Development and validation of a disruptive discharge simulator for use in proficiency testing activities

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Abstract. The participation of testing or calibration laboratories in Proficiency Test activities offers advantages such as performance evaluation, fault identification, method comparison, increased customer confidence, and validation of uncertainties. In Brazil, accredited laboratories must follow the requirements of NIT-DICLA-026, which includes defining the significant parts of the scope and selecting appropriate providers. However, laboratories that perform destructive tests face difficulties in finding programs that meet their needs because they require homogeneous and stable artifacts, which are not feasible for tests that permanently alter the tested material, such as dielectric strength. This work aims to develop an artifact to enable the comparison of results in a dielectric strength proficiency test. The artifact should simulate the breakdown of dielectric strength without affecting electrical characteristics, following stability criteria. After validation through calibration, the artifact was used in a pilot proficiency testing program between the Electrical Metrology Laboratory and the End-Use and Energy Management Laboratory of Technological Research Institute (IPT). The results and their respective analyses are also presented.

1. Introduction

The participation of testing or calibration laboratories in Proficiency Test activities provides several advantages. According to ISO/IEC 17043:2023 [1], some of the purposes of participation include performance evaluation of participants, fault identification (methodology, training, metrological traceability, or environmental conditions), which can allow corrective actions or improvements to begin; allows comparison between different test or measurement methods, increases customer confidence, and validates declared uncertainties, allowing the participant to identify if the uncertainty is underestimated or overestimated.

In Brazil, accredited testing or calibration laboratories seeking accreditation or extension of accreditation by the General Coordination of Accreditation (Cgcre) must demonstrate their competence in performing the test or calibration following the requirements established in the normative document of the Laboratory Accreditation Division, NIT-DICLA-026 [2] of the National Institute of Metrology, Standardization and Industrial Quality (Inmetro).

Among the requirements of NIT-DICLA-026, it is mentioned that laboratories must analyze, define and document the significant parts of their scope. From this, the laboratory develops the participation plan in proficiency test activities and meets the minimum quantity and frequency of participation by selecting proficiency testing providers or other inter-laboratory comparisons (in the absence of proficiency testing programs).

The selection of providers should be made by analyzing the program protocols, ensuring that all necessary records required by NIT-DICLA-026 will be available. In addition, attention should be paid to whether the test method is compatible with the laboratory's needs. According to the normative document, the laboratory can participate in programs that are not exactly linked to the test performed by the participant, but where the test method is similar. In this case, the laboratory must demonstrate the scope's coverage definition.

Although proficiency testing activities programs have increased, mainly due to the increased number of accredited providers, laboratories still have difficulty to find proficiency testing activity programs that can fully meet their significant scope parts, mainly in tests considered destructive, i.e., those that alter some characteristic of the item under test after the service is performed, such as dielectric strength or withstand voltage testing.

This is because in a proficiency testing activity where the test results will be compared among participating laboratories, the artifact to be used must be homogeneous and stable enough not to affect the result of the comparison. In the case of insulation resistance testing, if the insulation resistance is broken, the insulating characteristics of the material used as an artifact are definitively altered and therefore cannot be used in other tests.

1.1. Insulation Resistance Testing

The insulation resistance testing (IR) purpose to verify the quality of a product regarding electrical insulation. The importance of the test is due to the need to evaluate the protection of equipment and systems, but primarily to prevent a possible accident to patient and professional responsible who may be near or in contact with a supposedly insulating surface, due to the risk of electric shock. Such a failure can result in physical, structural, and even vital damage to anyone in contact with the energized surface.

Several different techniques determine the performance of the insulation resistance testing, combined with other tests, such as grounding resistance and leakage current, as a necessary part of evaluating the electrical safety of a product. For example, the Brazilian Health Regulatory Agency (Anvisa), by Normative Instruction 116 of 12.21.2021 [3], determines the use of IEC 60601-1:2005 (Medical electrical equipment Part 1: General requirements for basic safety and essential performance) for the conformity certification of equipment under the Agency's regime.

Chapter 20 of this standard presents the dielectric strength test. A table is presented with the voltage limits to be applied, according to the supply voltage and the insulation type of the item to be tested [4]. For example, a medical device powered at 127 V (60 Hz), with basic insulation, the standard determines that the test should start by applying a voltage no greater than 500 V to the insulation parts. Then, the voltage should be raised to 1000 V in 10 s and maintained for 1 minute. Finally, the voltage should be reduced to a value lower than 500 V in a period of 10 s. Throughout the test process, there should be no significant increase in the electrical current flowing through the insulation. If this occurs, it is considered that the dielectric has been broken and, therefore, the product is considered unsatisfactory for this specific test. Figure 1 below presents the defined rise and fall ramp specified by the standard for the example given in this paragraph.

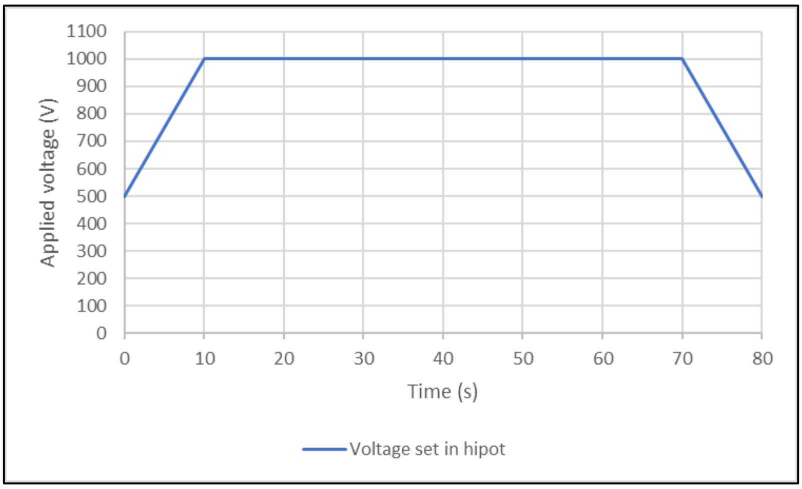

Figure 1. Ramp-up and ramp-down for the dielectric strength test, according to the IEC 60601-1:2005.

Usually, a high voltage source, also known as a hipot, is used for this test. With this equipment, it is possible to configure the voltage ramps and electrical current limits according to the standard under which the product should be tested.

If the dielectric is broken, the test material becomes conductive due to the low resistance to the flow of electrical current that will flow through the material surface. The hipot detects the fault by measuring the electrical current and comparing it with the user-specified limit. At this point, the electrical voltage is turned off, activating a continuous high-pitched audible signal and the visual indicator of the voltage limit reached. In some models, it is also possible to display the test time before confirming the failure.

1.2. Proficiency Testing Activities in Dielectric Strength Testing

Conforming to the Inmetro website [5], it is possible to identify proficiency testing providers accredited by Cgcre according to ISO/IEC 17043. Although there are 21 active accredited providers, none of them have the dielectric strength test in their scope.

As per the recommendation of NIT-DICLA-026, in the absence of accredited proficiency testing providers, other providers can be sought through the EPTIS database, which is coordinated by the Federal Institute for Materials Research and Testing (BAM) in Germany [6]. In the EPTIS search, only two active providers were identified, one of which was IPT itself.

Usually, proficiency testing programs for tests that can be destructive are organized so that the comparison results are qualitative, for example, of the binary type "satisfactory" / "unsatisfactory". In the case of the dielectric strength test, it is possible to consider the use of an artifact whose insulation voltage, i.e., the limit voltage before rupture, is higher than the voltage applied by the participants. By adopting this type of artifact, there would only be one participating laboratory with an unsatisfactory result if the applied voltage is higher than the voltage defined, usually in the proficiency testing program protocol. In cases where the true value of the voltage applied by the hipot is lower than the value displayed by the equipment, the comparison result could still be "satisfactory," even if this error is hidden from the laboratory (due to a lack of calibration, for example), and could even cause false positives in tests performed on products that are not suitable for their respective technical standards regarding electrical safety. Figure 2 shows the graph where this situation can occur in a proficiency testing program whose artifact used has an insulation voltage higher than the voltage defined by applicable technical standard adopted.

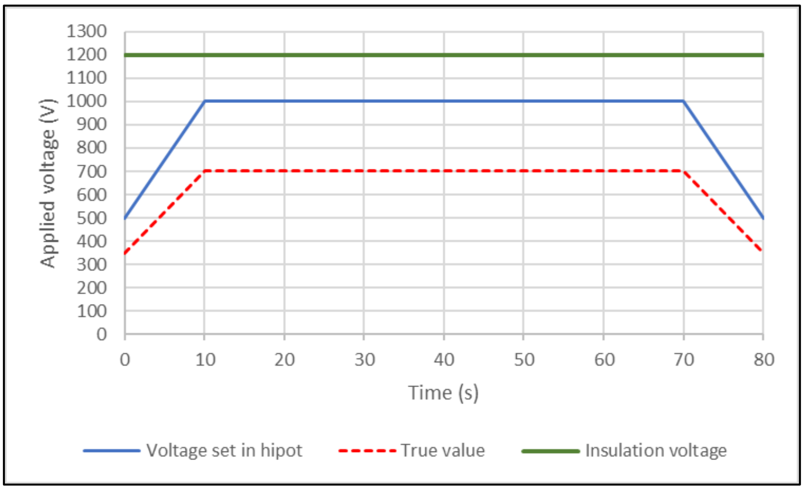

Figure 2. Situation that the voltage applied by a hipot is 30 % lower than the expected value by the participant, but their result in a proficiency testing program is satisfactory.

2. Methodology

Firstly, it was necessary to develop an artifact that could offer a quantitative comparison of the results declared by participants in a proficiency test in dielectric strength. To do so, the artifact should simulate the breaking of the dielectric strength (significant increase in electrical current) without affecting the electrical characteristics of the device, meeting the stability criteria necessary for a proficiency testing program.

The developed device (figures 3 and 4) consists of a vitrified wire resistor of 5 kΩ/200 W and a 680 V varistor. The electrical resistance of a varistor is inversely proportional to the electrical voltage applied to the component. Usually, a varistor is used as a protection component against short-duration voltage surges since, due to its characteristic of reducing its electrical resistance in these situations, the voltage surges do not reach the electrical circuit protected by it and are transformed into heat, due to the Joule effect.

In the disruptive discharge simulator, the high-power resistor limits the maximum current to a value sufficient for a hipot tester to consider it as a breakdown of dielectric strength and automatically disarm the electrical voltage. It also limits the current to a safe value that does not damage the varistor. Under this condition, the device can be used multiple times without significant alteration in the internal characteristics of the component, providing a highly stable artifact for proficiency testing.

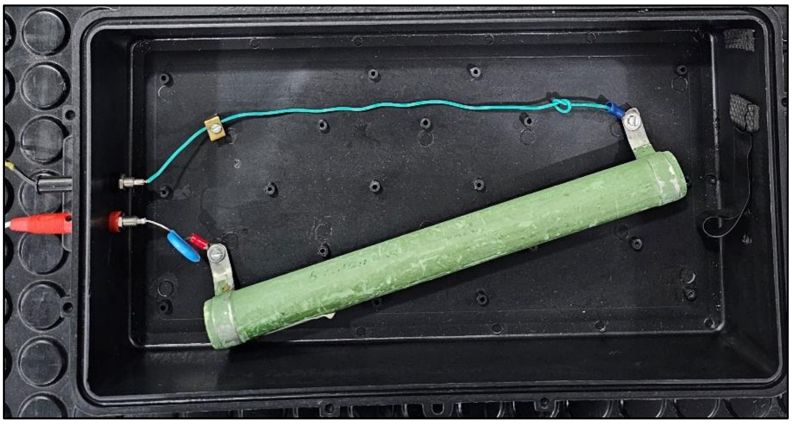
Figure 3. Disruptive discharge simulator developed (opened).

Figure 4. Disruptive discharge simulator developed (closed).

Next, the developed device was validated through calibration, which consisted of using a voltage source (transfer standard, model HT100.1E) connected in series to the device and a standard miliammeter (model 289). In parallel to the source, the electrical voltage signal was obtained using a standard voltage divider (model HVA-100) and a standard voltmeter (model 34401A). All standards used are previously calibrated by a laboratory accredited by Cgcre, guaranteeing the metrological traceability of the measurements. Figure 5 below shows the diagram used to calibrate the device and figure 6 presents the calibration being performed.

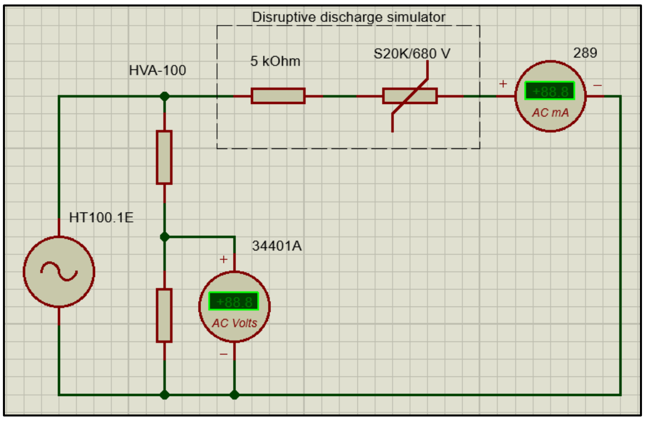

Figure 5. Diagram for device calibration.

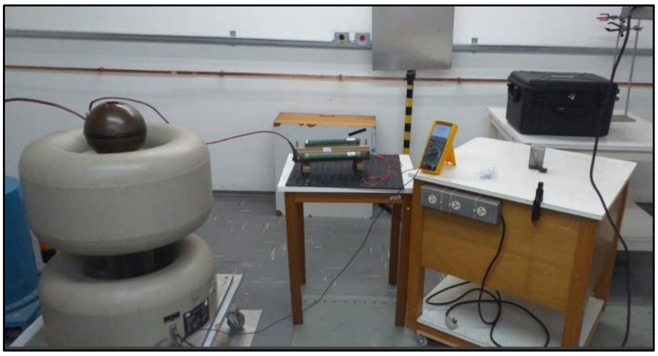

Figure 6. Circuit assembled for artifact calibration.

The calibration curve was raised, obtained by linear regression in the range between 80 mA and 100 mA. The equations used for linear regression are in accordance with [7] and the uncertainty (S), due to the calibration curve error, is estimated by (1) below.

$$S = \frac{\sqrt{\sum_{i=1}^{n} \Delta E_i^2}}{n-2} \qquad (1)$$

Where,

ΔEi corresponds to the difference between the measured voltage values and the values obtained through the regression curve adjustment.

This calibration process was carried out before starting the proficiency testing program, obtaining the initial curve, and after the completion of the measurements by the participating laboratory, obtaining the final curve.

2.1. Organized Proficiency Testing Activities in Dielectric Strength Testing

The organized proficiency testing activity in dielectric strength consisted of an interlaboratory comparison between the Electrical Metrology Laboratory and the End-Use Laboratory and Energy Management Laboratory, both located at IPT.

Proficiency testing was organized considering that the high voltage applicator was configured as follows.

- Minimum voltage (initial) = 0 V
- Maximum applied voltage = 1000 V (60 Hz)
- Ramp-up time = 10 s
- Breakdown electrical current = 95 mA

These settings were performed according to the hipot manufacturer's recommendation. After starting the test, the hipot [8] should disable the electrical signal at the moment it reaches the breakdown current, since the artifact was developed in such a way that the breakdown current was reached at a voltage value a little lower than the maximum voltage applied (1000 V). The participant needs to record the voltage value at the moment of dielectric rupture and the current measured by the high voltage applicator in a Results Sheet.

The evaluation of the breakdown voltage measured by the participants was performed based on the Normalized Error (2).

$$En = \left| \frac{V_D - V_{LAB\_X}}{\left(U_D^2 + U_{LAB\_X}^2\right)^{1/2}} \right| \qquad (2)$$

Where:

V_D: Designated value;
V_{LAB_X}: Value obtained by participating laboratory;
U_D: Uncertainty of designated value;
U_{LAB_X}: Expanded uncertainty of measurement of value obtained by participating laboratory;

If Normalized Error ≤ 1, then the result is considered satisfactory and;
If Normalized Error > 1, then the result is considered unsatisfactory.

3. Results and Analysis

The expanded uncertainty attributed to the Reference Value was declared as the standard measurement uncertainty multiplied by the coverage factor k = 2. The measurement's expanded uncertainty was also considered due to the accuracy of the standards, resolution and the artifact's instability, represented by the assignment of individual uncertainties of the calibration curves performed before the program's start and end. Table 1 below presents the results obtained from the calibration curve (angular coefficient (b) and linear coefficient (a)).

Table 1. Results obtained from the initial and final calibration curves.

Descrição	Value
Linear coefficient (a)	41,98 V
Angular coefficient (b)	5,4 V/mA
Standard uncertainty of initial curve	0,96 V
Standard uncertainty of final curve	3,2 V

The results declared by the participating laboratory (End-Use and Energy Management Laboratory – LGE) and the respective evaluation based on the Normalized Error are presented in Table 2.

Figure 7 presents the point declared by the participant with its respective measurement uncertainty and a section of the calibration curve (blue line) between 94 mA and 96 mA, added and subtracted from the expanded measurement uncertainty of the Designated Value (red lines).

Table 2. Analysis of the results obtained in the interlaboratory comparison through the Normalized Error.

LGE current (mA)	V_{LGE} (V)	U_{LGE} (V)	V_D (V)	U_D (V)	Normalized Error
95,17	570,0	28,5	556,3	4,2	0,48

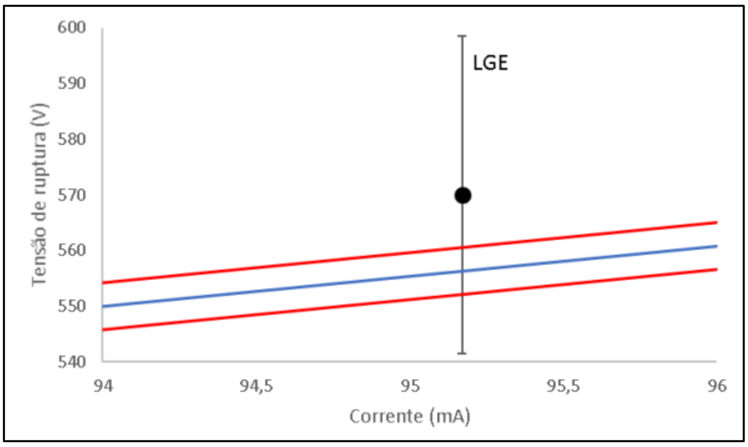

Figure 7. Analysing results.

4. Conclusion

Due to the scarcity of proficiency testing programs in dielectric strength, which could offer quantitative results and thus provide a more appropriate analysis between participating laboratories, a device called as disruptive discharge simulator was developed. This device obtained satisfactory results regarding stability and was used as an artifact in an interlaboratory comparison program. For the comparison, a protocol was defined, and the program was run. From the presented program results, it was possible to quantitatively evaluate the participating laboratory based on Normalized Error.

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