Digital Processing of Impulse Measurements in Transformer Tests

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Abstract: Tests using high voltage impulse waveforms are used to evaluate power transformers. This test simulates the overvoltage that may exist during a lighting storm. This paper proposes digital processing of the voltages and currents recorded during the test to evaluate if the transformer under test pass or not the standard requirements.

Key words: Impulse test, power transformer, high voltage, peak voltage.

1. INTRODUCTION

Impulse test is a common technique in high voltage laboratories to test many materials and components of power networks. It consists in generating a high voltage pulse that reaches its peak value in times around the microsecond, and decreases to zero in tens of microseconds (lighting impulse).

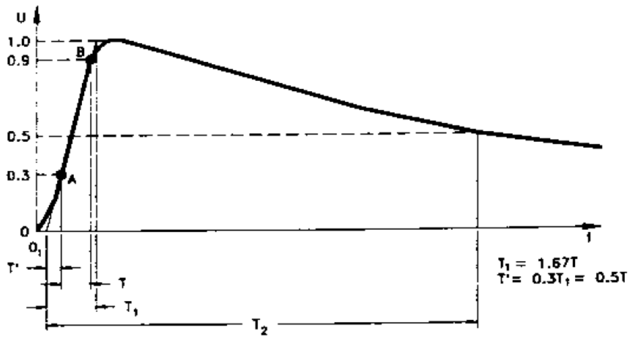

Figure 1 – Full lightning impulse

The following parameters are defined in the standards [1] and shown in Figure 1. The front time T_1 is defined as 1.67 times the interval T between the instance when the impulse is 30% and 90% of the peak value (points A and B in Figure 1). The virtual origin O_1 is the intersection with the time axis of a straight line drawn through the reference points A and B. The time to half-value T_2 (tail) is defined as the interval between the virtual origin O_1 and the instance when the voltage has decreased to half the peak value. Standard lighting waveforms have front time 1,2 μs and tail time 50 μs.

For power transformers not only the voltage waveform is recorder, but also current waveforms that circulate through the unit under test. The evaluation of the result is done inspecting these voltage and current waveforms, comparing reduced impulses with full impulses. The first ones have peak voltages around 50% of full ones. In this way, if an internal failure occurs in the transformer under test, the waveforms will be different. The standards [2] propose to compare voltage and currents waveforms. The last ones are the currents measured from some parts of the transformer to ground. One possibility is to measure the current of one end of the tested winding to ground. One end of the winding receives the impulse, and the other is connected to ground by a resistor shunt.

Large failures produce very large differences between both, voltage and current waveforms. However, minor failures, as turn-to-turn short-circuits, are associated with small differences. Digital recorders and software processing are very useful tools to determine the result of the test, analyzing these differences.

2. SIGNAL PROCESSING

According to [3], the sampling rate must be, at least, 30/Tx, where Tx is the time interval to be measured. For lighting impulses, the shortest time is the front time (0.84 μs) which leads to 60 MS/s of sampling frequency. Regarding resolution, the same standard imposes that a rated resolution of 2^{-9} must be used when signal processing is needed, as it is the case for transformer tests. However, in practice better resolution is preferred because of the small differences that are necessary to detect in this type of measurement. Digitizers up to 12 bits are usually used.

One of the first determinations is the peak value of the applied pulse. The standard [1] define this parameter as the real maximum value of the voltage waveform, only if there is no oscillations near the peak, or if they exist, their frequencies are relative low. If high frequencies oscillations or overshoots are overlapped, then a mean curve must be considered for the computation of the peak value. Figure 2 reproduces these situations.

If the frequency of the oscillations is higher than 0.5 MHz or the overshoot interval is less than 1 μs, the peak value is determined by a mean curve (curves a and b in Figure 2). For cases c and d, the peak value is determined by the crest value.

The developed proposed software includes filters to implement this criterion. To verify this calculation, standard waveforms [4] have been analyzed with results inside the tolerances.

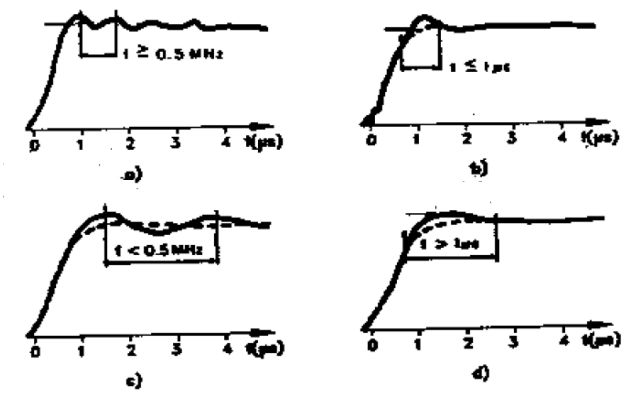

Figure 2 – Examples of lightning impulses with oscillations.

Figure 3 shows a real example of an impulse waveform analyzed by the developed software. The crest value is -203.9 kV, and the computed peak value using the software after calculating the mean curve is -187.2 kV. This coincides with graphical calculation.

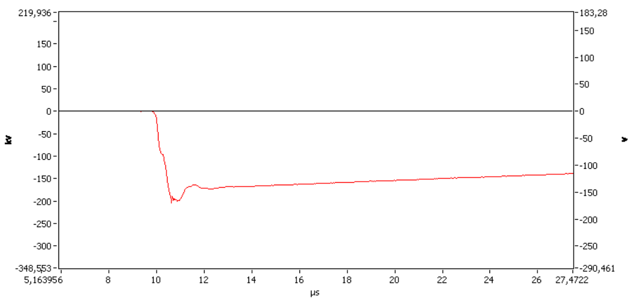

Figure 3 – Example with overshoot

The most important signal processing is the comparison of the waveforms. Very small differences between reduced and full waveforms can indicate a failure in the transformer. Figure 4 shows the records of a test. Green (voltage) and blue (current) waves correspond to the reduced voltage impulse. Red and grey waves correspond to the full voltage test.

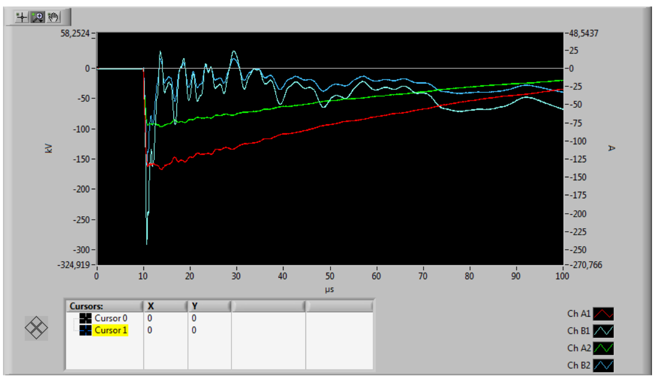

Figure 4 – Comparison, full versus reduced waveforms.

To detect differences, the software must overlap both couples of waveforms the best as possible. For that, first, the program must compute the best adjust in the time scale. If both waveforms have not the same time origin (as generally occur), a time shift is evaluated. In order to measure the similarity of the waveforms, the cross-correlation is calculated and the maximum evaluated. Then, the signals are shifted according to the index of this maximum. This criterion is much better than using only one point (i.e. the peak value or the beginning of the pulse), because noise can leads to errors in this adjust.

The second adjust is the amplitude of the two waveforms. An amplitude scale constant must be calculated in such a way that both waveforms overlap as best as possible. Again, only one point (i.e. the peak value) for calculating this adjust is not the best choice. Small oscillations around that point may leads to a bad adjust in all other parts. To overcome this issue, the modulus averages of a relevant portion of the two signals are calculated by the developed software and the amplitude is adjusted based on this ratio. In addition, the offset of the signals is evaluated using the first samples, and subtracted before the amplitude adjustment. Otherwise, significant differences may appear near the low amplitude zones of the waveforms. Figure 5 and 6 show better results obtained using the average criterion for the amplitude adjustment instead of using the peak value. The first figure shows the adjustment based only on the peak value. Although the peak value adjust is perfect, significant deviations appear in all other parts of the curves.

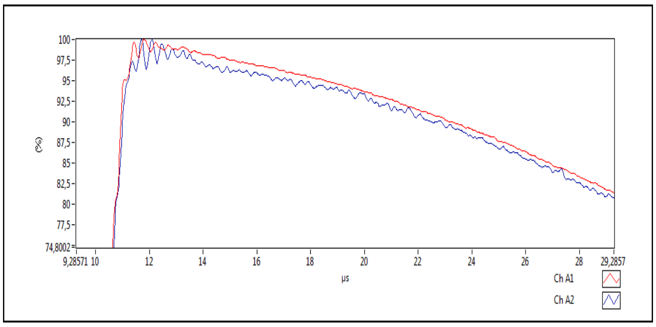

Figure 5 – Adjustment based on peak ratio.

On the other hand, Figure 6 shows a better adjustment based on the average criterion. Most parts of the curve fit well, although differences appear near the peak.

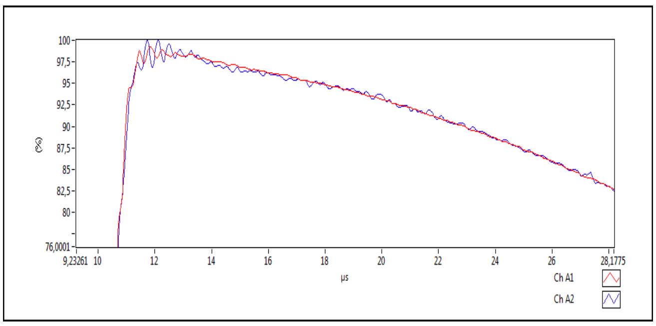

Figure 6 – Adjustment based on average ratio

In a second step, voltages and current waveforms must be compared. The software permits to overlap or to subtract. Figures 7 and 8 show the overlapping of voltage and current waveforms, and Figures 9 and 10 the subtraction of them.

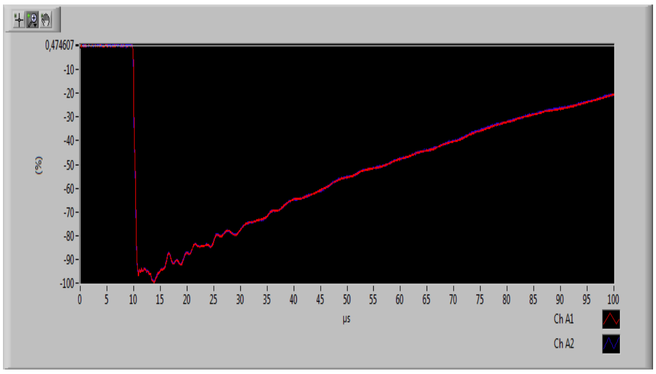

Figure 7 – Voltage comparison using overlapping.

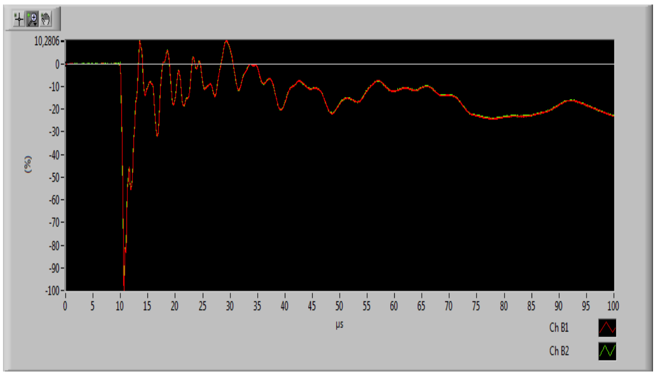

Figure 8 – Current comparison using overlapping.

Both figures shows a good agreement between full and reduced waveforms, but a better inspection needs to compute the subtraction.

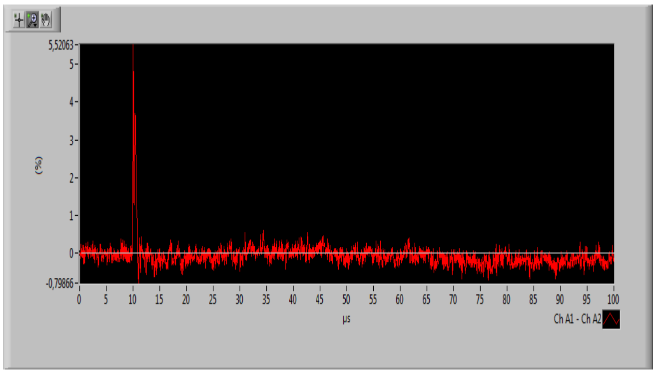

Figure 9 – Voltage comparison using the subtracting method.

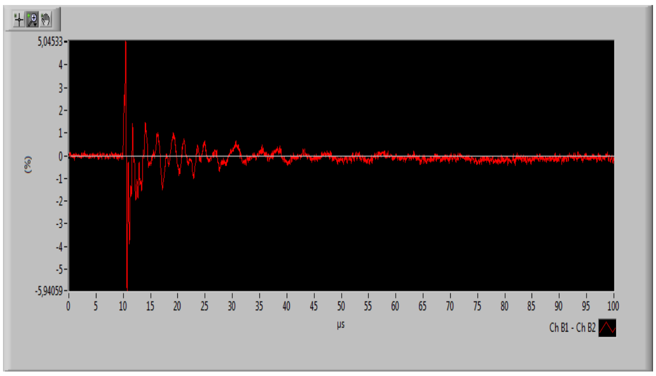

Figure 10 –Current comparison using the subtracting method.

In these last figures, differences around 5% can be noted during the first microseconds. After that, the differences are inside a band of 1%.

Other possibilities of the software are: smoothing, insertion of filters, computing of times of the voltage waveform. The last one implements the calculation of the crest and tail times automatically, implementing the criteria of the standard.

The smoothing function is useful to reduce the noise of the records. However, the signal processing does not introduce any visible variation in the shape of the waves.

A bandwidth reduction enables to reject interferences and noise generated outside the test. Transformers have a cutoff frequency so any part of the spectrum higher than that frequency does not come from the under-test-transformer.

Figure 11 shows the main screen of the software with all these possibilities.

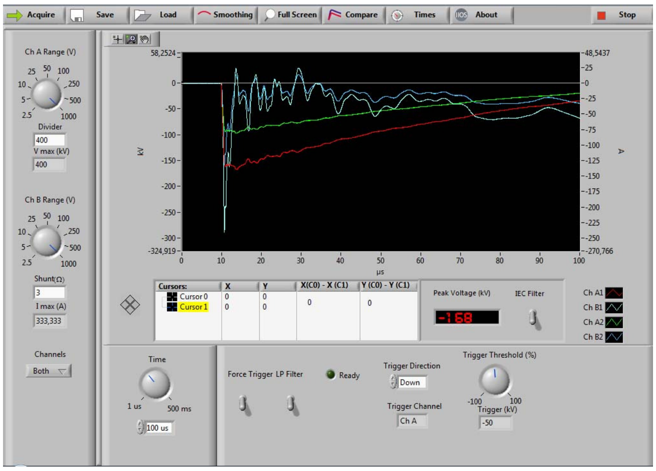

Figure 11. Main screen of the software.

REFERENCES

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