On the Influence of Measuring Instruments Bandwidth Limitations on the Inferred Statistical Parameters for Lightning Currents

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Abstract

We present a general methodology to investigate potential effects on the statistical assessment of lightning current parameters due to bandwidth limitation in measuring systems. The proposed methodology is illustrated starting from pure log-normal distributions for current peak and risetime and assuming different upper frequency bandwidths for the measuring system (250 kHz, 500 kHz and 1 MHz). It is shown that, depending on the cutoff frequency of the measuring system (assumed to be a low pass filter), the resulting statistical parameters can be significantly affected.

1. Introduction

The knowledge of lightning current parameters is of primary importance for understanding the involved physical processes, for evaluating lightning interaction with electrical systems, and for designing efficient lightning protection systems [1]. In addition to direct measurement using instrumented towers (e.g., [2]) and artificially-initiated lightning (e.g., [3]), channel-base current parameters can be indirectly estimated from measured electromagnetic fields (e.g., [4]).

Among instrumented towers, recorded data at Mount San Salvatore by Berger and collaborators [2] are still considered to be the reference in lightning protection standards. However, the data of Berger et al. suffered from the technological limitations of instruments essentially associated with an insufficient frequency bandwidth of the measurement system.

Data from other currently operations instrumented towers are also bandlimited. For instance, statistical parameters for data from the Gaisberg tower in Austria were calculated after applying a 250 kHz low pass filter to the current waveforms [5]. Also, denoising algorithms were applied to some of the data obtained on other instrumented towers, such as CN Tower in Toronto [6] and Säntis Tower in Switzerland [7]. Thus, the limited frequency bandwidth may be due to the frequency response of either measuring sensors, or the acquisition system, but also due to the presence of denoising filters or digital postprocessing.

Statistical parameters of lightning currents may be affected by the limited frequency response of measuring systems, as well as by lower and upper bounds for the measured peak currents. To the best of the authors' knowledge, there is no study on how these limitations may affect the derived statistical data.

In this paper, a first attempt is presented to address this issue where we investigate possible effects of limited frequency response of measuring systems on statistical distribution of lightning current peaks and risetimes. The structure of the paper is as follows. In Section 2, we describe the proposed methodology. Section 3 presents simulation results on the effect of limited frequency response on the statistical distribution of lightning current peak and risetime. Finally, conclusions are given in Section 4.

2. Methodology

The general methodology that we have adopted to investigate possible effects of bandwidth limitation in the measuring system consists of three steps, described as follows.

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Step 1: *Generation of a set of lightning current waveforms satisfying 'ideal' distributions*.

Statistical distributions of lightning current parameters are given in international lightning protection standards (e.g., IEEE STD 1410-2010, IEC 62305-1). These distributions are largely based on direct current measurements by Berger et al. [2] and they are generally assumed to be log-normal [8]. We have assumed in this study log-normal distributions for the lightning current peak and for the 10-90% risetime[1]. The parameters of the assumed log-normal distributions are given in Table 1. The adopted parameters are similar to those associated with subsequent strokes. We have then generated a set of *N* current waveforms satisfying the log-normal distributions for the peak and the risetime. Each waveform is represented using Heidler's function [9]

$$i_0(\mathrm{t}) = \frac{I_0}{\eta} \frac{\left(t/\tau_1\right)^n}{1+\left(t/\tau_1\right)^n} e^{-t/\tau_2} \tag{1}$$

The parameters of the Heidler's functions were determined according to Table 2.

Table 1 – Assumed parameters for the log-normal distributions of current peak I_o and 10-90% risetime t_r.

Parameter	Median	Logarithmic (base e) standard deviation
I_o (kA)	12.67	0.61
t_r (μs)	0.67	0.80

Table 2 – Parameters of the Heidler's function represeting current waveforms

Parameter		**Description**
I_o	Peak current	Log-normal distribution
τ_1	Front time constant	Based on log-normal distribution of 10-90% rise time
τ_2	Decay time constant	$10\tau_1$
n	Current exponent	10
η	Amplitude correction factor	$\exp\left(-\frac{\tau_1}{\tau_2}\left(n\frac{\tau_2}{\tau_1}\right)^{\frac{1}{n}}\right)$

Step 2: *Evaluation of the effect of the bandwidth limitation of the measuring system*

Figure 1 shows a general model of a linear measurement system from the sensor to the final data [10]. In this figure, $H_s(\mathrm{f})$, $H_e(\mathrm{f})$, $H_d(\mathrm{f})$ and $H_p(\mathrm{f})$ represent transfer functions associated, respectively, with the sensor, analog electronics unit that preprocesses the waveforms before digitization, digitizer, and post processing blocks.

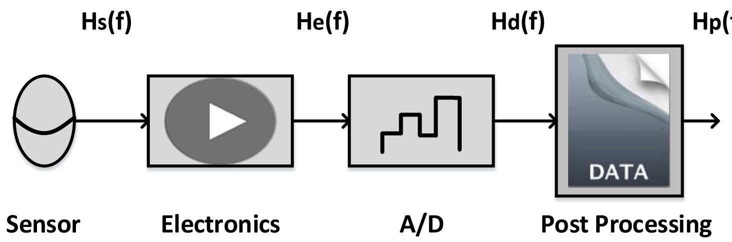

Fig. 1 – Model of a linear measurement system from the sensor to the final data (adapted from [10]).

[1] Any possible correlation between current peak and risetime was disregarded in this study.

In this study, for the sake of simplicity, an ideal first-order low-pass filter with a cutoff frequency $f_c = \omega_c / 2\pi$ is assumed as the overall frequency response of the system. Output responses of the system $i_{out}(t)$ are obtained numerically for each of the N initial waveforms $i_0(t)$ using the following equation, which results from the convolution integral for a first-order filter [11].

$$i_{out}(t) = \omega_c \exp(-\omega_c t) \int_0^t i_0(\tau) \exp(\omega_c \tau) d\tau \tag{2}$$

Step 3: *Extraction of the statistical parameters of the output waveforms*

Probability plots of the output waveforms (peak and 10-90% risetime) are derived and compared with the initially assumed distributions.

3. Results

A set of N = 10'000 waveforms were generated according to the procedure outlined in the previous section. Three different cutoff frequencies of 250 kHz, 500 kHz and 1 MHz were assumed in order to investigate the effect of the measuring system bandwidth.

Figs. 2 and 3 present the resulting probability distributions for the three considered cutoff frequencies.

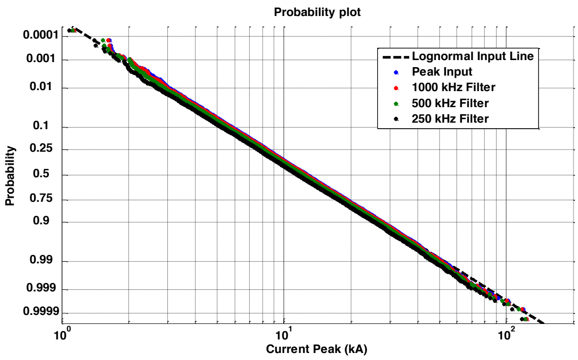

Fig. 2 – Probability plot of peak current

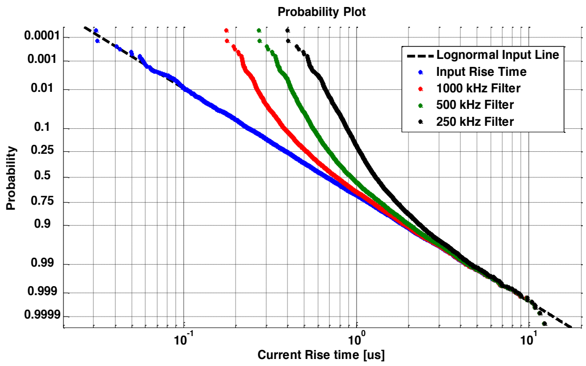

Fig. 3 – Probability plot of the risetime

It can be seen that the current peak and the risetime are affected very differently by a limited bandwidth of the measuring system. In Figure 3, it can be seen that a limited bandwidth affects more significantly the part of the probability distribution associated with shorter risetimes than the part associated with longer risetimes. The low pass filtering moves waveforms with fast risetemes to lower-risetime bins in the probability curve. As expected, the lower the cutoff frequency, the higher the deviation of the filtered distributions from the ideal lognormal curve in Fig. 3.

Comparing Figs. 2 and 3, it can be seeen that the effect of low-pass filtering on the probability distribution of the peak current is less significant than for the risetimes. In addition, contrary to the case of the risetimes, the effect appears to affect the whole range of the peak currents relatively evenly.

4. Conclusion

In this paper, we presented a general methodology to investigate possible effects of bandwidth limitation in measuring systems for lightning currents. The proposed methodology was illustrated starting from log-normal distributions for current peak and risetime and assuming different upper frequency bandwidths for the measuring system (250 kHz, 500 kHz and 1 MHz). It was shown that depending on the cutoff frequency of the measuring system, the resulting statistical parameters can be significantly affected.

Future work includes the extension of the proposed methodology to decontaminate statistical distributions resulting from the limitations in the response of the measuring system, either due to limited frequency response or finite upper and lower bounds for the peak current.

6. Acknowledgments

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7. References

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