direction Finding (MDF). Information received is relayed via satellite to a central processing site, where the data from a number of sensors are combined and through the use of spherical geometry, a location solution is computed. Because maintaining the exact time among a set of widely dispersed sensors is critical to the accuracy computations, all sensors use GPS clocks. Further improvements to DE were realized with the introduction of the Optical Transient Detector which can gather lightning data under daytime conditions as well as at night.

As can be seen from the last paragraph, there is a vast difference between the methodology and equipment that has been in broad use over the past 15 years and the single- station sensors and low-resolution slow-frame-speed video camera and 1958 vintage cathode-ray oscilloscope[11] which Berger was forced to use.

4.2 Quality of Results: Cumulative Distribution of Peak Current

The table below comes from an analysis (Hussein et al 2003) which compares Berger's findings of the distribution of peak currents with those of more recent but similar studies.

Table 1: Hussein et al comparison of Berger findings.

	Absolute Current Peak [kA]					
	min.	max.	mean	95%	50%	5%
CNT	1.01	59.2	9.0	2.2	7.2	23.3
ESB	2.5	60	-	4.17	9.99	33.91
Berger	1.9	101.6	-	3.5	12.1	63.8
German Tower	1.57	21.1	8.49	2.53	8.05	17.89
New Mexico	0.1	40.0	17.94	3.47	18.26	37.73
Florida	5	49	13.48	6.14	11.75	38.47

Berger's data was 200% – 300% higher than 5 similar recent studies employing broad band high-resolution current measurement systems.

4.3 Quality of Results: I-peak Distribution—Positive vs. Negative Flashes

As mentioned above, Berger reported that positive CGs were characterized by higher I-peaks and greater charge than negatively charged CGs.[12] IEC 61312-1 concluded from this that the I-peaks of positive (cloud-to-ground) return strokes were much higher than that of their negative counterparts. But when the National Lightning Detection Network (NLDN) completed its census of 60 million measured flashes, it found "***for all values of Imax >75 kA, the large negative CGs outnumbered the large positive CG events by considerable margins.*** In terms of absolute numbers for all ranges of peak current>75 kA, negative CGs are clearly dominant…" [13, 14]

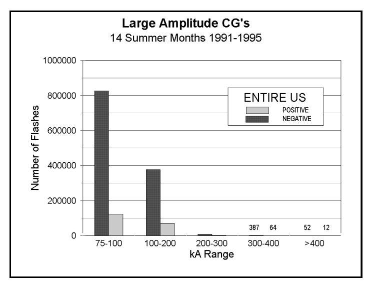

Fig. 2 – NLDN large amplitude +ve and –ve CGs

4.4 Quality of Results: First Return Stroke vs. Subsequent Strokes

Berger reported that negative first strokes represented the largest current in a lighting flash (266% greater than subsequent strokes.) Recent studies have found this is often not to be the case.[15, 16]

4.5 Quality of Results: Long Duration currents.

The long duration currents reported by Berger as a result of his single-station field change measurements have been called into question for another reason: "*The longer durations were obtained from single-station field-change measurements. The few streak-film and TV recordings of continuing current obtained thus far indicate that later portions of the slow field change may not always be from* *continuing current in the channel to ground but may be additional intra-cloud activity.*"[17]

4.6 Quality of Results: Other factors influencing Berger's positive CG stroke data

Recent research has established that the following variables will impact on parameters of positively-charged cloud-to-ground lightning: geography, temperature, latitude, height of structure, time of year, topography, intra-cloud activity, and the recording media itself.

Even Anderson, in Section 5.1.2 of his Electra 69 article wrote: "The possibility of a positive flash incidence of about 10% is noted, however, and it is thought likely that this incidence may well vary seasonally, as well as in different regions of the world and on prominent structures. **The incidence and characteristics of positive flashes thus requires to be measured in different countries."**

All of Berger's data came from two TV towers atop one mountain above a small lake in a small country in central Europe. There is no way that 26 recordings all made from that single location can be offered as representative of "positively-charged cloud-to-ground lightning."

4.7 10/350 µs Waveform—Berger's opinion of it

IEC 61312-1 introduced the 10/350 µs waveform in 1995.[18] This waveshape is based solely on these 4 recorded positive CG flashes.

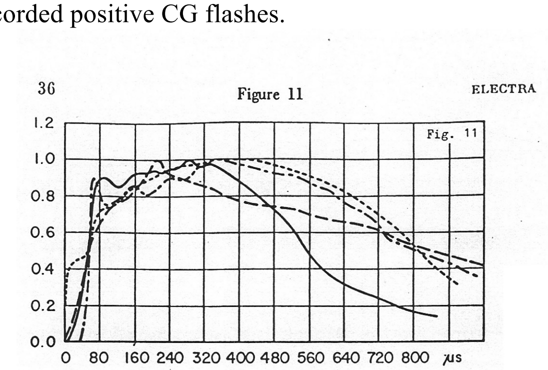

Fig. 3 - Berger's "Fabulous Four" from *Electra 41*.

Berger warned against using this data to promulgate some kind of representative positive CG waveform. On p.35 of Electra 41 he wrote: " *positive strokes…do not have enough common features to produce an acceptable mean current shape. This may also be due partly to the small number of positive strokes which were recorded in the period. A selection of 4 of the most typical of 21 recorded curves is therefore shown in Figure 11.*" [19]

Thus can be seen that TC 81, by imputing a 10/350 µs waveform to Berger's results, did exactly what Berger cautioned should not be done.

The controversy of the 10/350 waveform continues to rage and is best seen in the following 2 quotes:

"The 10/350 waveshape is contrived rather than the result of scientific analysis."[20]

"The 10/350 waveform is the "ideal" power source."[21 22]

5. BERGER'S POSITIVELY CHARGED CLOUD TO GROUND LIGHTNING

IEC 61312-1 explains quite clearly its justification for adopting the parameters of Berger's positively charge cloud to ground (CG) lightning:

"As a first approach it is assumed that 10% of all flashes are positive and 90% are negative. Despite this low ratio of positive to negative flashes, ***the positive ones, consisting only of a first stroke and a long duration stroke, determine the maximum values of the parameters I, Q and W/R to be considered.****"*

Following this logic TC 81 extracted the following values from Berger's table reported to represent positive CG lightning.

Table 2: Values taken from Electra 41
Positively Charged CG (Cloud to Ground)

Parameter	Unit	Maximum Value
Peak Current	kA	250
Charge	C	350
Impulse charge	C	150
Integral I^2dt	$A^s s$	1.5×10^7
Stroke duration	µs	2000

They reasoned that they would be safe if they used the maximum value of these parameters. They then went one step further. They asserted that these parameters somehow represented the shape of "direct lightning." [23, 24]

Directly from the above came the idea of a 10/350 µs waveform.[25] Directly from the above came the parameters for charge and I-peak that became the IEC's "Class I Test" for SPDs.[26] Directly from the above came the IEC's "Lightning Protection Zone" system.[27]

Unfortunately, there is a glitch. There is another entirely different type of lightning, known as upward lightning flashes, which "originate from stationary grounded objects, usually tall towers, and propagate upward toward charged clouds overhead. Upward lightning, as opposed to "normal" downward lightning, would not occur if the object were not present and hence, can be considered to be initiated by the object."[28] Berger was fully aware of upward lightning since 84% of the lightning striking his towers in Switzerland was of that variety.

Fig. 4 - Picture of an upward lightning strike propagating from Berger's TV tower on Mount San Salvatore.

Berger had the following to say about it in Electra 41: "***Since upward flashes are thought to be primarily associated with the effect of the television towers on Mount San Salvatore, the analysis presented in this report deals exclusively with downward flashes, which are believed to be more representative of natural lightning.*** "

Shortly after the publication of Electra 41, Berger realized his equipment was insufficiently discriminative to allow him to determine with certainty whether what he was observing was actually positively-charged lightning or whether it was upward lightning. He wrestled with this problem for awhile, but had it resolved by the time Electra 69 was issued in 1980. Anderson explained on page 81 of Electra 69: "**Berger has recently pointed out that all positive records from this station should, in fact, be classified as upward discharges."**

On p. 84 he amplified this: "Note: the parameters of positive flashes were originally analyzed by Berger et al (Electra 41) in 1975 – but on the assumption that these were downward flashes. In his new analysis, he has …classified all these records as upward. In consequence, there is apparently no comprehensive source of data available on the impulse characteristics of positive downward flashes."

Anderson's data is corroborated at the beginning of Chapter 5 of *Lightning* by Rakov/Uman: *"**Finally, Berger and Garbagnati (1984) assigned all 67 positive flashes observed on Monte San Salvatore to the upward discharge category**…"*

In simple terms the "positive CG flashes" whose parameters were adopted as the IEC 62305 lightning model turn out to have not been positive CG flashes at all.

6. CONCLUSION: A TIME FOR DAMAGE CONTROL

Anyone can make a mistake. It is the mark of the truly great men and their institutions, that when confronted with incontrovertible evidence of wrongdoing, they will take immediate steps to right the matter.

Berger and Anderson were both that kind of people. Politics didn't influence them, neither did commercial interests. They were interested in discovering scientific truth and when they discovered their data on "Positively-Charged Cloud to Ground" lightning In Electra 41 was completely without basis, they were the first to admit it.

In as much as the most fundamental principle upon which the 62305 standards was based (i.e. the model of the lightning environment coming from Electra 41) has been found to be not only badly flawed, but completely lacking a scientific basis, the 62305 documents should be immediately recalled pending review.

The lightning model parameters taken from Berger's Electra 41 study of the positively-charged cloud-to-ground lightning that turned out to have not been cloud-to-ground lightning at all, must be immediately removed from IEC standards. These include, but are not limited to:

1) Any reference to a 10/350 µs waveform
2) Any reference to a total stroke charge (Q) of 100, 200, 250, or higher coulomb values
3) Any reference to a Class I test that must utilize the above values
4) Any reference to a system of Protection Zones which requires SPDs to be used based on the above values.

Once a matter such as this (with such potentially deadly and devastating consequences) is brought to attention, it behooves the responsible parties to immediately and forcefully act upon it. In doing so they would be following the ethical path so well exemplified by their predecessors Berger and Anderson. Lightning is lightning, whether it strikes in the European Union, in China, or in the USA. The IEEE and IEC should convene an emergency joint summit meeting to hammer out a workable and reasonable lightning model based on the wealth of existing scientific data. -- January 2009

7. REFERENCES

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[2] *Data Sheet No. 1 – December 2000* Issued by the French Lightning Protection Association

[3] IEC 61312-1 appears as a normative reference in many of the earlier IEC references. See for example IEC 61643-1, in which Annex A p.143 gives IEC 61312-1 as the only reference for its lightning test parameters. IEC 61643-12 gives the 61312-1 reference with the accompanying warning on page 23: "indispensable for the application of this part of IEC 61643." See also bibliography in IEC/TR 61400-24 p. 68. Also IEC 60364-5 Cl. 534.1.2.

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[23] IEC 1312-1 See clauses 2.2 and 3.1

[24] See for example IEC 62305-1 Table E2, IEC 62305-1 Clause E-4A, and IEC 62305-4 Clause C.1 p. 78.

[25] IEC 1312-1 Annex B 1st paragraph.

[26] IEC 61643-1 *2001 Surge Protective Devices Connected to Low Voltage Power Distribution Systems – Part 1: Performance Requirements* Edition 1.1 2001 p. 143

[27] IEC 1312-1 Section 3