IEC TS 62836

Edition 1.0 2020-11

TECHNICAL SPECIFICATION

colour inside

Measurement of internal electric field in insulating materials – Pressure wave propagation method

IEC TS 62836:2020-11(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.220.99; 29.035.01

ISBN 978-2-8322-8993-8

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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MEASUREMENT OF INTERNAL ELECTRIC FIELD IN INSULATING MATERIALS – PRESSURE WAVE PROPAGATION METHOD

FOREWORD

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IEC TS 62836 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is a Technical Specification

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
112/472/DTS	112/499/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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INTRODUCTION

High voltage insulating cables, especially high voltage DC cables, are subject to charge accumulation and this may lead to electrical breakdown if the electric field produced by the charges exceeds the electrical breakdown threshold. With the trend to multiply power plants, especially green power plants such as wind or solar generators, more cables will be used for connecting these power plants to the grid and share the electric energy between countries. Therefore, the materials for the cables, and even the structure of these cables, when considering electrodes or the junction between cables, need a standardized procedure for testing how the internal electric field can be characterized. The measurement of the internal electric field would give a tool for comparing materials and help to establish thresholds on the internal electric field for high voltage applications in order to limit breakdown risks as much as possible. The pressure wave propagation (PWP) method has been used by many researchers to measure the space charge distribution and the internal electric field distribution in insulators. However, since experimental equipment, with slight differences, is developed independently by researchers throughout the world, it is difficult to compare the measurement results between the different equipment.

The procedure outlined in this Technical Specification provides a reliable point of comparison between different test results carried out by different laboratories in order to avoid interpretation errors. The IEC has established a project team to develop a procedure for the measurement of PWP.

MEASUREMENT OF INTERNAL ELECTRIC FIELD IN INSULATING MATERIALS – PRESSURE WAVE PROPAGATION METHOD

1 Scope

This document provides an efficient and reliable procedure to test the internal electric field in the insulating materials used for high-voltage applications, using the pressure wave propagation (PWP) method. It is suitable for a sample with homogeneous insulating materials and an electric field higher than 1 kV/mm, but it is also dependent on the thickness of the sample and the pressure wave generator.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms, definitions and abbreviated terms apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
pressure wave propagation
PWP
pressure wave that is propagated in a material containing electric charges and measurement of the induced electric signal from electrodes

3.2 Abbreviated terms

CB carbon black

EVA ethylene-vinyl acetate

LDPE low density polyethylene

LIPP laser induced pressure pulse

PE polyethylene

PIPP piezoelectric induced pressure pulse

PMMA poly (methyl methacrylate)

PWP pressure wave propagation

S/N signal to noise ratio

4 Principle of the method

The principle of the PWP method is shown schematically in Figure 1.

The space charge in the dielectric and the interface charge are forced to move by the action of a pressure wave. The charge displacement then induces an electrical signal in the circuit which is an image of the charge distribution in short-circuit current measurement conditions. The expression for the short-circuit current signal with time t is

$$i(t) = C_0 \int_0^d BE(x) \frac{\partial p(x,\ t)}{\partial t} dx\ , \qquad (1)$$

where

$E(x)$ is the electric field distribution in the sample at position x;

d is the thickness of sample;

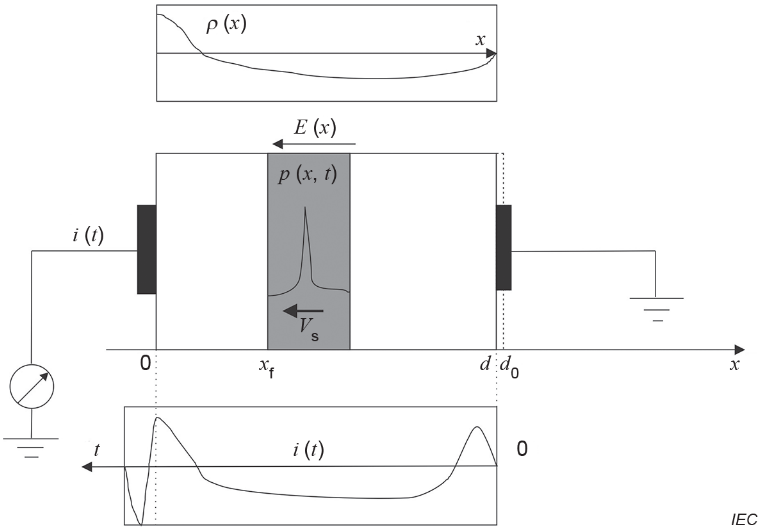
$p(x,\ t)$ is the pressure wave in the sample, which depends on the electrode materials, dielectric sample material, the condition of coupling on the interface, etc.;

C_0 is the sample capacitance without the action of a pressure wave.

C_0 depends on the thickness of the sample, and its surface area which is equal to the area of action of the pressure wave.

The constant $B = \chi(1 - a/\varepsilon)$ only depends on the characteristics of the dielectric materials. In this formula, χ is the coefficient of compressibility of the material, ε is the permittivity of the material and a is the coefficient of electrostriction of the material. For heterogeneous dielectric materials, B is a function of space. For homogeneous dielectric materials, B is not a function of space and can be put outside of the integral. In this proposition, only homogeneous dielectric materials are considered, so B is a constant.

In Equation (1), the electric field distribution can be obtained if it is deconvolved.



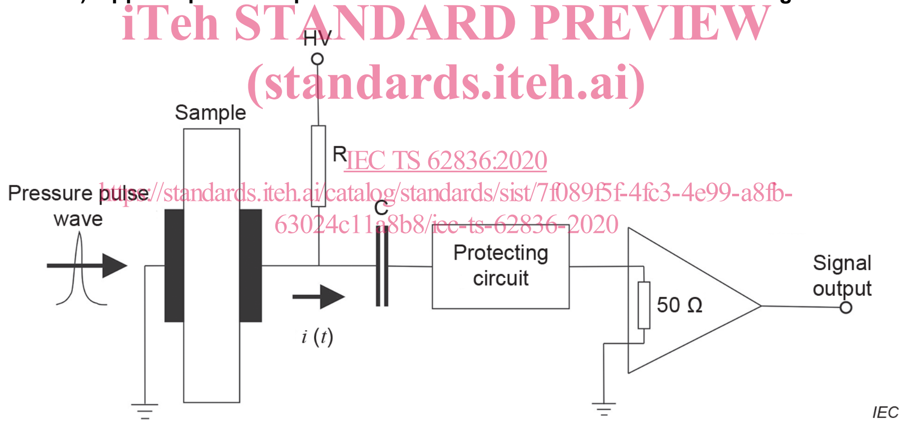
Key

x_f is the position of pulse front

d_0 is the original thickness of sample

$d_0 \approx d$ in the case of a narrow pulse

a) Applied pressure pulse and measured short-circuit current signal



b) Measuring schematics

Figure 1 – Principle of the PWP method

The applied pressure wave can be generated by different techniques, but the same kind of analysis can be done for any of these techniques. The main practical PWP method can be divided into two ways: a pressure pulse is induced by a powerful laser pulse, a technique called LIPP method, and a pressure pulse generated by a piezoelectric device, a technique called PIPP. The sensibility and resolution of the PWP method depends mainly on the amplitude and width of the pressure pulse. The advantage of the LIPP method is to produce highly sensitive measurements without contact. The advantage of the PIPP method is to obtain the measurement with a high measuring rate and allow a cost measurement system.

In the case of a narrow pulse, for example when the width of the pressure pulse is much smaller than the thickness of the sample, τ is the pressure pulse duration with $\tau << \left[\min\left(d_0, d_x\right)\right] / v_s$,

$$\begin{cases} \int_0^t i(t')\,dt' = C_0 B \overline{E(x)} \int_0^d p(x,\ t)\,dx \\ x = v_s t \end{cases}, \tag{2}$$

where

v_s is the sound speed in the sample;

$\overline{E(x)},\ x = v_s t$ is the mean electric field during the pressure pulse width at the position x. For simplicity, it is shown as $\overline{E(x = v_s t)}$ in this document.

Because of sound loss and sound dispersion in polymer dielectrics, the amplitude of $p(x,t)$ will decrease, and the width of $p(x,t)$ will increase during the propagation of a pressure pulse in the sample. For polymer dielectrics, the sound dispersion is dominant, therefore, even if $p(x,t)$ is not a constant in the dielectrics, its integral $\int_0^d p(x,t)\,dx$ remains constant during its propagation in the sample.

From the Equation (2) and from the signal obtained with a sample free of charges and submitted to an intermediate voltage V_0, $B\int_0^d p(x,t)\,dx$ can be obtained since the electric field $\overline{E(x = v_s t)} = E_0$ is uniform in this case and the sample capacitance C_0 is directly proportional to the thickness of the sample. This can be used as a calibration base for the other measurements.

5 Samples

A dielectric insulating material is suggested, for example polyethylene, with a thickness of 1 mm or 2 mm planar plaque sample with a diameter sufficiently large to avoid edge discharges, typically larger than 20 cm with 5 cm centred electrodes for 60 kV.

6 Electrode materials

The selection of electrode materials depends on the method of the generation of the pressure pulse wave. Usually, semi-conductive electrodes with ethylene-vinyl acetate (EVA) + carbon black (CB) or polyethylene (PE) + carbon black (CB) are used. For laser PWP (also called LIPP), the suitable thickness of the semi-conductive electrode is about 0,5 mm, and it shall be less than 1 mm. If different materials are used for the electrode and the insulator, the transit time of the pressure wave through the electrode should be at least half the one in the insulator to avoid spurious echoes.

It is important to keep good contact between the electrode and the insulator. It is recommended to use the hot-press method for marking the electrode on the sample.

7 Pressure pulse wave generation

The suggested pressure pulse wave should have a 20 ns to 50 ns duration, and a 1 MPa to 10 MPa amplitude. It can be produced by a piezoelectric driven device, or by a powerful pulsed laser. If a powerful laser is used, the suggested energy is about 300 mJ to 500 mJ per pulse with a 3 ns to 7 ns duration.