

TODAY'S PROBLEMS WITH THE EVALUATION METHODS OF FULL LIGHTNING IMPULSE PARAMETERS AS DESCRIBED IN IEC 60060-1

S. Berlijn,
M. Kvarngren*

KEMA Nederland B.V.,
High-Voltage Laboratory,
The Netherlands
*Kungl Tekniska Högskolan,
Dept. of Electric Power
Engineering, Sweden

F. Garnacho,
P. Simon

Fundacion para el
Fomento de la
Innovacion
Industrial-LCOE,
Spain

E. Gockenbach, P. Werle,
K. Hackemack

Schering-Institute of High
Voltage Technique and
Engineering University of
Hannover, Germany

M. Watts,
K.C.P. Wong*

NGC Engineering &
Technology,
*University of
Sunderland, School
of Engineering,
United Kingdom

ABSTRACT

In this paper the present problems with the evaluation methods for lightning impulse parameters, as defined in IEC 60060-1, are described. Also the current practice of evaluation in many laboratories world-wide, that is obtained by a questionnaire, is presented. Some of the work performed up to the present time and the initial conclusions are reported, then some recommendations are made for future work.

I. INTRODUCTION

Tests with impulses are designed to demonstrate the response of high voltage equipment to transients over a wide frequency range. Lightning impulse voltages represent transients occurring in high voltage systems under operating conditions. Therefore tests with lightning impulse voltages are part of routine and type tests. For the evaluation of the test results it is imperative to determine the characteristic parameters of these lightning impulse voltages as defined in international standards. At present the standard lightning impulse voltage is defined in IEC 60060-1 [1] by its peak value (U_p) and its time parameters; the front time (T_1) and the time to half value (T_2).

Reproducibility of the calculation of the parameters with various algorithms is possible for smooth impulses, but the definitions in IEC 60060-1 and IEEE Std. 4 are insufficient for the evaluation of wave shapes with oscillations and/or overshoot [2]. It is well known that even bigger problems with the evaluation of parameters arise when the impulse is a non-standard lightning impulse voltage, since no guidelines are given in IEC 60060-1.

KEMA, FFII-LCOE, Schering-Institute (University of Hannover) and NGC have collaborated in a project funded by the European Community through its SMT program. The aim of this international project is to define one or more sets of parameters to characterise full lightning impulses, prove the relevancy of these parameters and establish unambiguous algorithms to evaluate them and write a proposal for the relevant parts of IEC 60060-1 and IEC 61083-2. The project was started at January 1 1997 and it will end at July 1 1999.

In the framework of this project, today's problems with present definitions were studied. A questionnaire was sent to several laboratories world-wide, to obtain information about the present evaluation problems and the evaluation methods used by different laboratories.

II. DEFINITIONS IN IEC 60060-1

In order to point out where the problems with the interpretation are, hereafter a brief revision of the definitions of IEC 60060-1 relating to full lightning impulses is given.

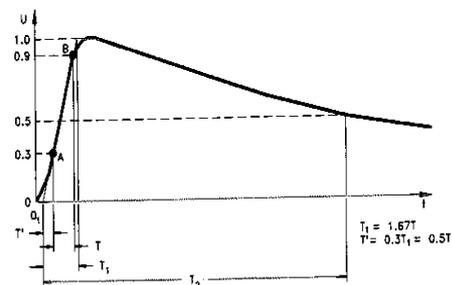


Figure 1: Evaluation rules for a Full lightning impulse according to IEC 60060-1

A. Value of the test voltage

During testing of actual specimens, impulses with different wave shapes can occur. Besides the standard full lightning impulse (Figure 1), also impulses with wave shapes as shown in Figure 2, Figure 3 and Figure 4 can occur.

For a lightning impulse without oscillations or overshoots, the value of the test voltage is its peak value. For lightning impulse with oscillations or overshoots the evaluation method for test voltage is depending on the amplitude and duration of the overshoot or frequency of the oscillation. In any case, a mean curve, that has neither overshoot nor oscillations has to be drawn to decide if there are oscillations or overshoot in the recorded impulse.

Overshoot or oscillations in the neighbourhood of the peak, measured by a system according to IEC 60060-2 [3], are tolerated provided their single peak amplitude is not larger than 5% of the peak

value. If the amplitude of the oscillation or overshoot is larger than 5% the impulse does not represent a standard impulse. For these and other impulse shapes (see for example Figure 3) the relevant Technical Committee shall define the value of the test voltage taking into account the type of the test and test object.

If the amplitude of the oscillation or overshoot are not larger than 5%, the duration of the overshoot or the frequency of the oscillation has to be determined. If the frequency of such oscillations is not less than 0,5 MHz or the duration of overshoot not more than 1 μs , as in Figure 2 a) and b) a mean curve that has neither overshoots nor oscillations should be drawn. For the purpose of measurement, the maximum amplitude of this curve is chosen as the peak value defining the value of the test voltage. In the cases of Figure 2 c) and d) the peak value of the original wave is considered to be the test voltage.

B. Front Time T_1

The front time T_1 of a lightning impulse is a virtual parameter defined as 1,67 times the interval T between the instants when the impulse is 30% and 90% of the peak value U_p , (points A and B, Figure 1).

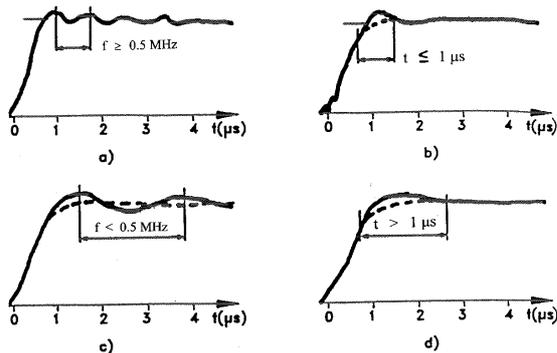


Figure 2: Evaluation rules for lightning impulses with overshoot or oscillation

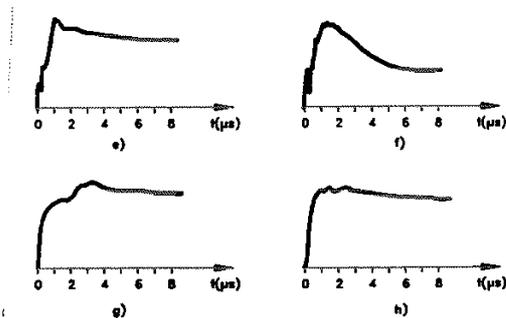


Figure 3: Examples of non standard lightning impulses

C. Time to half-value T_2

The time to half-value T_2 of a lightning impulse is a virtual parameter defined as the time interval between the virtual origin O_1 and the instant when the voltage has decreased to half the peak value.

III. HOW TO INTERPRET IEC 60060-1?

Independent if manual or digital evaluation methods are used, there are some problems with the interpretation of IEC 60060-1. The following list is of some of the problems associated with the definitions and interpretation of the standard. They are certainly not all of the questions to be resolved, but most of them are probably included.

- What is the definition of the mean curve, especially for impulses with both overshoot and oscillations?
- How to determine the $T_{30\%}$ and $T_{90\%}$ when there are oscillations close to these times (see case no. 11 in IEC 61083-2 [4])?
- For the calculation of the front time, T_1 , the peak value should be used as reference for the 100% value of the impulse. When you have overshoots or oscillations, which peak value shall be used, the peak value of the original impulse or the peak value of the mean curve?
- How should the amplitude and duration or frequency of overshoots and oscillations be calculated?
- How should a non standard wave shape, for instance those that occur during real testing, see Figure 3 or Figure 4, be evaluated?
- How to know if they are inside the tolerances of IEC 60060-1?
- What is the physical background that supports the “magical 0,5 MHz value” for the frequency of oscillations and the “1 μs value” for the duration of the overshoot?
- Are the parameters described in IEC 60060-1 really the parameters that characterise the breakdown process? Could other parameters describe this process better?
- Should the same parameters be used for all materials (XLPE, SF6, oil, vacuum, etc.)?

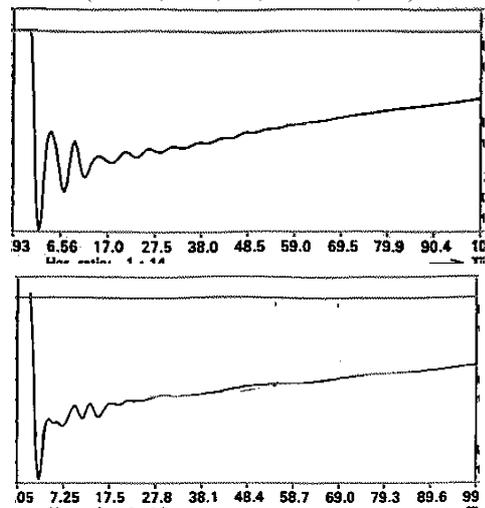


Figure 4: Typical lightning impulses in transformer testing

IV. CURRENT PRACTISE IN LABORATORIES

In order to know how the high-voltage laboratories around the world are facing the evaluation problems and to note which evaluation methods are used, two different questionnaires (one for manufacturers and testing laboratories and another one for calibration laboratories) were prepared.

In the questionnaire questions were asked, amongst others, about the kind of measuring instrumentation used to measure voltage and time parameters of lightning impulses. Also questions were asked about details of the test circuit that they think are relevant when oscillations and overshoot are present. Besides this, questions were asked how these laboratories evaluate voltage and time parameters in the cases of full and chopped impulses with oscillations superimposed ($f \geq 0,5$ MHz) and/or overshoot ($d \leq 1$ μ s). Only manufacturers and testing laboratories were asked about the possible influence on the breakdown behavior of dielectric materials of these overshoots and/or high frequency oscillations with small amplitude superimposed to the lightning impulse. Below the result of the questionnaire is presented.

A. Results of the questionnaires

The questionnaires were answered by 23 manufacturer laboratories, by 8 testing laboratories, and by 12 calibration laboratories, all over the world.

The manufacturers laboratories were classified in power transformers, cables and other high voltage equipment.

Some of the questions were focused on the evaluation of lightning impulse waveforms when high frequency oscillations ($f \geq 0,5$ MHz) or short duration overshoots ($d \leq 1$ μ s) are superimposed on the impulse. The main conclusions are summarized below.

B. Manufacturers laboratories

For full impulses:

- The majority of manufacturers of power transformers and cables use the maximum value as the test voltage (not in accordance with IEC 60060-1), while the majority of manufacturers of other high voltage equipment considers the peak value of the mean curve.
- The majority of the laboratories determines T_1 from the original curve, using the peak value of the mean curve as the 100% value.
- Only some manufacturers of transformers determines T_1 from the original curve, using the peak value of the original curve as the 100% value.

For chopped impulses:

- For the two methods to determine the test voltage (maximum value, or the peak value of the mean curve) the majority of laboratories uses the maximum value.

For the questions to the possible influence of oscillations and overshoot:

- About 30% of the manufacturer laboratories supplied information of the possible influence on the breakdown behaviour of different dielec-

tric materials, when overshoots and/or high frequency oscillations are superimposed on the lightning impulse. There was no agreement between the received answers.

C. Testing laboratories

For full impulses:

- All laboratories consider the peak value of the mean curve as the test voltage, which is in accordance to the standard IEC 60-1.
- The majority of the laboratories uses a mean curve that removes the oscillations to determine the time parameters.

For chopped impulses:

- Almost all laboratories consider the maximum value at the test voltage.
- The majority of the laboratories considers the time to the point when the voltage decreases suddenly as the time to chopping.

The answers from testing laboratories are in a better agreement than the ones of manufacturer laboratories, and are also in better agreement with IEC 60060-1.

D. Calibration laboratories

For full impulses:

- Half of the laboratories considers the peak value of the mean curve as the test voltage and the other half considers the maximum value the test voltage.
- The majority of the laboratories uses a mean curve that removes oscillations to determine the time parameters.

Calibration laboratories propose some alternative methods for evaluating lightning impulses, which are not described in this paper.

For chopped impulses:

- The majority of the laboratories considers maximum value the test voltage.
- There is no general agreement on how to determine the time to chopping, although in the majority of the answers the time to chopping is considered to be the time when the voltage decreases suddenly.

V. STATE OF THE ART AND FUTURE WORK

The accuracy in the determination of impulse parameters is limited when using analogue measuring instruments and manual evaluation. The digital measuring techniques removed this limitation, being the reason for the replacement of analogue measuring equipment by digital measuring equipment [5]. The use of digital measuring equipment have made it possible to improve the accuracy, but also introduced some more evaluation problems.

For many years people have attempted to find a solution for the evaluation problems, which have mainly been focused on the definition of the mean curve.

Because computers are used for the evaluation, modern methods for calculating the mean curve can be used [6, 7].

Besides that the present rules for the evaluation of parameters are ambiguous, it can be questioned whether the present parameters are the most suitable ones for modern insulating materials. Also because the change from analogue to digital measuring equipment removed limitations in the number and type of parameters used to characterise lightning impulses, it was appropriate to start investigate the relevancy of present or new parameters. As mentioned in the introduction KEMA, FFII-LCOE, Schering-Institute (University of Hannover) and NGC are collaborated in a project funded by the European Community to investigate the relevancy of parameters for different insulating materials (SF₆, XLPE, oil, air and vacuum).

To test the relevancy of for instance U_p , T_1 , and dU/dt , tests mentioned in Table 1 will be performed for homogeneous and non-homogeneous fields as well as for both positive and negative polarities:

Table 1 Tests to be performed

Parameters to vary	Parameters to keep constant
$0,5\mu s < T_1 < 2,0\mu s$	$T_2 = 50\mu s$
$200\text{ kHz} < f < 5\text{ MHz}$ $5\% < A < 20\%$	$T_1 = 1,2\mu s$, $T_2 = 50\mu s$
$200\text{ kHz} < f < 5\text{ MHz}$ $5\% < A < 20\%$	$T_1 = 1,2\mu s$, $T_2 = 50\mu s$, $U_p = U_{10\%}$

For this purpose, a special generating circuit, as shown in Figure 5, has been designed and built. The special generating circuit comprises of two parts that are very nearly independent. One part generates a standard lightning impulse and the other part generates the oscillations or overshoots superimposed. In Figure 6 an example of a generated impulse is shown. It can be seen that this looks similar to the impulses in Figure 4.

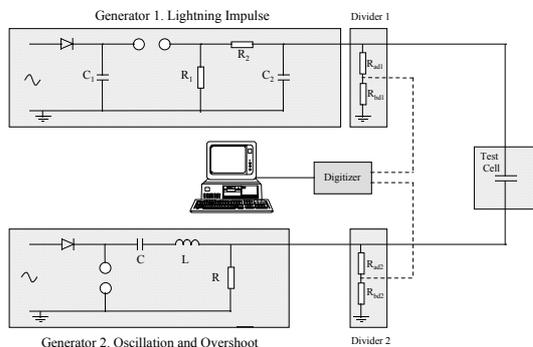


Figure 5: Special generating circuit

VI. CONCLUSIONS

The main conclusion of the questionnaire is that different laboratories are using different algorithms and evaluations methods. Some of them are quite far of the IEC 60060-1 rules, as for power transformer

manufacturers. The differences in the obtained parameters when evaluating the same impulse are large, because of these dissimilar evaluation methods.

Besides this, there is not a well-established physical background about the relevancy of the parameters, and the information supplied by the laboratories on this subject is contradictory. Because of this it can be questioned whether the present parameters and evaluation methods used are the most suitable ones.

The conclusions mentioned above, were the reason the research project funded by the European Community was started. The results of tests performed or to be performed are not available at the time of printing and will be published at a later time.

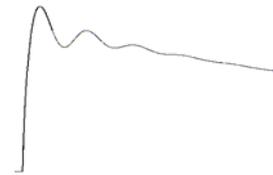


Figure 6: Example of a generated wave shape

VII. ACKNOWLEDGMENT

The authors thank the European Community for financial support of the project "Digital Measurement of Parameters used for Lightning Impulse Tests for High Voltage Equipment" that is within the scope of the SMT-programme contract no. PL-95120-SMT4-CT96-2132 and the institutions involved in this project: KEMA (Netherlands), F²P-LCOE (Spain), NGC (UK), Schering-Institute (Germany). The authors also thank all laboratories who filled in the questionnaire.

- [1] IEC 60060-1: "High Voltage test techniques, Part 1: General definitions and test requirements": 1989.
- [2] F. Garnacho et al.: "Evaluation procedures for lightning impulse parameters in case of waveforms with oscillations and/or an overshoot". 96 SM 522-3 PWRD, IEEE Power Engineering Societe. Summer Meeting. Denver 1996.
- [3] IEC 60060-2: "High Voltage test techniques, Part 2: Measuring systems": Second Edition 1994.
- [4] IEC 1083-2: "Digital recorders for measurement in high-voltage impulse test-part 2: Evaluation of software used for the determination of the parameters of impulse waveforms" International standard, First Edition, 1996.
- [5] Gockenbach, E.: "A basic concept for the use of digital recorders in high voltage impulse measuring technique", 8th ISH, Yokohama Japan, 1993.
- [6] A. Brede, P. Werle, E. Gockenbach, H. Borsi: "A new method of determining the mean curve of lightning impulses according to IEC 60060-1" 11th ISH, London, 1999.
- [7] K.C.P. Wong, J. Tindle, H.M. Ryan, M. Watts: "Digital measurement of lightning impulse parameters using curving fitting algorithms" 11th ISH, London, 1999.