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Automated Evaluation of Dynamic Performance of Impulse Voltage Measurement Systems

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Abstract. This manuscript presents and describes an automated system for the evaluation of the dynamic performance of high-voltage measurement systems, according to the requirements of the standard IEC 60060-2/2010. The system was developed in LabVIEW and controls the acquisition, measurement and analysis of step response tests of measurement systems, automatically calculating the relevant amplitude and time parameters.

1. Introduction

The periodic performance verification of the measurement systems is one of the essential activities that ensure the technical quality of the results obtained in test laboratories of high voltage electrical equipment [1]. Such verification is required to prove and guarantee that the characteristics of the measurement systems are adequate for each particular test. The measurement systems used in high voltage and high current impulse tests are among the systems to which it is demanded more detailed performance verification.

Part of this verification refers to characterization of the dynamic performance, especially for voltage dividers and shunts, which are basic components of the systems. Such a characterization is based on the measurement and analysis of the voltage or current step response [2]. The step response of measurement systems is measured and processed in order to determine some characteristic parameters, according to known and standardized technical criteria. Such parameters delimit the application of the measurement systems in high voltage tests, related to the front time of lightning impulse voltage tests and current impulses.

In 2010, the International Electrotechnical Committee (IEC) revised the standard IEC 60060-2 [1], aiming at defining new requirements for test and calculation of the parameters that allow the evaluation of the dynamic performance of the measurement systems employed by high voltage test laboratories. Such a performance evaluation is performed in resistive, capacitive and hybrid dividers and in resistive shunts used in tests involving voltage/current impulses. With the advent of digital signal processing techniques, it was necessary to develop new software to control the acquisition and automatically analyze the step response parameters, as presented in this manuscript.

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Next section describes the various components of the measurement chain. On following, the step response test is explained and the software STERAL 2.0 is presented, having been developed according to the new standard IEC 60060-2.

2. Measurement Chain

The evaluation of dynamic performance is necessary to obtain the limits of application of an impulse measurement system. The main components of the measurement chain are defined in more details in the next subsections.

2.1. System Under Test

In order to guarantee accuracy, traceability and reliability of the results, the measurement systems used by high voltage laboratories must be periodically calibrated. The calibration process can be summarized as a comparison between the system being calibrated and a standard system and, additionally, by the measurement and analysis of the dynamic performance of the measurement system, based on a step response evaluation.

2.2. Step Generator

The step response evaluation is performed by applying, to the system under test, a voltage step with 4 ns rise time and 90 V amplitude, produced by a step generator. Based on the response of the measurement system to the voltage step, it is possible to assess its measurement range. For lightning impulses, the front time ranges from 0.84 μs to 1.56 μs, and the measurement system dynamic performance must be compatible with such times. The measurement system includes the following components: divider/shunt, transmission system and digital recorder.

2.3. Digital Oscilloscope

The output signal of the system under test is acquired by a Tektronix digital oscilloscope, model TDS 5104B or TDS 7104, both having 4 channels and maximum sampling frequency of 4 GS/s. Both models have GPIB control interface and can be connected, through GPIB–USB adapter cable, to a microcomputer, what allows the oscilloscope to be automatically controlled by software developed specifically for this process. STERAL 2.0, as described below, controls the oscilloscope, acquires and automatically calculates the step response parameters, storing the data in a text file.

2.4. STERAL 2.0 Control System

The platform used for the development of STERAL 2.0 was LabVIEW 9. By using the adequate oscilloscope drivers provided by Tektronix, the program controls the acquisition of the step response signal, providing to the user all the controls available in the oscilloscope front panel.

3. Step Response Measurement

A voltage step is applied to the divider or measurement system and its response is measured and analyzed by an oscilloscope or digitizer. The step response test is performed based on standard IEC 60060-2, being presented in Figure 1 a typical signal [1]. Is is also automatically calculated the curve $T(t)$, the integral over time of the function $1–g(t)$, shown in Figure 2 [1].

Based on both curves $g(t)$ and $T(t)$ several parameters are measured:

- Reference Level (l_R)*:* average amplitude of the acquired curve taken over the reference level epoch, i.e., between $0.5t_{min}$ and $2t_{max}$, where the interval [t_{min}, t_{max}] defines the nominal epoch for the relevant time parameter (e.g. in the case of full lightning impulses, the relevant time parameter is the front time T_1, and the nominal epoch is typically [0.8 μs, 1.8 μs]). In practice, due to limitations of the oscilloscope, the reference level is calculated over the interval [$0.25t_{aq}$, t_{aq}], where t_{aq} is the total acquisition time. The reference level l_R is used as a reference for the normalization of the step response curve in order to obtain $g(t)$, and identifies the stabilization level of the step response waveform.

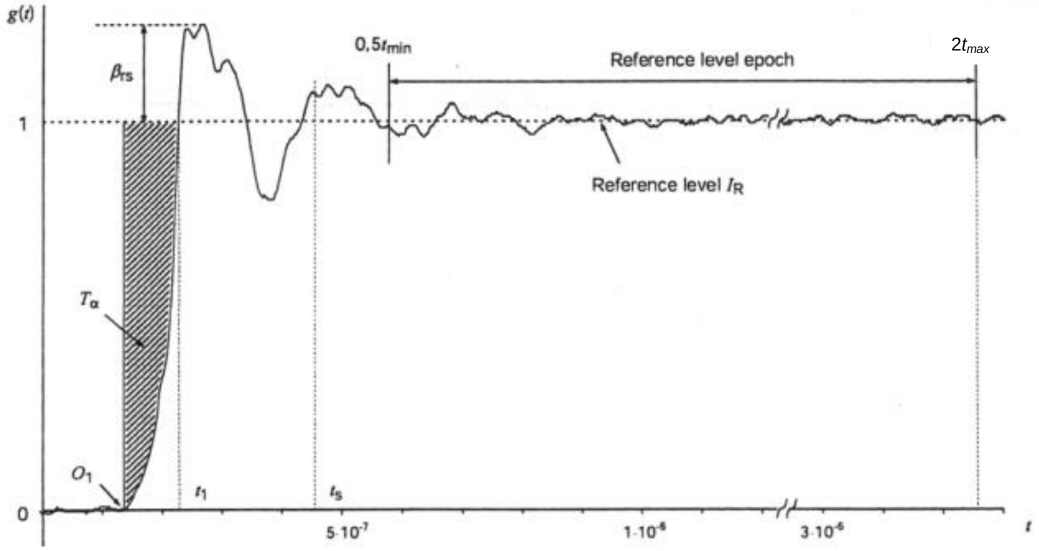

Figure 1. Typical Normalized Step Response Curve $g(t)$ [1]

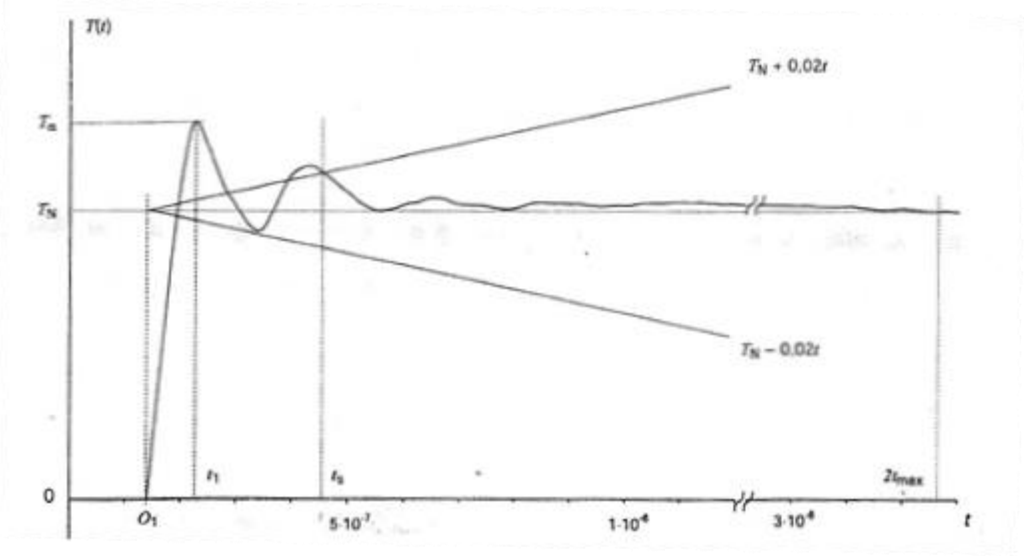

Figure 2. Typical Step Response Integral $T(t)$ [1]

- Virtual Origin of the Step Response (O_1): instant when the wave front initiates a monotonic rise above the amplitude of the noise at the zero level of the unit step response. All other time parameters are calculated using this instant as a time reference.

- Experimental Response Time (T_N): value of the step response integral $T(t)$ at $t = 2t_{max}$ (or $t = t_{aq}$)

- Partial Response Time (T_α): maximum value of $T(t)$ for $t \leq 2t_{max}$ (or $t \leq t_{aq}$)

- Residual Response Time ($T_R(t_i)$): T_N subtracted by $T(t_i)$, where $t_i < 2t_{max}$. In the case of STERAL 2.0, t_i is the instant when $g(t)$ first becomes higher than unity

- Overshoot of the Unit Step Response (β_{rs}): difference between the maximum value of the normalized waveform, g_{max}, and unity, as a percentage of unity.

- Settling Time (t_S): shortest time for which the residual response time $T_R(t)$ becomes and remains less than 2% of t.

- Initial Distortion Time (T_0): partial area between the line of zero and the virtual origin.

4. STERAL 2.0

The software STERAL 2.0 comprises 2 modules: Acquisition and Analysis. The Acquisition module, shown in Figure 3, controls the oscilloscope and acquires the step response waveform, with a typical sampling frequency of 1 GHz and a length of 1000 samples. The software initially identifies the oscilloscope that is connected to the computer and, if it is not one of the compatible models, from the series DPO4000 and DPO7000, an error message is shown and the program is halted.

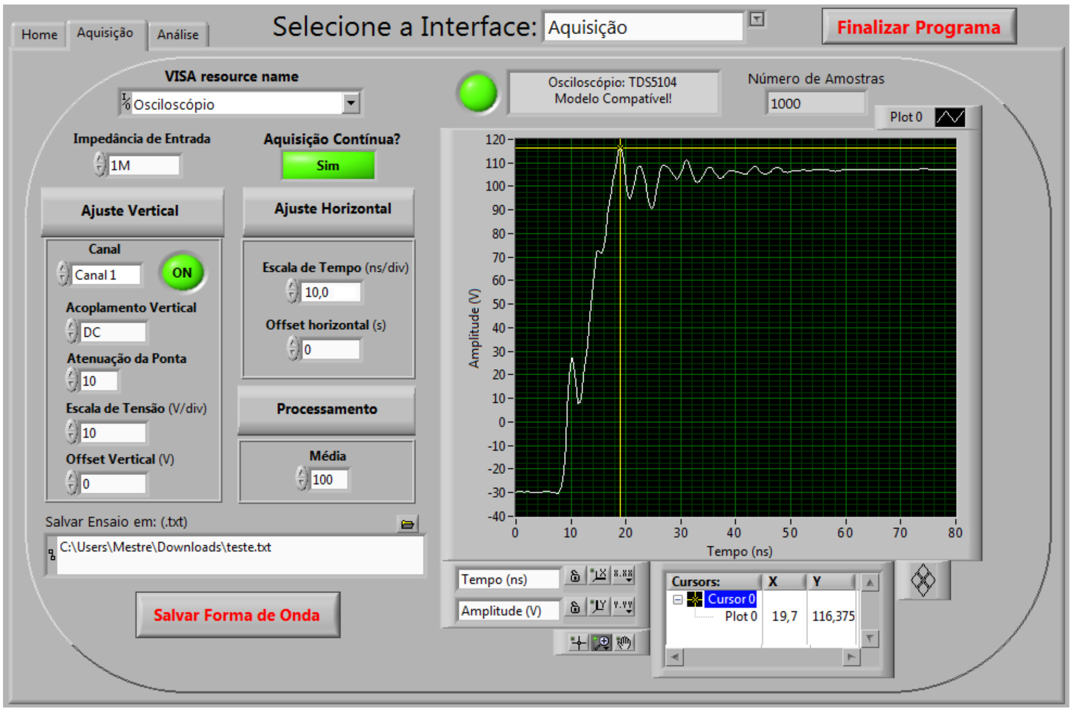

Figure 3. STERAL 2.0 Acquisition Module

On following, it is immediately started the reading of the oscilloscope selected channel, using the **Voltage Scale** and **Time Scale** values previously defined by the operator. Another important control in high voltage tests is the **Input Impedance**, which can be set to 1 MΩ or 50 Ω.

The interface also has controls for **horizontal offset** and **vertical offset**, so that the operator might adjust the waveform to the graph display and optimize the acquisition. It is also possible to include the attenuation factors introduced by dividers and other attenuators used by the measurement system.

The second module of STERAL 2.0, shown in Fig. 4, is the Analysis, presenting to the user an interface that allows the analysis of a previously acquired waveform. It is possible to analyze a series of tests with different voltage dividers, for example, without the need to follow a predefined sequence.

After the waveform to be analyzed is selected, the relevant parameters are automatically calculated and the waveforms related to the analysis are presented in 3 separate graph displays, called: $G(t)$, $g(t)$ and $T(t)$. $G(t)$ is the original step response waveform, being the reference level automatically estimated and indicated in the graph; $g(t)$ is the normalized step response, based on the reference level, being also shown the so-called adjustment line and the initial level; $T(t)$ is the integral over time of the normalized step response $g(t)$, used by the operator to verify the settling of the step response.

The initial level is automatically calculated, but can be manually adjusted should the operator desires to select a different value. It affects the determination of the virtual origin O_1. As described in the previous section, the parameters calculated by this module are: virtual origin (O_1), experimental response time (T_N), partial response time (T_α), residual response time (T_{re}), t_S, T_0 and Overshoot (%). Other important value presented are the Number of Samples and the acquisition interval dt (s).

As for the wave front adjustment line, the software allows two types: linear regression and maximum derivative, the selection being made by the operator based on his expertise. After the operator finalizes the adjustments, the parameters calculated can be saved in an Excel spreadsheet.

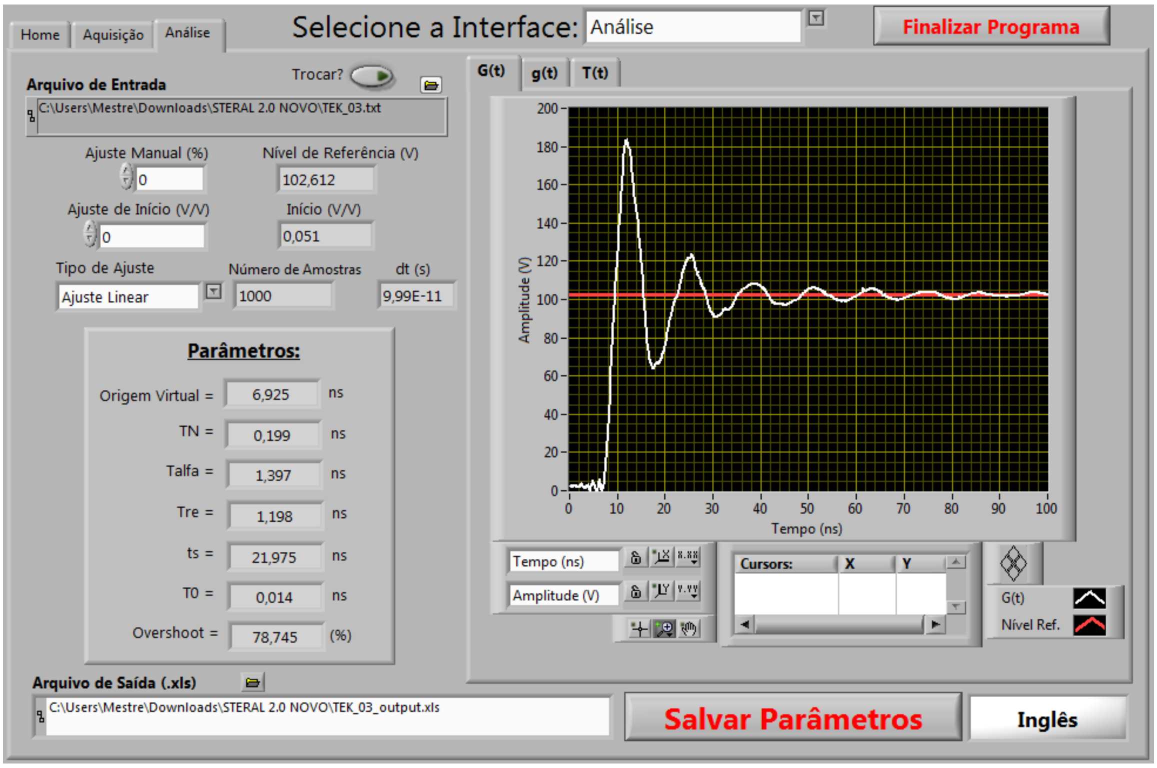

Figure 4. STERAL 2.0 Analysis Module

5. Conclusion

The implementation of the STERAL 2.0 software yields reliability in the evaluation of the dynamic performance of impulse measurement systems, aiming at guaranteeing the adequacy of voltage dividers used in high voltage impulse tests. Such a reliability is derived from the results that have a level of accuracy higher than the previously used software (STERAL 1.0), also presenting a more versatile operation, employing new technologies that allow better evaluation of the systems under test.

STERAL 2.0, having been developed following the new standard IEC 60060/2010, is updated and will be able to be used for several years without the need of further updates, aside from new versions of the IEC standards. One important feature of the new software, which provides a differential in relation to the prior version, is the portability for the tests, as STERAL 2.0 can be executed in a laptop computer connected to an oscilloscope, precluding the need for a large and complex experimental setup. Finally, STERAL 2.0 can also be used to evaluate the dynamic performance of measurement systems used with current impulse test according to standard IEC 62475/2010 [2].

6. References

[1] IEC 60060-2/2010
[2] IEC 62475/2010