Effect of the overshoot level in an alternative method for processing of tail chopped lightning impulses

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Abstract: The construction of new Ultra High Voltage laboratories requires more studies about standards for equipment, as well as for testing and measurement techniques. Currently, the analysis of tail chopped lightning impulse waveforms is possible only by prior application of a full reference lightning impulse, creating difficulties for testing and processing of waveforms. A new method for evaluating the relevant parameters of tail chopped waveforms has been previously developed and this paper studies the effect of the overshoot in this alternative method.

Keywords: UHV, testing, calibration, tail chopped lightning impulse.

1. INTRODUCTION

The energy transmission perspectives in Ultra High Voltage (UHV), with 1200 kV AC and ±1000 kV DC, requires a new laboratory infrastructure for testing equipment used in UHV. The current facilities at high voltage equipment suppliers and at research labs, for the most part, are limited to 765 kV AC and ±600 kV DC. The construction of new laboratories to cater to UHV systems requires more studies about standards for equipment, as well as for testing and measurement techniques. Consequently, with the increase in the voltage levels for AC and DC transmission systems, some adaptations and changes to existing standards might become necessary.

The current version of the standard IEC 60060-1: "High-voltage test techniques, Part 1: General definitions and test requirements" [1] issued in 2010 by the International Electrotechnical Commission (IEC) has as the main requirement, with regard to lightning impulse tests, the test voltage function, established based on experimental results of a European project. The test voltage function is frequency dependent and is the response of the equipment insulation to impulses with overshoot, being given by

$$k(f) = \frac{1}{1 + 2.2f^2}, \qquad (1)$$

f being the frequency in MHz.

The revision of IEC 60060-1 also includes a description of the assessment process to the test voltage, as currently all recording instruments are based on digital recorders.

In practice, the use of the test voltage function involves digitally filtering the original waveform and calculating the amplitude and time parameters from this filtered waveform. This processing, described in the standards for impulses, should be applied also to tail chopped lightning impulse waveforms.

The processing is briefly described with the help of figure 1, starting with the original data record $U_0(t)$, from which the base curve $U_m(t)$ is obtained by adjusting a double exponential. The difference between the base curve $U_m(t)$ and original curve $U_0(t)$ gives the superimposed oscillation $R(t)$ (basically the overshoot information), which is filtered by the test voltage function $k(f)$ according to equation 1. By summing the filtered oscillation to the base curve $U_m(t)$, one obtains the test voltage curve $U_t(t)$, from which the test voltage value U_t and the time parameters are determined. [2]
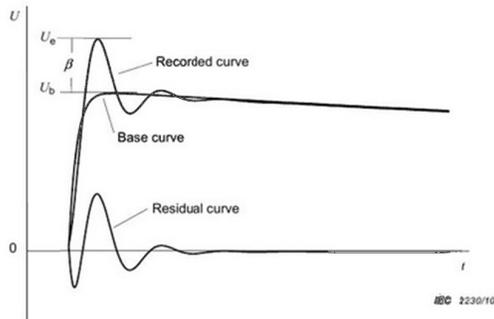

Figure 1. Recorded and base curve showing overshoot and residual curve.

Practically all tests involving high voltage equipment with large dimensions have the presence of overshoot, which is caused mainly by the inductance of the high voltage conductor, the capacitance of the object under test, as well as the intrinsic parasitic capacitances of the test arrangement. This LC circuit induces overshoot in the crest of the impulse waveform, being difficult to compensate it.

In the present paper, a study is performed on the effect of overshoot in tail chopped lightning impulses, based on experimental results with various waveforms, calculating the relevant parameters (value of test voltage U_t, front time T_1 and time to chopping T_c). These results are compared with the results of an alternative method which excludes the need for a full lightning impulse as a reference waveform.

2. TAIL CHOPPED LIGHTNING IMPULSES

Tail chopped lightning impulses (LIC) are based on a standard full lightning impulse, which rises to its peak value in around 2 µs a 5 µs and slowly falls to zero. After the application of the full lightning impulse, using the same impulse generator settings, it is then inserted a chopping gap to cause disruption of the waveform.

Referring to figure 2, the parameters that need to be calculated to evaluate the tail chopped lightning impulse waveform, according to the IEC 60060-1 standard, are the time parameters T_1 (front time) and T_c (time to chopping), which is the time interval between the virtual origin O_1 and the instant of chopping t_c (extrapolation of the line between the 70% and 10% points on the voltage collapse) and the amplitude parameter U_t (value of the test voltage), which is essentially the extreme value of the waveform. O_1 is the intersection with the time axis of the line through points A (30% of peak) and B (90% of peak).
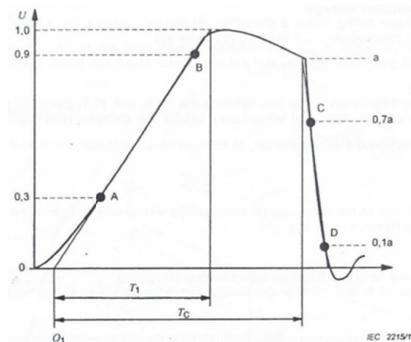

Figure 2. Typical normalized tail chopped lightning impulse showing the relevant time parameters T_1 and T_c.

A lab bench recurrent surge generator RSG 482 from Haefely has been used to generate full reference lightning impulses and corresponding tail chopped lightning impulses. Tail chopped waveforms with front time $T_1 = 1.280$ µs, time to chopping $T_c = 6$ µs and test voltage $U_t = 49$ V have been generated, with 3 levels of overshoot (0%, 4% and 20%). The data has been acquired by the system IMPREAL 2.0 (acronym for Impulse Response Analysis), developed in LabVIEW 2011, which acquires, analyses and calculates the relevant time parameters for the six types of high-voltage impulse waveforms [2].

3. STANDARD PROCESSING ACCORDING TO IEC 60060-1

This processing is used for the test voltage curve, from which the impulse parameters are calculated. This processing is dealt with more details in [3] with good results.

Table 1 presents the time parameters described in the previous section defined in the standard IEC 61083-2:2010, for the tail chopped lightning impulse using the standard processing with the aid of system IMPREAL 2.0 with 3 levels of overshoot (0%, 4% and 20%) and figure 3 shows a zoom on the tail chopped lightning impulse with 20% overshoot, together with the relevant points identified by the software.

Table 1. Results of the standard processing of the LIC impulse with 3 levels of overshoot.

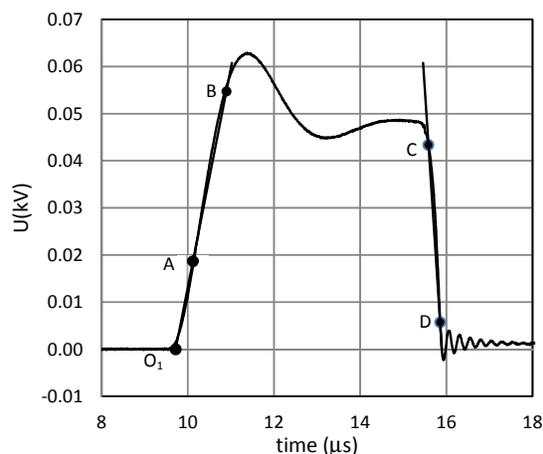| Overshoot	Parameter	Value
0%	Front time T_1 (µs)	1.280
	Time chopping T_c (µs)	6.144
	Test voltage U_t (V)	48.56
4%	Front time T_1 (µs)	1.280
	Time chopping T_c (µs)	5.967
	Test voltage U_t (V)	49.74
20%	Front time T_1 (µs)	1.293
	Time chopping T_c (µs)	5.727
	Test voltage U_t (V)	60.76

Figure 3. Results of the standard processing of the LIC with 20% overshoot. O1 is the virtual origin, A is the 30% point, B is the 90% point, C is the 70% point and D is the 10% point.

4. ALTERNATIVE PROCESSING

According with IEC standard, the need for a full reference lightning impulse is due to the fact that a tail chopped waveform does not follow the smooth double exponential shape, and this would preclude a proper fitting.

However, as the test voltage curve $U_t(t)$ needs to be calculated only up to the instant of chopping t_c, the fitting of the double exponential also needs to be done only for this period.

Thus, if the recorded curve $U_0(t)$ is truncated at t_c, it should be possible to fit a double exponential and proceed with the overshoot processing without the need of the full lightning impulse [4].

This alternative processing has been tested in this paper for the three different levels of overshoot shown in section 3 and the results are shown in table 2, together with a comparison with the standard method, by calculating the percent difference between the estimated parameters.

Figure 4 presents the result of the double exponential fitting described in [4], which yields an acceptable residual, with an RMSE of 1.66%.

Table 2. Results of the alternative processing of LIC impulse with 3 levels of overshoot.

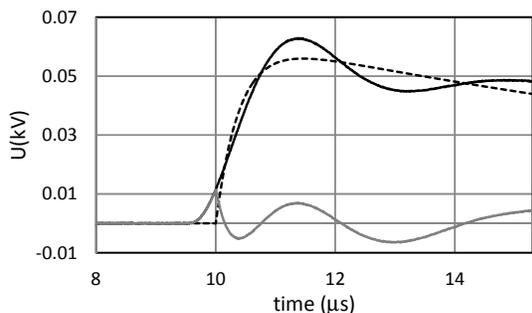| Overshoot	Parameter	Value	Difference
0%	front time T_1 (µs)	1.293	1.02%
	time to chopping T_c (µs)	6.166	0.36%
	test voltage U_t (kV)	48.60	0.08%
4%	front time T_1 (µs)	1.280	0.0%
	time to chopping T_c (µs)	6.005	0.64%
	test voltage U_t (kV)	49.86	0.24%
20%	front time T_1 (µs)	1.253	-3.09%
	time to chopping T_c (µs)	5.879	2.65%
	test voltage U_t (kV)	61.18	0.69%

Figure 4. Fitting of a double exponential to the waveform shown in figure 4 truncated at the instant of voltage collapse. The solid line is the tail chopped waveform, the dashed line is the fitted double exponential, and the gray line is the residual.

5. CONCLUSIONS

This paper presented the effect of the overshoot level in an alternative method for processing of LIC impulses that has the potential to simplify the procedures for this type of high voltage testing. The method was tested with 3 levels of overshoot and compared with the standard method with good results.

For the largest overshoot there is a larger difference between the methods, especially regarding the front time T_1, and the alternative method is presently being refined in order to reduce this discrepancy. As expected, the difference in the time to chopping T_1 increases as the overshoot level increases.

Another aspect that needs to be further studied is the effect of the chopping time on the accuracy of the alternative method.

REFERENCES

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