On the report: EVALUATION OF LIGHTNING VOLTAGES BASED ON EXPERIMENTAL RESULTS

proposal for the revision of IEC 60060-1 and IEC 61083-2,

by F. Garnacho, P. Simón, E. Gockenbach, K. Hackemack, S. Berlijn, P. Werle,

Published in ELECTRA No 204, October 2002, pp. 31-39

BY PROF. L. SATISH AND PROF. B.I. GURURAJ (INDIA)

We have read with great interest the cited paper. At the outset, we place on record our appreciation for efforts taken by authors in planning and conducting extensive experimentation. However, we believe that there are some serious drawbacks in the paper. These are the following. Firstly, a few major concepts, which are proposed in the paper, are wrong in theory. Secondly, the test engineer is misled to believe that, by following the paper, all his worries will be alleviated while processing non-standard, lightning impulse waveforms. Our letter to the Editor covers both these issues.

1. INADMISSIBILITY OF USE OF K-FACTOR CURVE AS GLOBAL FILTER

It is made out in the paper that the experimental results summarized in Section 4 and ending with Equation (4), has directly led to the visualization of a digital filter termed as "global filter".

However, it has NOT BEEN PROVED that the k-factor curve derived from experiments – Figure 3, Curve (d) or the modified version of it, Curve (b) – CAN BE TAKEN AS THE FREQUENCY RESPONSE OF THE PROPOSED GLOBAL FILTER. This error in logic, perhaps, originated from the EU Report – Ref. [5] – is still being continued. Further, the paper projects, as though the "global filter" is a natural and direct outcome of the experiments conducted. This view is INCORRECT. The very fact that, the experimental results are compromised from Curve (d) to Curve (b) just to get DESIRABLE PEAK VALUES for smooth impulses, in itself, shows the fallacy of the approach.

Specifically and, with reference to Fig. A, it has to be proved MATHEMATICALLY that Equation 6 is satisfied for all types of practical impulse waveforms, if the GLOBAL FILTER is to be accepted.

The APPARENT agreement between $U_t$ values in Columns 7 and 8 of Table II is due to the well-known properties of low-pass filters, as well as compromises and adjustments made in the k-factor data rather than a success of application of experimental results.

Determination of time parameters is also important. However, these CANNOT be determined from the output obtained from the "global filter" and are to be determined from the original data. The method suggested by the authors in Section 3.2, last sentence, lacks clarity and leads to different results as seen in Table A.

Method 2 fails even for standard LI while results using Method 1 are unacceptable. This is another disadvantage of the "global filter approach".
2. IMPLEMENTATION ISSUES IN K-FACTOR METHOD USING THE MEAN CURVE

While implementing "mean-curve" approach in Section 5.1, the k-factor curve considered should have been only Curve (d) of Figure 3, as only the experimental results must be used. It is strange that, the authors having found experimentally that k starts to decrease after 160 kHz, have chosen to discard it.

Further, in Table II, Case 11, discovery of a small overshoot, 4 kV in 960 kV, after the first processing using k-factor curve is very puzzling. After having made gross and unacceptable approximations in deriving a single k-factor curve, identification of a mere 0.42% overshoot and its specialized treatment is spurious, more so as the authors themselves started out with the premise that use of mean curves can lead to errors.

The authors state in Section 1 that, difficulties in processing non-standard waveforms was the prime motivation for initiation of this research. Advice in Section 5.1 advocating double-exponential fitting for applying the "mean curve procedure" is often impracticable, particularly for waveforms arising in impulse testing of transformers.

3. EXPERIMENTAL DATA AND ITS STATISTICAL TREATMENT

The extent of adjustment that has been made in arriving at the average k-factor curve will be clear from Fig. B, that shows the original k-factor data for different dielectrics, electrode shapes and polarities. It would seem to be •••

<table>
<thead>
<tr>
<th>Waveform Data</th>
<th>$T_1$ using Method 1 (µs)</th>
<th>$T_1$ using Method 2 (µs)</th>
<th>$T_1$ from IEC Pub. 61083-2, (µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 11</td>
<td>1.38</td>
<td>0.83</td>
<td>1.07 - 1.19</td>
</tr>
<tr>
<td>Case 13</td>
<td>3.55</td>
<td>2.13</td>
<td>3.4 - 3.76</td>
</tr>
<tr>
<td>Case 14</td>
<td>2.38</td>
<td>1.43</td>
<td>1.85 - 2.05</td>
</tr>
<tr>
<td>Std. LI, 1.2/50</td>
<td>1.2</td>
<td>0.7</td>
<td>--</td>
</tr>
</tbody>
</table>

Method 1: linear interpolation between 30% and 90% points, Method 2: linear regression between 30% and 90%.

Table A - Comparison of $T_1$ using different methods.

![Fig. B - k factor data provided by the first author.](image)

[1: Air - uniform field; 2: Air - non uniform field, +ve; 3: oil - uniform field, +ve; 4: XLPE - uniform field, +ve; 5: SF$_6$ - uniform field, +ve; 6: SF$_6$ - non uniform field, +ve; 7: SF$_6$ - non uniform field, -ve]
a statistical wonder that this scattered data, when combined, has resulted in the fitted line segment, answer 1 in Fig. B, which is the same as Curve (d) in Figure 3 of the paper with very small uncertainty bands. While collating the data, the authors have postulated a strange logic that the data of Fig. B should be differentially weighted to favour those with small scatter (this means, in effect, only data for uniform field, air medium). Scatter in the data for any dielectric medium, electrode shape and polarity depends strongly on the breakdown processes and also on sample homogeneity. As all participating laboratories had very good measurement systems, it is incorrect to obliterate the data having such natural scatter. Even more illogical is the assertion that Curve (b) is not deviating much from Curve (d), which is already severely compromised. Therefore, Figure 3 masks much of these serious implications.

4. SUMMARY

Summarizing the situation, one wonders whether the initial goal of removing “ambiguity” and “empiricism” in IEC 60060-1 and IEC 61083-2 has actually been achieved and, in spite of the above mentioned serious shortcomings, would it still be worthwhile to recommend adoption of these methods by IEC?

Answers to the Letter to the Editor:

F. Garnacho, E. Gockenbach, S. Berlijn, P. Werle, P. Simón

The authors thank Prof. B. Gururaj and Prof. L. Satish for their comments in form of “Letter to the Editor” and they would like to answer the statements.

1. USE OF A K-FACTOR CURVE AS GLOBAL FILTER

In the paper published in the ELECTRA no. 204 it is clearly stated that the method for determining the test voltage through the k factor can be implemented in different ways. In fact, three ways are discussed in the paper:

- Direct application of the formula of the test voltage directly.
- Filtering the residual curve.
- Global filtering.

Each implementation method has some advantages and disadvantages. The first one is the reference method, but its use is only possible if the oscillation has a single frequency. The other two methods are now under consideration in a specific Task Force, inside the old WG33.03, in such a way that around 57 impulse waveshapes will be analyzed by different participants, and the advantages and disadvantages will be clearly quantified as well as the implementation errors of each method.

The k factor is derived from equation (3).

\[ U_t = U_{imp} + k \cdot \beta \]

This expression is equivalent to filtering the residual curve (difference between the original impulse and the mean curve) by the k factor curve and then adding the filtered residual curve to the mean curve. The extreme value of the resulting addition is the test voltage. The global filter approach was suggested because the filter proposed (curve b-figure 3) does not significantly affect the double exponential mean curve.

The use of the global filter is not an error in logic, but an approximation to the theoretical method. The authors have studied the global filter approximation and its associated error is less than 1% of the derived values through equation (4) in all ranges of frequencies (from 0.2 MHz to 2 MHz). Nevertheless, the determination of which is the best implementation method is still an open question.
The experimental results are not compromised if curve (b) is selected instead of curve (d), because both curves are inside the measurement uncertainty of the experimental results. Curve (d) was derived giving more weight to the most accurate measurements and punishing the less accurate. In consequence, curve (d) is closer to the result corresponding to air with an homogeneous field because it has a very low type A uncertainty in comparison with other dielectric media results that have greater uncertainty. Repeating the tests with better accuracy could lead to different results within the present uncertainty limits. Therefore, the use of curve (b) or curve (d) in order to allow an easy implementation is a decision that has to be taken when the Task Force work is finished because both curves are statistically compatible with the experimental results.

The agreement between columns 7 and 8 of table II is not apparent, but it is a real fact. If you study the discrepancy between the results obtained applying equation (4) and those by the global filter when you have decided to apply the curve (b) you can see that the maximum discrepancy is around 0.6%. In fact, it is not an apparent agreement but the conclusion of a more extended study of impulses with superimposed oscillations between 0.2 MHz to 2 MHz, with overvoltages around 5% Uc.

The calculation of time parameters is not specifically addressed in the paper. The paper deals with the influence of the front time on the test voltage. Another conclusion is that oscillations in the front were shown to have negligible influence on the breakdown voltage, therefore a method to remove these oscillations (between 30% and 90% of the extreme value of the impulse) should be used, and some method should be agreed in the revision of the standard in order to have reproducible results in the front time calculation.

3. EXPERIMENTAL DATA AND ITS STATISTICAL TREATMENT

The test voltage factor function has been determined using all the experimental data and their associated uncertainties. As different dielectrical media and in general different experimental results have different uncertainties, it is sensible to give more weight to those results of less uncertainty, in such a way that a function considering individual k factors and their uncertainties is defined. The uncertainty of this function finally could be evaluated resulting in quite narrow bands in spite of big scattered measurements. All these studies will be published in further articles.

4. SUMMARY

Summarizing the proposed new k-factor approach substantially improves the present IEC 60060-1 ambiguities and gives more reproducible results.