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colour inside

Electrical test methods for electric cables –
Part 3: Test methods for partial discharge measurements on lengths of extruded power cables

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Part 3: Test methods for partial discharge measurements on lengths of extruded power cables

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60885-3 has been prepared by IEC technical committee 20: Electric cables.

This second edition of IEC 60885-3 cancels and replaces the first edition, published in 1988 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- The definition of sensitivity as twice the background noise level has been removed and replaced by a practical assessment of sensitivity based on the minimum level of detectable discharge.
- References to measurements of pulse heights in mm on an oscilloscope have been replaced by measurements of partial discharge magnitude in pC.
- The order of the clauses has been revised in line with the general numbering scheme of IEC standards and to provide clarity in order to facilitate its practical use. Section 3 of the first edition (Application guide) has been removed as it is considered that background information is better obtained from the original references as listed in the bibliography.

The text of this standard is based on the following documents:

FDIS	Report on voting
20/1560/FDIS	20/1587/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60885 series, published under the general title *Electrical test methods for electric cables*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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ELECTRICAL TEST METHODS FOR ELECTRIC CABLES –

Part 3: Test methods for partial discharge measurements on lengths of extruded power cables

~~1 SECTION ONE – GENERAL~~

1 Scope

This part of IEC 60885 specifies the ~~essential requirements~~ test methods for partial discharge (PD) measurements on lengths of extruded power cable, but does not include measurements made on installed cable systems.

Reference is made to IEC 60270 which gives the techniques and considerations applicable to partial discharge measurements in general. ~~The first edition of IEC 60270 appeared in 1968. All references in this standard apply to the second edition (1981).~~

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60270:2000, *High-voltage test techniques – Partial discharge measurements*

~~2 SECTION TWO – PARTIAL DISCHARGE TESTS~~

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60270 apply.

3.2 Symbols used in Figures 1 to 14

a_1 discharge magnitude measured with the calibrator at the end near to the detector

a_2 discharge magnitude measured with the calibrator at the end remote from the detector

C_{cal} calibrator

C_{K} coupling capacitor

C_{x} power cable

D detector

I double pulse generator

l length of the power cable

M coaxial signal cable

Q discharge magnitude

$R_1 R_2$ matching resistors

RS reflection suppressor

v propagation velocity of partial discharge

V voltage indicator

W power supply

Z impedance/filter

Z_A input unit

Z_W terminal impedance

4 Overview

4.1 General

Partial discharge measurements shall be carried out using the test techniques specified in IEC 60270.

4.2 Object

The object of the test is to determine the discharge magnitude, or to check that the discharge magnitude does not exceed a specified value, at a specified voltage ~~with~~ and a ~~given~~ declared minimum sensitivity.

4.3 Problem of superposition of travelling waves for long lengths

Short lengths of cable behave in the same way as a single capacitor in that the discharge magnitude can be measured directly by considering the cable as a single capacitor. However longer cables behave like a transmission line and PD pulses travel away from their source in both directions along the cable, in the form of a wave. On reaching the remote end from the measuring equipment, the pulse will be reflected with the same polarity if the end is open circuit. The reflected pulse will then travel back along the length of cable and arrive at the detector at a time after the directly received pulse. If the time between the arrival of the two pulses is short (the time difference depending on the length of the cable) then the detection instrument may give a false response, indicating either a larger or smaller magnitude of discharge than was actually the case. The methods detailed in this standard allow correct measurement of partial discharges under these conditions.

Figures 1 to 4 illustrate the behaviour of travelling waves and possible superposition effects.

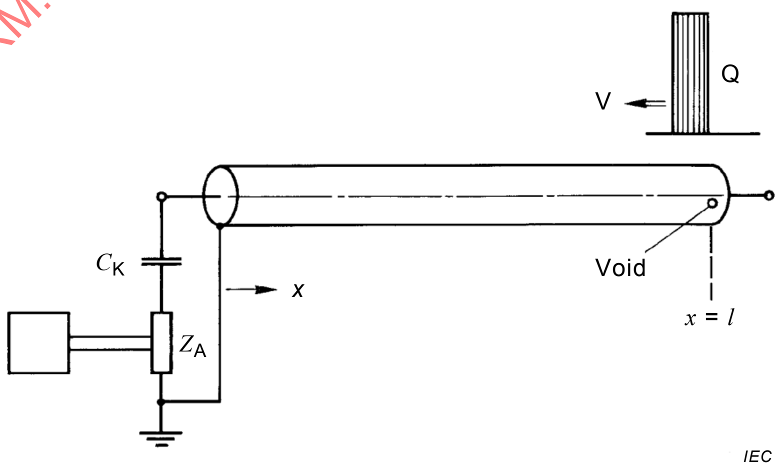


Figure 1 – Discharge site exactly at the cable end remote from the detector ($x = l$)

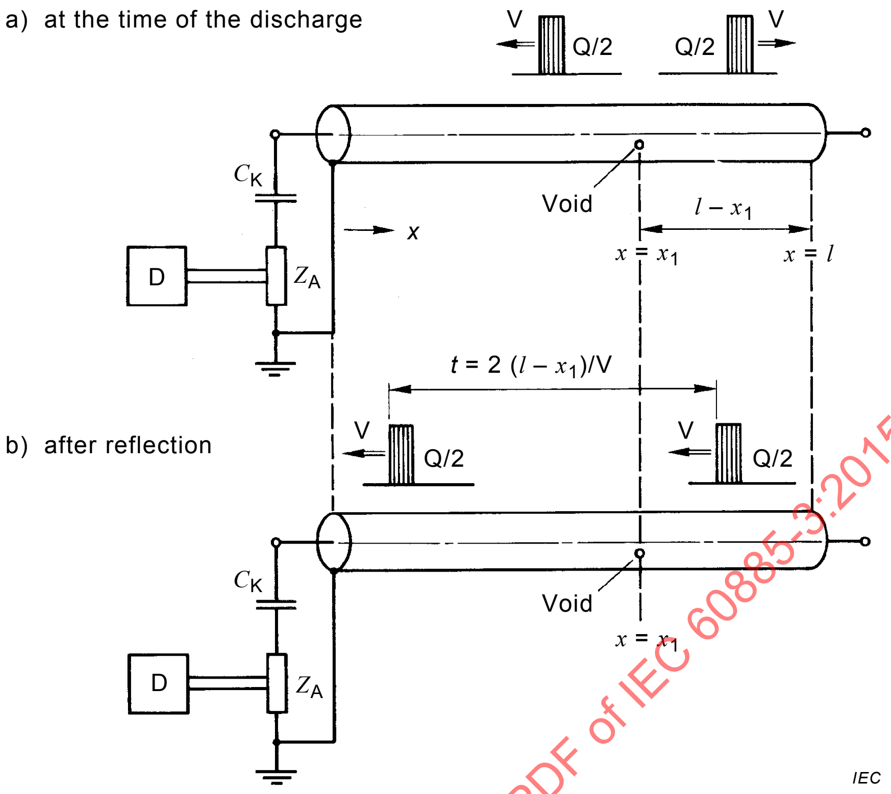


Figure 2 – Discharge site at a distance $x = x_1$ – Travelling waves

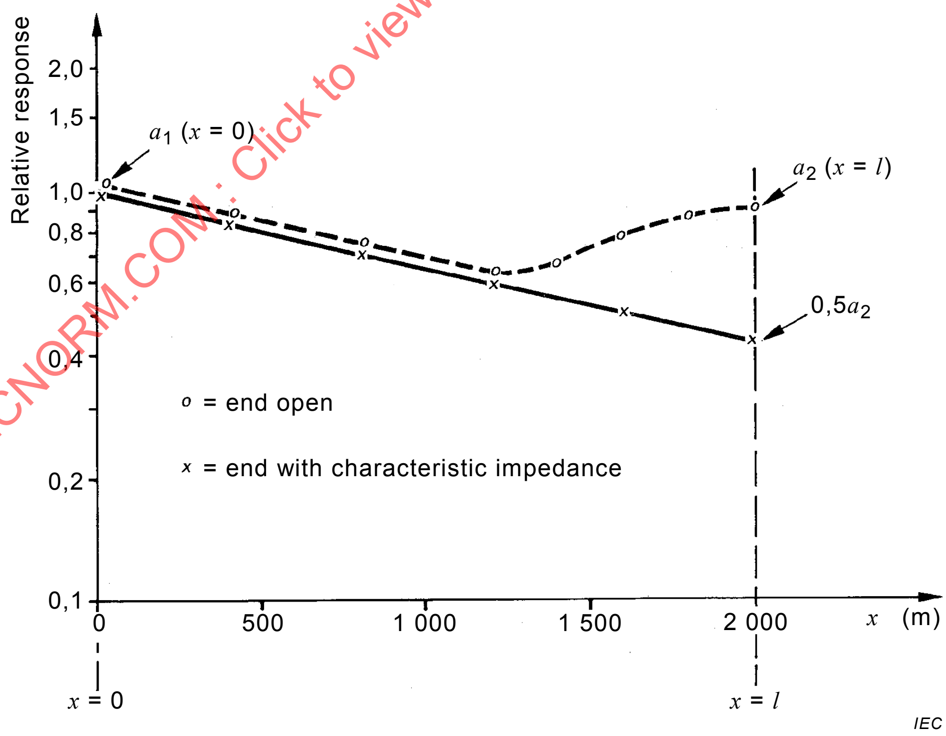


Figure 3 – Attenuation of PD pulses along the cable

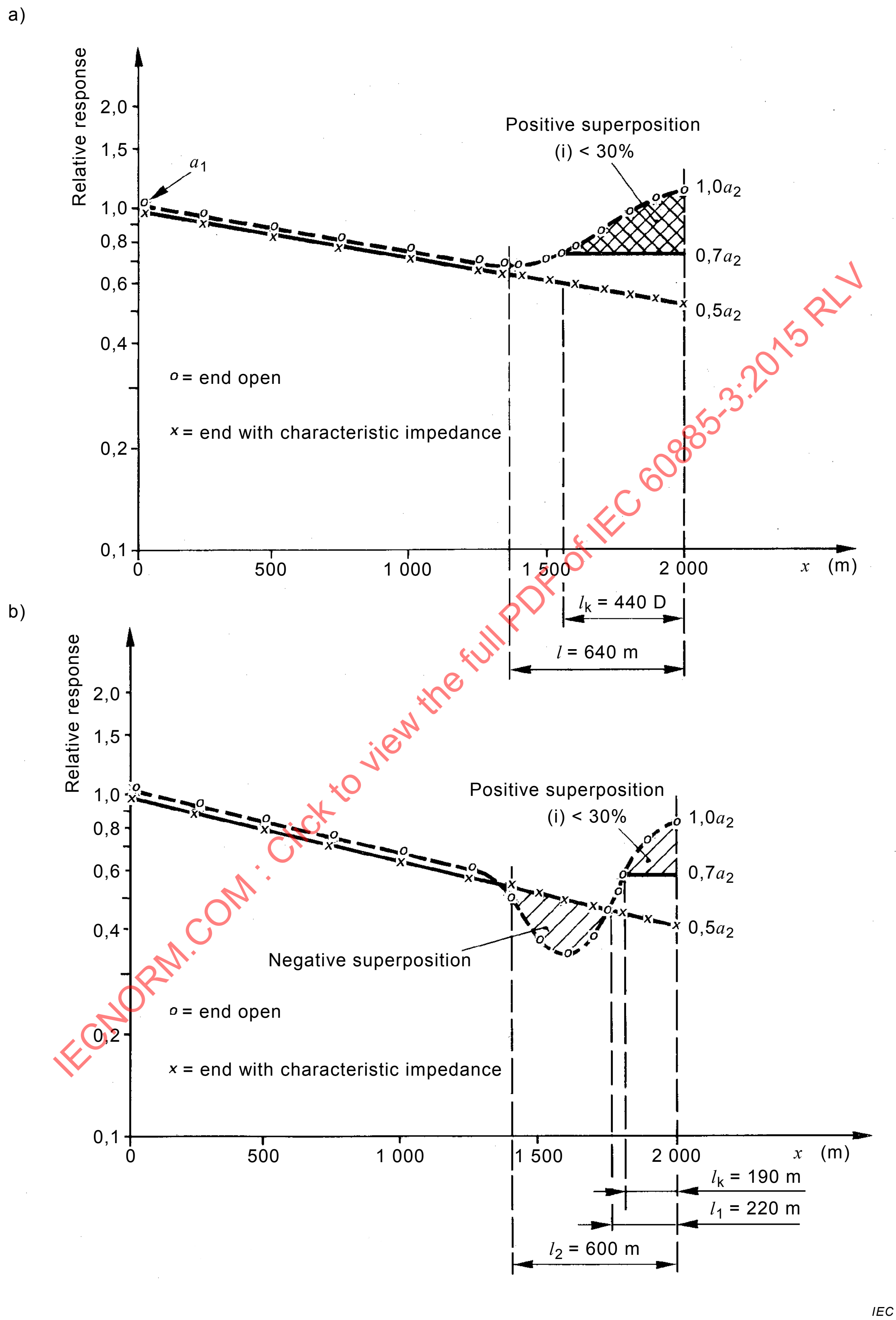


Figure 4 – Superposition and attenuation of PD pulses

5 Partial discharge tests

5.1 Test apparatus

5.1.1 Equipment

The equipment consists of a high-voltage ~~power~~ alternating voltage supply having a ~~kilovolt-ampere capability~~ rating adequate ~~for~~ to energise the length of cable under test, a voltmeter for high voltages, a measuring circuit, a discharge calibrator, a double pulse generator and, ~~if necessary~~ where applicable, a terminal impedance or reflection suppressor. All components of the test equipment shall have a sufficiently low noise level to achieve the required sensitivity. ~~The frequency of the test supply is assumed to be the power frequency a.c. 49 Hz to 61 Hz of approximately sine-wave form, the ratio peak value/r.m.s. being equal to with a tolerance of ±7 %. The main subjects considered in this standard, calibration and attenuation of partial discharge pulses, are not affected by using different frequencies of the power supply. However, the partial discharge characteristics are affected by the test frequency; the measurement procedure should take this fact into consideration.~~
The frequency of the test supply shall be in the range 45 Hz to 65 Hz with a waveshape approximating to a sinusoid with the ratio of peak to r.m.s. values being equal to √2 with a maximum tolerance of 5 %.

5.1.2 Test circuit and instruments

The test circuit includes the high voltage power supply, test object, the coupling capacitor and the HV and PD measuring ~~circuit~~ equipment. The measuring circuit consists of the measuring impedance (input impedance of the measuring instrument and the input unit which is selected to match the cable impedance), the connecting lead and the measuring instrument. The measuring instrument or detector includes a suitable amplifying device, an oscilloscope ~~and, if desired, an additional~~, or other instrument to indicate the existence of partial discharges and to measure the apparent charge. The measuring system shall comply with IEC 60270.

5.1.3 Double pulse generator

~~The properties of the partial discharge test circuit shall be checked by means of~~ A double pulse generator is an instrument producing two equal pulses (with the same apparent charge) following each other within a ~~continuously~~ time interval which can be varied between 0,2 µs to 100 µs. The rise time of the pulses shall not exceed 20 ns (10 % to 90 % of peak value); the time between 10 % values of the front and the tail shall not exceed 150 ns. The pulses may be synchronized with the power frequency.

5.1.4 Terminal impedance ~~(characteristic impedance)~~

A terminal impedance is an impedance, equal in value to the characteristic impedance of the test object ~~may be~~, which is connected to the open end of the cable remote from the detector. ~~This will suppress the reflection of pulses at this end.~~ It may be a combination of resistance and capacitance (R & C) or resistance, capacitance and inductance (R, C & L). The components shall be suitable for operation at the test voltage to be applied to the cable under test. Additional requirements are specified in section 5.6.

5.1.5 Reflection suppressor

~~To avoid superposition effects when testing without a terminal impedance, a reflection suppressor may be used.~~ This is an electronic switch which ~~in most cases can~~ is designed to block the input of the ~~detector~~ measuring instrument from pulses reflected from the open end of the cable. ~~However, when the partial discharge source is located at or near the open end some positive superposition is unavoidable.~~ This is achieved by blocking the input for a fixed time after the first pulse is received.

5.2 Setting up the test circuit

5.2.1 Determination of characteristic properties of the test circuit

The characteristic properties of the test circuit should be determined under the conditions to be used. The test circuits normally used for connections to a single cable end are those shown in Figures 5, 6, 7, 8 and 9. Similar test circuits are also applicable when both ends of the cable conductor are connected together; in this case the two ends of the metal cable screen ~~must~~ shall also be connected together.

5.2.2 Terminal impedance

~~If a terminal impedance is used (see Figure 4) its suitability for the type of cable under test should be demonstrated using the procedure described in 2.7. This check should be carried out at least once a year and also upon request and when any significant circuit component has been repaired or changed.~~

If a terminal impedance is connected to the remote end of the cable under test, with an impedance value equal to the characteristic impedance of the cable then the cable will behave as if it is of infinite length and there will be no reflected wave. The circuit for connection of a terminal impedance is shown in Figure 8. The values (RC and L where applicable) of the components of the terminal impedance and its suitability for the type of cable under test should be demonstrated using the procedure described in 5.6. This check should be carried out when the test circuit is set up and also when any changes are made to the circuit.

5.2.3 ~~Superposition~~ Determination of superposition of travelling waves

If a terminal impedance is not used, it is necessary to determine the properties of the test circuit with respect to superposition of travelling waves. A double pulse generator is connected according to Figure 10 and a double pulse diagram is plotted (see 5.5 and Figures 11, 12 and 13). This check should be carried out ~~at least once a year and also upon request and when any significant circuit component has been repaired or changed~~ when the test circuit is set up and also when any changes are made to the circuit.

5.2.4 Reflection suppressor

The purpose of using a reflection suppressor is to obtain a double pulse diagram of Type 1 corresponding to Figure 11. Using the arrangement shown in Figure 14, the efficiency of the reflection suppressor should be checked ~~at least once per year and also upon request and when any significant circuit component has been repaired or changed~~ by plotting a double pulse diagram (see 5.5 and Figures 11, 12 and 13), when the test circuit is set up and also when any changes are made to the circuit.

5.2.5 Calibration ~~charge~~ of the measuring system in the complete test circuit

~~The "charge transfer" method of calibration shall be used in accordance with 5.2.1 of IEC 60270. Further guidance for the use of discharge calibrators is given in CIGRÉ Report 1968-21-01, Appendix III. In this method, a calibrator is connected directly across one end of the cable being tested to inject short current pulses of predetermined charge magnitude into the test object as detailed in 2.4. The resulting pulse on the oscilloscope should have a height of at least 10 mm.~~

~~Unless the calibrating capacitor is rated for use at the test voltages involved, it is necessary to disconnect it before the high-voltage test transformer is energized. The amplifier gain shall not be re-adjusted after this has been done, unless a means is provided for continuous display of a suitable calibrating signal throughout the test.~~

~~Such a means may be as follows:~~

a) the calibrating capacitor may be full voltage rated and may form part of the test circuit. It need not, in this case, be disconnected before the high-voltage test transformer is energized, or

b) a secondary calibrator can be used additionally. This calibrator is connected to the input of the detector. In this case, the amplitude of the secondary pulse response shall be pre-calibrated against the primary calibrator before the latter is disconnected and the high-voltage test transformer is energized in accordance with CIGRÉ Report 1968-21-01, Appendix III, Section I, Sub-clause 1.2.

The calibration discharge, q_{cal} (in picocoulombs), is equal to the product of the calibration pulse amplitude ΔU (in volts) and the calibrating capacitance C_{cal} (in picofarads), of the calibrator as long as this capacitance is small compared with the capacitance of the test object, C_x.

$$q_{cal} = C_{cal} \cdot \Delta U$$

The characteristics of the calibrating pulse shall comply with 5.2 and 5.3 of IEC 60270 and CIGRÉ Report 1968-21-01, Appendix III, Section III. For long lengths of cable there is an additional requirement that the calibrating capacitance shall be not larger than 150 pF.

Calibration of the measuring system in the complete test circuit shall be carried out in accordance with Clause 5 of IEC 60270:2000. The calibrator used shall comply with IEC 60270. For long lengths of cable (> 100 m) there is an additional requirement that the calibrating capacitance shall be not greater than 150 pF.

5.2.6 Sensitivity

a) The sensitivity of the test circuit (with the high-voltage supply and the instruments) measuring system is defined as the minimum detectable discharge pulse, q_{min}, (in picocoulombs – pC) that can be observed in the presence of background noise. Individual, clearly identifiable interference pulses may be disregarded. An oscilloscope display is required to monitor noise signal levels since a picocoulomb meter does not identify the source of the signal indicated. In order to be detectable, a discharge pulse shall be of at least twice the apparent noise height, h_n (h_n is the noise reading on the oscilloscope or the picocoulomb meter if this is used additionally).

Value of q_{min} shall be determined by evaluation of the background noise level and shall be no more than twice the apparent noise level, h_n (h_n is the noise reading on the measuring instrument).

Therefore:

$$q_{min} = 2\ k \cdot h_n$$

$$q_{min} = x \times k \times h_n$$

where k is the scale factor and x is the ratio of the minimum detectable discharge to the background noise. The maximum allowed value of x is 2. Typically values of x of between 1,25 and 1,5 should be achievable.

b) The maximum values of sensitivity shall be determined according to 5.4.

5.3 Measurement procedures

The test shall be carried out as a type test on short cable samples and as a routine test on production lengths.

5.3.1 General

The selection of the test circuit depends on whether the cable sample may be considered as a short length (see 5.3.2) or a long length (see 5.3.3, 5.3.4 and 5.3.5) depending on the double pulse diagram (subclause 2.6). The test circuit has to shall be discharge free in order to achieve the required sensitivity (see 5.2.6). Calibration does not necessarily have to be done with the HV supply on (see 5.2.5). During the partial discharge measurement, individual pulses clearly identifiable as interference may be disregarded.

5.3.2 Short cable lengths including type test lengths

5.3.2.1 Requirements

For short lengths the cable may be considered similar to a lumped capacitance. The limitation on length where this is not acceptable depends upon the test circuit used, however it may be assumed that cable lengths of up to 50 m (or 100 m, if both ends of the cable are connected together) behave as a lumped capacitance and therefore superposition of reflected waves need not be taken into account. The actual value would be determined using the double pulse diagram described in 2.6 and defined as l_k. For longer lengths whether they can be treated as a lumped capacitance shall be determined using the double pulse diagram as described in 5.5. The maximum length which can be considered as a lumped capacitance is defined as l_k. This may be as low as 100 m or even greater than 1 000 m, depending on the particular measuring system in use.

NOTE However, lengths up to $2l_k$ behave as short lengths when both ends of the cable are connected together. (See 2.3.)

The test circuits normally used are those in Figures 5, 6 and 7.

5.3.2.2 Verification of sensitivity

The calibrator shall be connected in parallel with the cable and only at the end remote from the detector. The calibration charge, q_{cal}, is injected, and the respective measured deflection value a_2, is used to calculate the scale factor $k_2 = q_{cal}/a_2$ (pC/ mm) and sensitivity, q_{min} (pC).

$$q_{min} = 2k_2 \cdot h_n$$

where:

h_n is the deflection (mm) from background interference

The determination of the scale factor k for the measurement of the apparent charge shall be carried out in accordance with Clause 5 of IEC 60270:2000. Therefore the partial discharge calibrator shall be connected in parallel with the cable at the end remote from the detector.

5.3.2.3 Test procedure

The measurement shall be made only at one end of the cable. For the measured deflection A (mm) the discharge magnitude q (pC) is

$$q = k_2 \cdot A$$

The voltage levels used shall be selected according to 2.5.

The measurement shall be made only at one end of the cable.

The test parameters shall be selected according to 5.4.

5.3.3 Long cable lengths tested without a terminal impedance

5.3.3.1 General

For long cable lengths (>50 m or >100 m with ends connected), tested without a terminal impedance, it is necessary to plot a double pulse diagram.

5.3.3.2 Requirements

For cable lengths in excess of l_k it may still be possible to test without a terminal impedance provided superposition and attenuation phenomena are taken into account. ~~A test without terminal impedance is permitted where the double pulse diagram (suclause 2.6) is either:~~

A double pulse generator is connected according to Figure 10 and a double pulse diagram is plotted (see 5.5 and Figures 11, 12 and 13). This shall be carried out when the test circuit is set up and also when any changes are made to the circuit.

A test without terminal impedance is permitted where the double pulse diagram is either

– type 1 (Figure 11) or

– type 2 and type 3 (Figures 12 and 13) but where the cable length, l, lies outside the limits $2l_1 \leq l \leq 2l_2$.

(See 5.5 for the determination of l_1 and l_2.)

For lengths inside these limits an alternative test circuit should be used or the procedures described in 5.3.4 or 5.3.5 should be adopted.

The test circuits normally used are those shown in Figures 5, 6, 7 and 9.

5.3.3.3 Verification of sensitivity

~~As shown in Figures 1, 2, 3 or 5, the calibrator shall be connected to each end in turn, in parallel with the cable, at first to the end remote from the detector and then — with the same setting of the amplifier and calibration charge — to the end near the detector.~~

The determination of the scale factor k for the measurement of the apparent charge shall be carried out in accordance with Clause 5 of IEC 60270:2000. Therefore the partial discharge calibrator shall be connected in parallel with the cable at the end near to the detector.

For the determination of the attenuation correction factor, the partial discharge calibrator shall be connected to each end in turn in parallel with the cable with the same setting of the amplifier and calibration charge. The following values shall be recorded:

– a_1 ~~(mm) the deflection~~ discharge magnitude measured with the calibrator at the end near to the detector;

– a_2 ~~(mm) the deflection~~ discharge magnitude measured with the calibrator at the end remote from the detector. ~~a_1 and the calibration charge q_{cal} (pC) are used to determine the scale factor k_1 (pC/mm):~~

~~$$k_1 = q_{cal}/a_1$$~~

a_1 and a_2 are used to determine a correction factor F to allow for attenuation. It is given by:

$$F = 1 \qquad \text{if } a_2 \geq a_1$$

$$F = \sqrt{\frac{a_1}{a_2}} \qquad \text{if } a_2 < a_1$$

5.3.3.4 Test procedure

The measurement shall be made twice by connecting the high voltage end of the coupling capacitor to each end of the cable in turn. The measured deflections discharge magnitudes A_1 and A_2 shall be determined and the higher value A_{max} (mm pC) selected. With the scale factor k_1 (pC/mm) and the correction factor F, the discharge magnitude q(pC) is:

$$q = k_1 \cdot A_{max} \cdot F$$

$$q = A_{max} \times F$$

The voltage levels used when measuring the highest deflection discharge magnitude A_{max} shall be selected according to 5.4.

NOTE Only if the double pulse diagram is of type 1 (see Figure 11) and $a_2 \geq a_1$, a measurement of A(mm pC) is sufficient when both cable ends are connected together (see 5.3.2).
The discharge magnitude is then: $q = k_1 \cdot A$ $q = A$

5.3.4 Long cable lengths tested with a terminal impedance

5.3.4.1 General

For long cable lengths (>50 m or >100 m with ends connected), tested with a terminal impedance, it is not necessary to plot a double pulse diagram.

5.3.4.2 Requirements

To eliminate superposition errors, cables of length greater than l_k may be tested with a terminal impedance as shown in Figure 8. This method may be used with all detectors and all cable lengths provided that the impedance Z_w meets the requirements specified in 5.6. The suitability of the impedance for the cable under test shall be demonstrated using the procedure described in 5.6.

5.3.4.3 Verification of sensitivity

As shown in Figure 4 the calibrator should be connected to each end in parallel with the cable at first to the end remote from the detector and then — with the same amplifier setting and calibration charge — to the end near to the detector.

The partial discharge calibrator shall be connected to each end in turn in parallel with the cable with the same setting of the amplifier and calibration charge. The following values shall be recorded:

– a_1 (mm pC) the deflection discharge magnitude measured with the calibrator at the end near to the detector. This need not be measured if the procedure in 5.3.4.4 b) is sufficient;
– a_2 (mm pC) the deflection discharge magnitude measured with the calibrator at the end remote from the detector.

The scale factor k_2 (pC/mm) is determined, and sensitivity q_{min} (pC) calculated:

$$k_2 = q_{cal}/a_2$$

$$q_{min} = 2\,k_2 \cdot h_n$$

For the determination of the scale factor k for the measurement of the apparent charge in accordance with Clause 5 of IEC 60270:2000, the value a_2 (pC) with the partial discharge calibrator connected in parallel with the cable at the end remote from the detector shall be used.

5.3.4.4 Test procedure

The test procedure is as follows.

a) When it is required to determine the value of the partial discharge magnitude as closely as possible, the high voltage end of the coupling capacitor shall be connected to each end of the cable in turn and both measured ~~deflections~~ discharge magnitudes A_1(pC) and A_2 (~~mm~~ pC) determined. The discharge magnitude q (pC) is given by:

$$q = q_{\text{cal}} \times \sqrt{\frac{A_1 \times A_2}{a_1 \times a_2}}$$

where q_{cal} is the calibration discharge magnitude (pC).

b) When it is sufficient to check that the discharge magnitude does not exceed a specified value, the measurement may be made with the high voltage end of the coupling capacitor connected to one end of the cable only. In this case the calibration pulse is injected only at the end of the cable connected to the terminal impedance remote from the detector (a_2). With the measured ~~deflection~~ discharge magnitude A_1 (~~mm~~ pC) and the scale factor k_2 ~~(pC/mm)~~ the discharge magnitude q (pC) is given by:

$$q = k_2 \times A_1$$

The voltage levels used when measuring the ~~deflections~~ discharge magnitudes A_1 and if necessary A_2 shall be selected according to 5.4.

5.3.5 Long cable lengths tested with a reflection suppressor

5.3.5.1 General

For long cable lengths (>50 m or >100 m with ends connected), tested with a reflection suppressor, it is necessary to plot a double pulse diagram.

The connection of the reflection suppressor is shown in Figure 9.

A double pulse generator is connected according to Figure 10 and a double pulse diagram is plotted (see 5.5 and Figures 11, 12 and 13). This shall be carried out when the test circuit is set up and also when any changes are made to the circuit.

5.3.5.2 Requirements

When using a reflection suppressor the double pulse diagram ~~must~~ shall be type 1 (see Figure 11).

5.3.5.3 Verification of sensitivity

~~These are the same as those indicated for testing long lengths without a terminal impedance (see 2.4.2).~~

See 5.3.2.2.

5.3.5.4 Test procedure

See 5.3.2.3.

5.4 Voltage levels/partial discharge limits

The test voltages, partial discharge sensitivity and partial discharge limits shall be determined in accordance with the requirements in the standard for the type of cable.

5.5 Double pulse behaviour and plotting the double pulse diagram

A double pulse generator should be connected to the components of the measuring circuit as shown in Figure 6.

The double pulse plot is affected by variations in each circuit component. It is important that the double pulse plot be obtained for the precise conditions to be used in the high voltage test.

NOTE The test cable is not connected whilst the double pulse plot is being plotted, the double pulse plot depends solely on the measuring system and test circuit, excluding the cable.

The power cable is replaced by a resistive load having the maximum characteristic impedance for extruded cables (R = 50 Ω to 60 Ω generally R_{max} = 40 Ω). The double pulses are injected in the same position as the calibration pulses for the various test circuits shown in Figures 5, 6 and 7. Figure 10 shows, as an example, the double pulse generator connected to the test circuit of Figure 5.

The following conditions should apply:

a) The double pulse generator I should satisfy the requirements of 5.1.3. Pulse spacing should be determined using an external oscilloscope with calibrated time base. In some cases the dials of the double pulse generator may have numeric (e.g. 0 to 9) markings for pulse separation, in which case it will be necessary to use a suitable oscilloscope to calibrate these scales in terms of µs; the required accuracy is ± 3 % or 50 ns whichever is the greater. The overall output impedance should be in the range of 50 Ω to 60 Ω approximately match the characteristic impedance of the cable, which is typically in the range of 20 Ω to 40 Ω. To achieve this it may be necessary to add external resistors in parallel to or in series with the output.

   Experience has shown that the double pulse plot may be reliably obtained in the following ways:

   – The simplest method is to connect the double pulse generator across the high voltage capacitor C_K and the measuring impedance Z_A with wires not longer than 3 m.

   – For longer connections a coaxial cable should be used (see Figure 10). In this case two adapter resistors R_1 and R_2 are necessary to ensure that the matched system presents an impedance in the range 50 Ω to 60 Ω as the load resistance system approximately matches the characteristic impedance of the cable, which is typically in the range of 20 Ω to 40 Ω.

b) The capacitor C_K and the other high voltage components of the test circuit should be the same and have the same connections as those used in the high voltage test.

c) The matching unit or detector impedance Z_A to be used in the high voltage test should be used to obtain the double pulse plot.

d) The detector amplifier D should be used with the gain setting and amplifier frequency response selected for the high voltage test. For accurate measurement of the changes in pulse magnitude caused by superposition distortions, the output of the detector amplifier D should be displayed on an external oscilloscope (for example the oscilloscope used in 5.5 a)).

   The time interval of the double pulse generator should be set to 100 µs and the deflections discharge magnitude of the partial discharge detector to the two pulses A_{100} should be measured. The time interval should then be reduced from 100 µs to 0,2 µs; for different values of an interval t measured between maximum peaks of the two pulses, the maximum deflection discharge magnitude A_t should be measured. Particular attention should be given to areas of positive and negative superposition. Values of A_t/A_{100} should then be plotted as a function of t to obtain the double pulse diagram. Examples of diagrams are in Figures 11 to 13.

The value t_k where A_t/A_{100} = 1,4 on the initial positive superposition should be determined from the plot. Times t_1 and t_2 where $A_t/A_{100} \leq 1{,}0$ at all areas of negative superposition should be determined. Taking into account the errors of measurement, areas of negative superposition with a maximum magnitude up to –10 % ~~can~~ may be ignored.

The cable lengths l_k, l_1 and l_2 corresponding to t_k, t_1 and t_2 should be calculated using the formula $l = 0{,}5 \times t \times v$. The mean propagation velocity is v and typical values for most extruded cable lie between 150 m/µs and 170 m/µs. On request the propagation rate shall be measured by injecting a calibration pulse into a cable not having a terminal impedance and measuring the time delay between incident and reflected pulse.

The cable lengths $l < l_k$ can be considered as short lengths. These may be as low as 100 m and even higher than 1 000 m.

Lengths between $2l_1$ and $2l_2$ ~~are considered forbidden lengths. These lengths~~ have to be tested with a terminal impedance (see 5.3.4.2) or under modified conditions of the test circuit (for example D, Z_A, C_K) to alter l_1 and l_2 to more suitable values. Alternatively, it is possible to effectively double the value of l_k by connecting both ends of the cable together.

5.6 Requirements for the terminal impedance

5.6.1 General

The terminal impedance Z_w, shown in Figure 8 comprises either RC or RLC elements which are selected on the basis of experimental evaluation.

5.6.2 RC element

The following measurement shall be used to prove the suitability of the terminal capacitor C_w.

The RC element shall be connected in parallel with the cable across the end remote from the detector. The capacitive component shall be short-circuited and the ohmic component shall be adjusted to correspond to the characteristic impedance of the cable. Subsequently the calibrator shall also be connected to the end remote from the detector and the measured ~~deflection~~ discharge magnitude a_2 shall be determined.

With the same amplifier setting, the short circuit of the capacitive component of the terminal impedance shall be removed.

The removal of the short circuit of the capacitor (C_w) shall not change the ~~deflection~~ discharge magnitude a_2 by more than ±15 %.

For PD detectors having a cut-off frequency lower than 2 MHz, a reasonable estimate for the value of the ~~capacitor~~ capacitance C_w (high voltage coupling capacitor of Z_w) may be obtained using the following formula:

$$C_w \geq 0{,}5 \frac{1}{R_w \times f_m}$$

where

R_w is the ohmic component of the terminal impedance (corresponding approximately to the characteristic impedance of the cable);

f_m is the mean measuring frequency of the detector (arithmetic mean of the upper and lower limiting frequencies of the detector).

For PD measuring instruments having a wide-band amplifier with an upper cut-off frequency more than 2 MHz in connection with an electronic integrator unit, C_w can be estimated on the basis of the relation:

$$C_w \geq \frac{3\,T_J}{R_w}$$

T_J is the time duration of the original PD pulse (in general smaller than 0,2 µs).

5.6.3 RLC element series resonance circuit

The following measurement shall be used for proving the suitability of the resonant circuit at the respective measuring frequency.

With the terminal impedance removed an ohmic resistor corresponding to the characteristic impedance of the cable shall be connected to the end remote from the detector in parallel with the cable. Furthermore the calibrator shall be connected to the end remote from the detector, and the measured ~~deflection~~ discharge magnitude a_2 shall be determined.

Then the ohmic resistor shall be removed — with the setting of the amplifier kept constant — and replaced by the terminal impedance, consisting of RLC.

At the measuring frequency the ohmic component of the terminal impedance shall correspond to the resistance R_w.

The measured ~~deflection~~ discharge magnitude a_2 shall not change by more than ±15 % when the terminal impedance is connected.

Reasonable estimates of the values of the capacitance C_w and the inductance L_w may be obtained by using the following formulas:

$$C_w \geq \frac{\Delta f}{2\pi \times f_m^2 \times R_w}$$

$$L_w \geq \frac{1}{(2\pi \times f_m)^2 \times C_w}$$

where

R_W is the ohmic component of the terminal impedance (corresponding approximately to the characteristic impedance of the cable);

f_m is the mean measuring frequency of the detector (arithmetic mean of the upper and lower limiting frequencies of the detector);

Δf is the bandwidth of the detector (upper limiting frequency minus the lower limiting frequency of the detector).

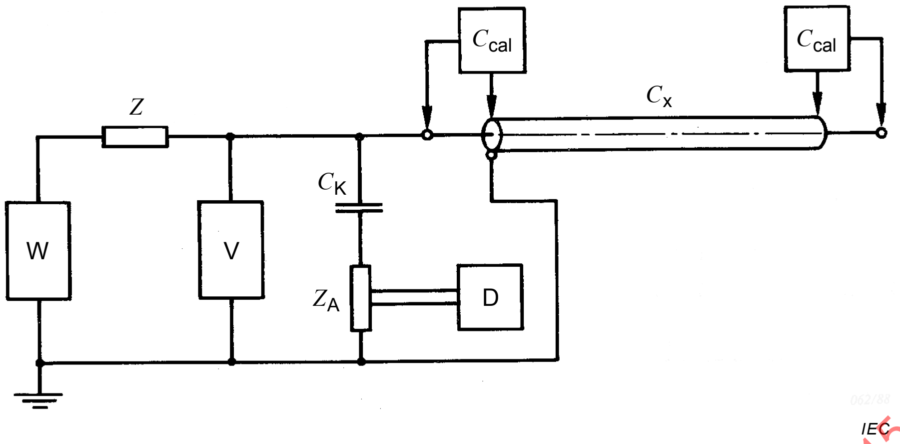


Figure 5 – Input unit Z_A connected in series with the coupling capacitor, C_K

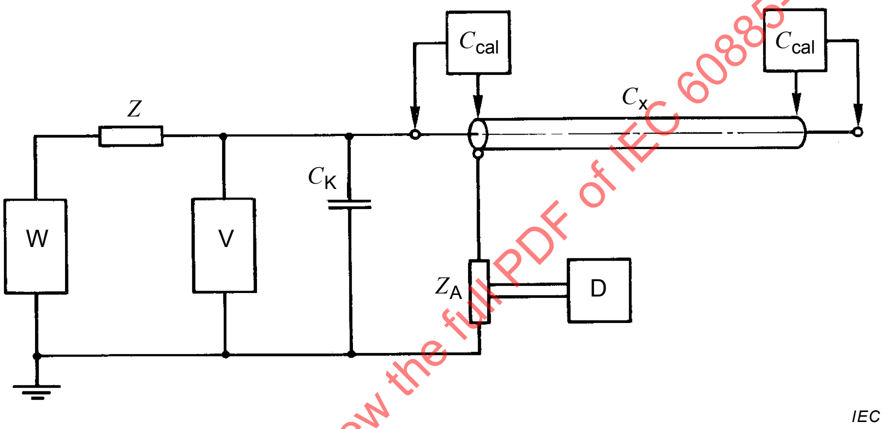


Figure 6 – Input unit Z_A connected in series with the cable, C_x

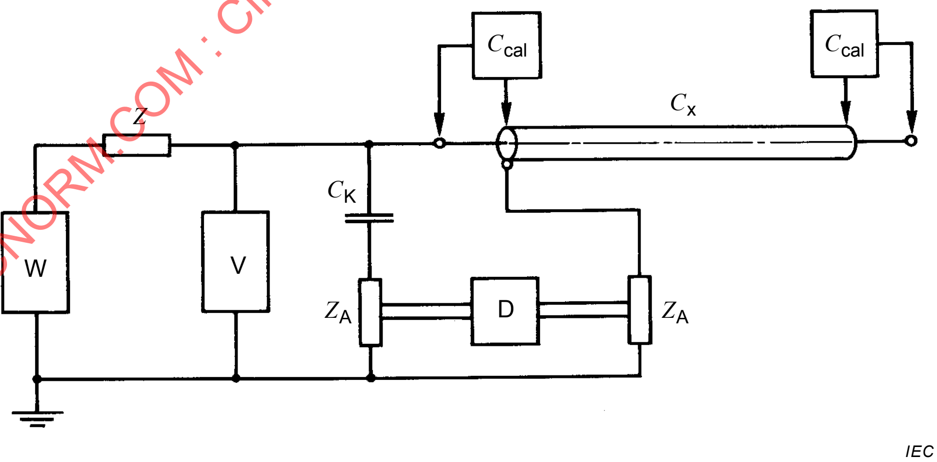


Figure 7 – Bridge circuit

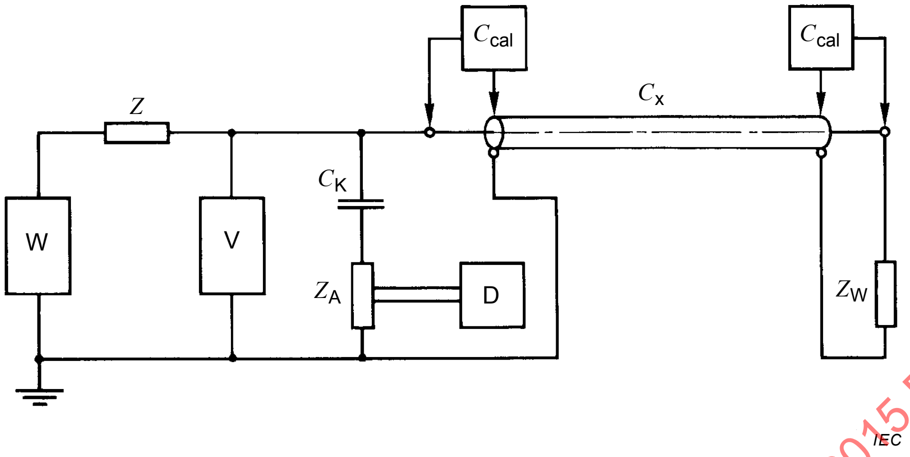


Figure 8 – Connection of the terminal impedance Z_W

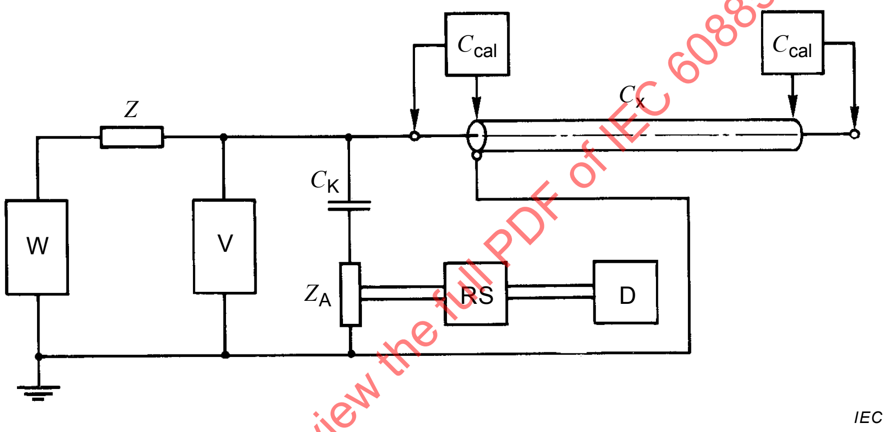
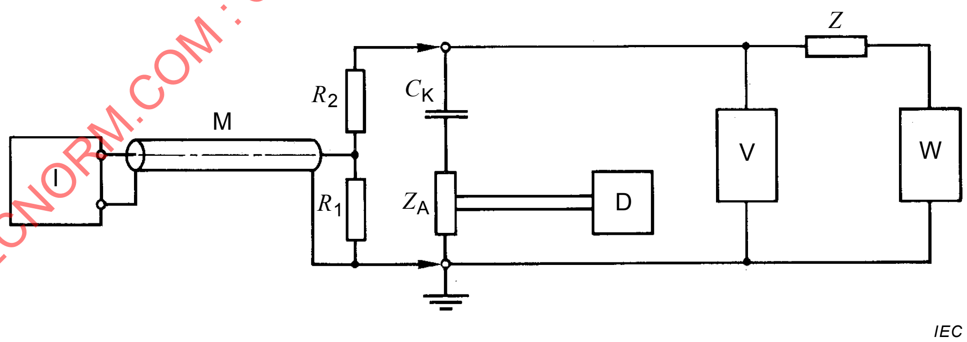


Figure 9 – Connection of the reflection suppressor, RS



Key

R_1 matching resistor with a value corresponding to the characteristic impedance of the coaxial signal cable M

R_2 matching resistor with a value $R_2 = R - \frac{R_1}{2}$ (load resistance R is typically 20 Ω to 40 Ω)

Figure 10 – Connection of the double pulse generator into the measuring circuit in Figure 5

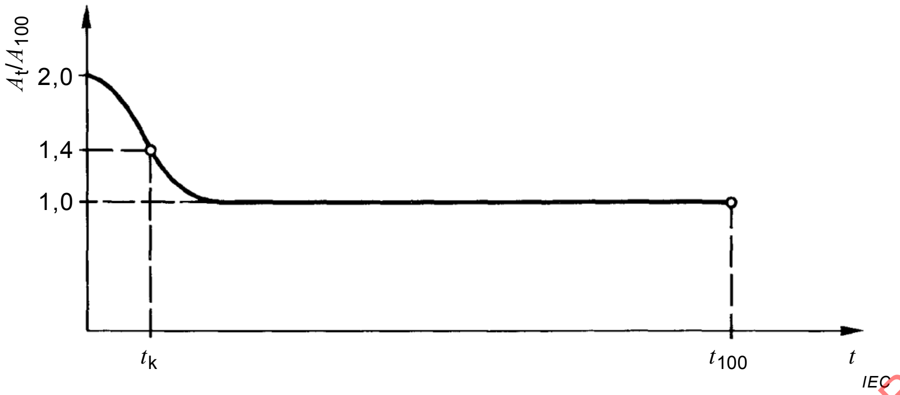
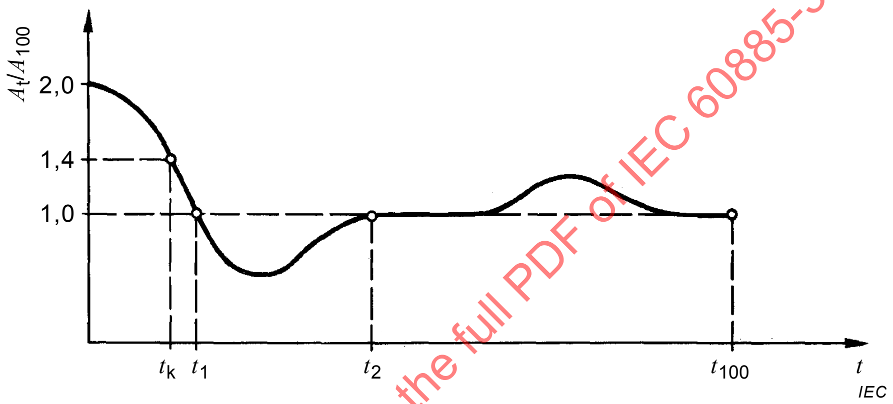


Figure 11 – Double pulse diagram type 1 without negative superposition



NOTE The influence of the positive superposition between t_2 and t_{100} is negligible.

Figure 12 – Double pulse diagram type 2 with negative superposition between t_1 and t_2

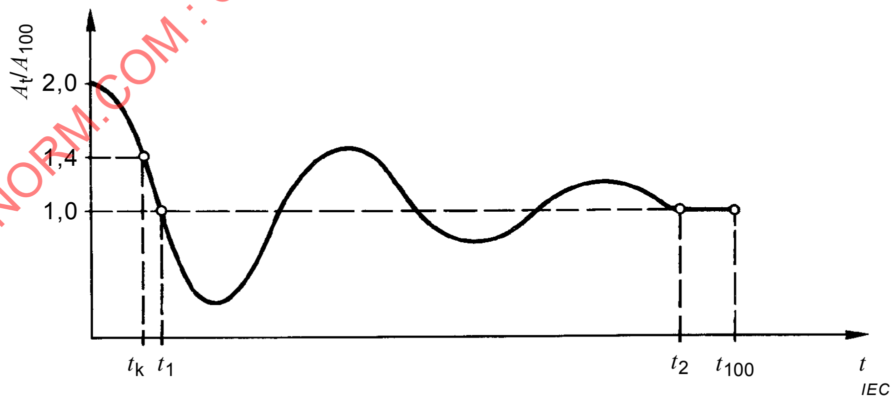


Figure 13 – Double pulse diagram type 3 with negative and positive superpositions between t_1 and t_2

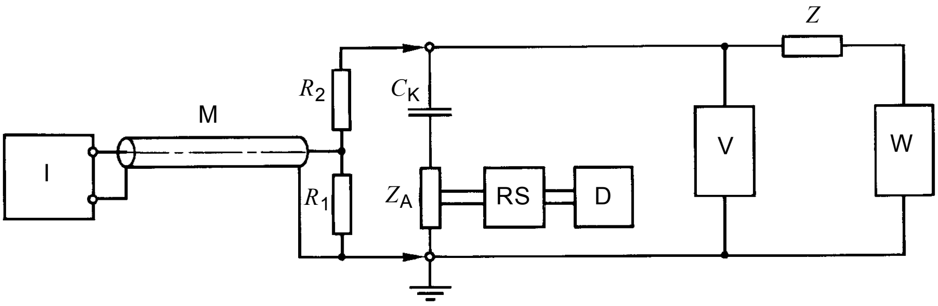


Figure 14 – Connection of the double pulse generator for the test circuit in Figure 9 with the reflection suppressor

3 SECTION THREE – APPLICATION GUIDE

The procedures to be adopted during partial discharge tests on lengths of extruded power cable are described in Section 2. This guide has been prepared to explain or justify some of the procedures.

3.1 Background information

3.1.1 Introduction

A partial discharge (PD) measurement is used as one of the quality control tests for extruded cables in the medium and high voltage range. The normal situation would be that partial discharges would not occur in such cables when energized to stresses usually required in specifications. Occasionally, however, there will be an isolated defect which does produce PD. The purpose of the test is to identify this particular situation. An essential requirement is that the procedures allow an accurate measurement of PD from a single site regardless of its position in the cable length.

Sensitive measurement techniques are used to detect the PD which occur in the form of pulses at a specific field strength in voids within the insulation or in defective areas of the semi-conducting layers. The procedures which may be used are described in a general document, IEC 60270. In this, some of the difficulties, such as restrictions in sensitivity caused by electrical interference, and methods of overcoming them are discussed. However, there are other problems specific to long lengths of cable which are outside the scope of IEC 60270. It is to these problems that this standard is addressed.

The electrical transient at a discharge site within a long cable length sets up travelling waves propagating to both ends of the cable. A PD detector located at one end will respond both to the wave arriving directly and the wave arriving after reflection at the other end of the cable. The arrival of the two wave trains can lead to superposition and the resulting response may be greater or less than the initial wave. If the response is greater than the initial wave this positive superposition error will lead to an overestimate of the discharge magnitude. As such it would not limit the effectiveness of the test. However, an underestimate will occur if the response is less than the initial wave. Such a negative error could lead to faults being undetected. The strategy of this standard is to permit positive errors and to keep negative errors to within acceptable limits.

The response and associated errors are determined by both the length of cable and the characteristics of the test circuit. The procedures required to take account of these errors and those due to attenuation are not considered in IEC 60270. The phenomena were considered by CIGRÉ some years ago (CIGRÉ Report 1968-21.01, Appendix IV), and earlier IEC

~~standards for tests on extruded cable have recommended the use of this Report in conjunction with IEC 60270. However, factory experience has subsequently indicated three important results:~~

~~a) Some of the techniques recommended by CIGRÉ are too complicated and time-consuming and therefore too expensive, particularly for higher voltage cables. Consequently it can be attractive to test with both attenuation and superposition occurring, but to do this in such a way that maximum errors are defined and contained within acceptable limits as specified in Section Two.~~

~~b) The conditions producing negative and positive superposition errors depend upon the complete test circuit. To describe a particular PD detector as having an α or β response[1] with consequential measurement strategies has led to unexpected and incomparable results. This is not the best method, therefore. This standard recommends a method based upon the determination of the characteristic properties of the complete test circuit by plotting the so-called "double pulse diagram". It is on the basis of this double pulse diagram that the most economic test method should be chosen.~~

~~c) There was an implication in the CIGRÉ report that an a or positive superposition condition was always to be preferred. Experience has shown the most economic test circuit to be where a cable can be considered sufficiently short that it may be tested as a lumped capacitance. The situation may arise where lengths normally tested can be considered short with a β response but not with an a response circuit. By evaluating the relevant double pulse diagrams it could be stated that the β response would then be preferred.~~

~~This standard is, therefore, complementary to IEC 60270 and relates specifically to the problems of discharge tests for power cables. Its essential theme is the determination of the most economic test method for a particular length of cable on the basis of the double pulse diagram. This calibration procedure enables the errors to be determined as a function of cable length and to specify methods for keeping the errors within acceptable limits.~~

~~The first consideration is to establish what lengths may be considered short or long for a particular test circuit since to test as a short length is the most economic test method. A short length might be as little as 100 m and can be as much as 1 000 m depending on the test circuit. For long lengths one possibility is to terminate the far end of the cable with the characteristic impedance. This will prevent the reflection of pulses and eliminate this source of error. Another possibility considered is to allow both pulses to be detected and suppress the reflected pulses electronically.~~

~~Both prevention and suppression methods require special checks to demonstrate their effectiveness. Finally the most economic method for long lengths is to test without preventing the reflection or suppressing the reflected pulses. However for some test circuits, the errors are too large and this method is not acceptable for tests on particular lengths of cable. In these cases, it would be necessary to test with a characteristic impedance, or with a suppressor, or change to an alternative test circuit having a different and more suitable double pulse diagram.~~

~~3.1.2 Superposition and attenuation~~

~~The transfer of charge within a PD at a site within a long cable length sets up two travelling waves which propagate to both ends of the cable. The waves are generated during the charge transfer and consequently are transients of short duration. The charge contained within each corresponds to half the discharge magnitude and propagates to the cable ends at a velocity *y* approximately given by (*c* is the velocity of light ands the relative dielectric permittivity). The detector input unit Z_A shown in Figures 1 to 3 is selected to match the cable's characteristic impedance.~~

~~[1] Most detectors produce a highly damped oscillatory wave. With an a response the first peak has the largest deflection; with a α response the second or a subsequent peak is the largest.~~

Consequently pulses reflected at the detector end of the cable are negligible. Reflection phenomena relate to a single reflection at the cable end remote from the detector. For a PD site exactly at the remote cable end there would be only one pulse which would contain the whole charge (see Figure 11). In this special case the influence of reflection and superposition phenomena has no relevance.

The conventional situation of a site within the length and a detector at one end is shown prior to and after reflection in a) and b) of Figure 12. At the open cable end remote from the detector, the wave is reflected on arrival; it then travels in the same direction as the unreflected wave with a time delay t. The greater the distance of the PD source from the cable end remote from the detector, the greater will be the time delay t.

The measurement circuit responds to each wave to produce a voltage pulse. For a discharge pulse the response of the measuring circuit is proportional to the peak voltage or to the charge, and the proportionality factor depends upon the frequency range and other parameters of the circuit. If a pulse arrives at the measuring circuit within the time the measuring device is responding to an earlier pulse, the resulting voltage pulse is the sum of the two superposed responses caused by the two individual pulses with their time delay t. Due to this superposition, the measured result is correspondingly modified and an error introduced in its proportionality to the PD pulse. This is the superposition error which, depending upon both the time delay t (i.e. site of the PD in the length) and the characteristic of the measuring circuit, may cause an increase or a decrease, a positive or a negative effect as shown in Figures 13 and 14.

Consequently, a cable measurement can be evaluated correctly only with an exact knowledge of the influence of these reflection and superposition phenomena.

The effect of superposition errors can be shown by injecting calibration pulses into a cable at various positions along the length to produce the responses such as those shown in Figures 13 and 14 or by simulating the sequence of two pulses travelling in the same direction with a constant time delay t. The latter possibility can easily be realized by injecting two successive pulses with a shape similar to PD pulses into the measuring circuit. This is shown in Figure 6. By varying the time delay t between these pulses all possible sites of a PD source on the cable length are considered. Plotting the voltage magnitude from the detector versus the time delay t between the double pulses leads to the double pulse diagram (see examples in Figures 7, 8 and 9). This describes the characteristics properties of the test circuit and is the basis for choosing the appropriate test method for each length of cable.

The other major effect influencing the measured result is attenuation. It depends on cable length, construction and the frequency response of the measuring circuit. It can be estimated using the equation :

$$a(x) = a_1 \exp(-\gamma x)$$

where:

a s the measured value at x

a_1 is the measured value at $x = 0$ (see Figure 13)

x is the site of PD source (see Figure 13)

γ is a constant, depending on cable construction and detector frequencies

The influence of attenuation alone is shown as the full line in Figure 13, and with additional reflection and superposition effects in the dashed curve. By calibrating from both cable ends and using the above equation the attenuation error can be calculated and corrections made. In Subclause 2.4.2 this is achieved by introducing a correction factor F which is calculated from the two calibrations and, by relating it to the attenuation equation, its use will ensure that the attenuation error does not exceed 30 %. In Figures 14a and 14b two typical examples with attenuation and superposition effects are shown. The latter occurs within the last 600 m or 640 m: had the cable been shorter than this all sites would have shown superposition. For longer lengths, as in the case of this 2 000 m length, the superposition errors would be restricted to PD sites in the end 640 m, for example, in Figure 14a, and 600 m, for example, in Figure 14b. For both examples, or in general, short lengths are defined by $l \leq l_k$, where the error is less than minus 30 % when calibrating only at the end remote from the detector. The length defined as l_k where the errors reach 30 % is 440 m, for example, in Figure 14a, and 190 m, for example, in Figure 14b. For these short lengths $l \leq l_k$ a simple test method is derived in 2.4.1.

For longer lengths $l > l_k$ two cases have to be strictly separated:

a) Positive superposition only (see figure 14a)

– A correct measurement is possible for all cables independent of the length by testing from each end in turn (A_1 and A_2) and selecting the higher value A_{max} for evaluation (see 2.4.2, Item c)). Negative errors ($A_X/A_Q < 1$) are caused by attenuation. In no cases are these negative errors increased by superposition. In some cases, when the attenuation is too high, correction may be needed (see 2.4.2, Item b), and 3.2.2.2).

b) Positive and negative superposition (see Figure 14b)

– For negative superposition shown for example in Figure 14b between l_1 = 220 m and l_1 = 600 m a correction is NOT possible. Using the above-mentioned method, all lengths longer than $2l_1$ = 440 m and shorter than $2l_2$ = 1 200 m would be designated "forbidden" for this arrangement of the test circuit. In this case some alternative method of test must be sought. A test circuit with different characteristic properties (frequency of detector, input unit, coupling capacitor) could be used. To eliminate superposition and obtain the results shown by points x in Figure 14, a characteristic impedance termination or an electronic device (reflection suppressor) could be used. All other lengths outside the "forbidden range" can be measured by using the method described in Item a).

3.2 Procedures and parameters

3.2.1 Determination of characteristic properties of the test circuit (see 2.3)

3.2.1.1 Superposition (see 2.3.1 and 2.6)

As described earlier, the test circuit can be quickly and easily evaluated for superposition errors from the double pulse plot obtained using a double pulse generator. The double pulse plot is affected. by variations in each circuit component. It is important, therefore, that it is obtained for the precise conditions to be used in the high voltage test as shown in Figures 1 to 3 but with the cable replaced with a load R corresponding to the maximum possible characteristic cable impedance. The test circuit comprising this load together with the high voltage components, capacitors, detector, input unit and detector amplifier is evaluated by injecting two pulses of variable time delay into the load.

The double pulses are injected in the same positions as the calibration pulses in the various test circuits shown in Figures 1 to 3. It should be noted that in the case of circuits shown in Figures 2 and 3 the double pulse generator must be capable of operating with both terminals isolated from earth.

The characteristic impedance of extruded high voltage cables is in the range 10 Ω - 60 Ω. The worst case for superposition effects is the higher value, 60 Ω. It is important, therefore, to match the overall load impedance to this value.

Since a common output impedance of commercially available double pulse generators is in the range 50 Ω to 60 Ω, the simplest and preferred method of obtaining the double pulse plot is to use such a generator and connect the output directly across the high voltage capacitor C_K and input unit Z_A with short unscreened connections. These connections should be as short as possible; experience has shown that up to 3 m would be acceptable. In this case the internal impedance of the generator acts as the load R. Where the output impedance is not 50 Ω to 60 Ω then additional resistors must be connected in series (for lower values) or in parallel (for higher values) with the generator terminals. For longer connections, a coaxial signal cable should be used between the generator and C_K and Z_A (see Figure 6). The unscreened part of the connections between the coaxial signal cable and C_K and Z_A should again be kept as short as possible and less than 3 m. To prevent reflections in the coaxial cable it must be terminated with its own characteristic impedance R_1. Normally a 50 Ω to 60 Ω cable would be used with a 50 Ω to 60 Ω generator. Otherwise, external resistors would be needed at the generator output to match the overall generator output impedance to the signal cable.

Since the overall impedance of the signal cable terminated by R_1 would be half of 50 Ω to 60 Ω it is necessary to add an additional resistor R_2 in series with R_1 to ensure that the matched system presents an impedance in the range 50 Ω to 60 Ω as the load resistor.

The double pulse generator is required to produce two pulses having a time separation variable between 0.2 µs and 100 µs, with a rise time ≤20 ns (10 % to 90 % of peak value). The latter should ensure that transients caused by partial discharge pulses and the double pulses have the same frequency components in the range of the detector frequency bandwidth. The time between the 10 % value of the front and the tail should not exceed 150 ns in order to determine the response for the shorter pulse separations (t = 0.2 µs). At 100 µs separation PD-detectors do not show any superposition and so the value obtained on the detector is used as the reference.

At 0.2 µs separation the pulses will be superposed and the value will be double the reference. Some standards restrict the range of calibration to between 1 µs and 100 µs. This is an unnecessary restriction. There are many commercially available double pulse generators covering the range 0.2 µs; the doubling effect can be evaluated properly.

Whilst the double pulse plot can be obtained using the oscillographic display of a detector, it is better to use a separate oscilloscope with a time base adjustable to display the two pulses adequately and with a calibrated vertical scale. Such an oscilloscope would also be needed to measure the time delay since a direct reading from some double pulse generators is inadequate. Typical plots are shown in Figures 7, 8 and 9 and these may be seen to correspond to Figure 14. The time interval may be converted to a length by using the formula $l = ½ \cdot t \cdot v$. From such a calculation it is possible to define important lengths l_K, l_1, and l_2.

3.2.1.2 Terminal impedance (see 2.3.2 and 2.7)

Superposition errors can be avoided if a cable is fitted with a high voltage termination having the characteristic impedance. It is important that the resistance used has the correct value, and for this reason, it is necessary to check the termination regularly to ensure its effectiveness for the cable under test. Normally the terminal impedance consists of low voltage components in series with a high voltage capacitor. Some care is needed to ensure that the latter does not produce a reactive combination and so nullify the use of the termination. Appropriate formulae are given in Sub clause 2.7. There is a financial incentive to keep high voltage capacitors to as low a capacitance value as possible and, in keeping with the overall containment of errors to within 30 %, a change in measurement a_2 with and without the capacitor of ±15 % is allowed.

However, the requirements for termination impedance can mean expensive high voltage; high value capacitors are therefore needed. These costs and time to match the resistor value may influence some organizations to use alternative techniques.

3.2.1.3 Reflection suppressors (see 2.3.3)

It is only recently that effective electronic suppressors have become commercially available. Consequently, their use is not widespread, and experience is limited. However, there is no reason why this technique should not become an effective one.

3.2.1.4 Calibration charge (see 2.3.4)

The charge transfer method of charge calibration is recommended and the background to this is discussed in IEC 60270. The gain of commercial detectors should be linear but Subclause 2.3.4 requires calibration to be made at the gain setting to be used. This will prevent nonlinearity errors. Additionally, some detectors have a wave shape which is gain dependent and since it is the waveshape which determines the superposition effect, it is particularly to prevent errors due to this that the gain requirement is stipulated.

3.2.1.5 Sensitivity (see 2.3.5)

Discharge measurements on cables are often made at the limits of sensitivity attainable in the cable factory environment. This is usually determined by external background interference. It will rarely be the case that a picocoulomb meter can be used. An oscilloscope display will allow some identification between noise and discharge signals.

3.2.2 Measurement procedures (see 2.4)

3.2.2.1 Short cable lengths 1 < l_k (see 2.4.1)

a) Requirements

Very short cable lengths, say up to 20 m, behave as capacitors where the travelling wave reaches both ends of the cable within the duration of the discharge in the void. As such there will be no superposition errors. However, discharge measurements are often imprecise when attempting to estimate discharge magnitude. It is considered that some superposition errors can be tolerated without impairing the more general errors, i.e. that to define a short length such as that where the cable behaves as a capacitor is unjustifiably restrictive. It is considered that a superposition error of up to 30 % would be acceptable. It should be emphasized that this is a consensus definition of which cables may be tested as short lengths without further complications. However, by accepting this, it may be possible to test lengths up to 1 000 m in this way. The actual value will depend upon the test circuit. It would be determined from a double pulse plot.

Short lengths of cable are those corresponding to the extreme right-hand parts of a) and b) in Figure 14 or the left-hand part of Figures 7, 8 and 9. Within the region of positive superposition the short length $l = l_k$ is defined as that where the voltage wave resulting from superposition from incident and reflected wavetrains has reduced to 70 % of the value a 2 obtained from a discharge at the end remote from the detector, i.e. A_t/A_{100} = 1.4 in Figures 7, 8 and 9. However, lengths up to 2 l_k behave as short lengths when both ends of the cable are connected together and $a_2 \geq v_1$ (see Figure 15).

b) Verification of sensitivity

For calibration purposes the calibrator is connected to the end remote from the detector. This will compensate for any attenuation and limit the error of superposition to less than 30 %.

3.2.2.2 Long cable lengths 1 > l_k without a terminal impedance (see 2.4.2)

a) Requirements

For lengths greater than l_k errors in general will be larger than 30 %. If the test circuit, detector and cable length are tested in a positive superposition region (see Figure 7) the error due to superposition would be between 0 % and 100 %. By detecting from each end of the cable in turn, as shown in Figure 16, it is possible to ensure that superposition errors can only result in an overestimate. A decrease in the original signal can be caused by attenuation only and this reduction can be calculated and compensated to be less than 30 % by using a value of a correction factor F in the calibration equation.

However, in regions of negative superposition, an underestimate of discharge magnitude occurs — and the extent cannot be calculated. Although some standards accept a 15 % negative superposition, there are sufficient possibilities for avoiding these conditions — by altering the test circuit or amplifier response — so that there is no need for any test to be made where negative superposition may occur. Where negative superposition can occur with any test circuit/amplifier combination the recommendation is that cable lengths corresponding to negative superposition are not tested. Lengths corresponding to t_1 and t_2 are shown in Figures 8 and 9 as $2l_2 > l > 2l_1$ where $A_t/A_{100} < 1$ are considered to be forbidden for the test circuit.

When both ends of the cable are connected together the following conditions shall apply:

— the double pulse diagram shall be of type 1 (see Figure 7);

— $a_2 \geq a_1$

— then the maximum error due to attenuation is always smaller than 30 % (see Figure 15).

b) Verification of sensitivity

Attenuation errors may be calculated using the formulae given in Item b) of 2.4.2 for a correction factor F. With no attenuation, the value measured by injecting at the end remote from the detector a_2 would be $2 \times a_1$, whilst with attenuation, a_2 will become less than $2 \times a_1$. The valid criterion must be that the error should not exceed 30 %. As shown in Figure 16, the attenuation error is greatest at the centre of the cable if measurements are made from each end in turn and the higher value is considered. The criterion is, therefore, that the value measured is $a(x = ½\ l)$ 0.7 a_1 (a_1 being the value measured due to a discharge at the end nearest the detector). Attenuation follows an exponential law, i.e.

$$a(x) = a_1 \exp(-\gamma \cdot x)$$

If the value a_2 is measured with superposition from a discharge at the end remote from the detector, $x = l$, the value without superposition is $a_2/2$ (as shown in Figure 13)

— i.e. $a(x = l) = a_2/2 = a_1 \exp(-\gamma \cdot l)$

— or

— and $a\ (x = 1/2l) = a_1 \exp \geq 0.7\ a_1$,

— i.e. $\geq 0.7\ a_1$

— or $a_2 \geq 0.98\ a_1$

Thus provided $a_2 \geq a_1$, the attenuation will not produce an error greater than 30 %. For a longer cable length, for which $a_2 < a_1$, it is necessary to calculate a value for a correction factor F and insert it in the calibration equation.

— $F \cdot a(x = 1/2\ l) \geq 0.7 a_1$

— $F \cdot \geq 0.7\ a_1$

— or $F =$

c) Test procedure

Subclause 2.4.2 requires that for lengths $l > l_k$ a discharge test is made first from one end and then the other end. The reasons for this can be clearly seen from Figures 17, 18, 19 and 20. For lengths $l > l_1$ (330 m in this example) an underestimate of discharge magnitude could occur in a region of negative superposition between l_1 and l_2 as in Figure 17, if the measurement is made from one end only. However, by testing from the second end and by taking the higher value of discharge magnitude as the true value, the negative error can be avoided (see the resulting curve — . — in Figure 18). This is not the case for lengths between $2l_1$ and $2l_2$ (the forbidden lengths $2l_1 \leq l \leq 2l_2$) as shown in Figure 19; negative errors from discharges in the centre of the cable cannot be avoided and this is the forbidden region. For lengths $l \leq 2l_2$ only positive superposition will occur (Figure 20).

3.2.2.3 Long cable lengths tested with a terminal impedance (see 2.4.3)

b) Verification of sensitivity

With a correctly terminated cable, the curve corresponding to the points x of Figure 14 is obtained. The response with the calibrator at the far end, a_2 is less than a_1. If only a_2 is used for calibration purposes, discharges nearer to the detector will be overestimated. With high quality manufacture, it is rare for discharges to be detected at specification voltage levels. It is adequate, therefore, to test establishing discharge freedom to a sensitivity defined from a_2.

If discharges are detected the calibration from both cable ends is used in order to determine the actual level as accurately as possible. The method using a correction factor F (see Item b) of 2.4.2) is not permitted because a possible error of ±15 % for the terminal impedance has to be taken into account.

A discharge of magnitude q at a position x might produce a response A_1. Attenuation with length follows an exponential relationship i.e.:

$$A_1 = E \cdot q \cdot \exp(-\gamma \cdot x)$$

where E is an equipment constant

With the detector connected to the other end of the cable a response A_2 is found

$$A_2 = E \cdot q \cdot \exp(-\gamma(l - x))$$

If a calibration charge q_{cal} is used at $x = 0$ and $x = l$ to yield a response a_1 and a_2

$a_1 = E \cdot q_{cal}$ and $a_2 = E \cdot q_{cal} \exp(-\gamma l)$

for which $A_1 A_2 = E^2 \cdot q^2 \exp(-\gamma l)$

and $a_1 a_2 = E^2 \cdot q^2_{cal} \exp(-\gamma l)$

or $q = q_{cal} \sqrt{\dfrac{A_1 A_2}{a_1 a_2}}$

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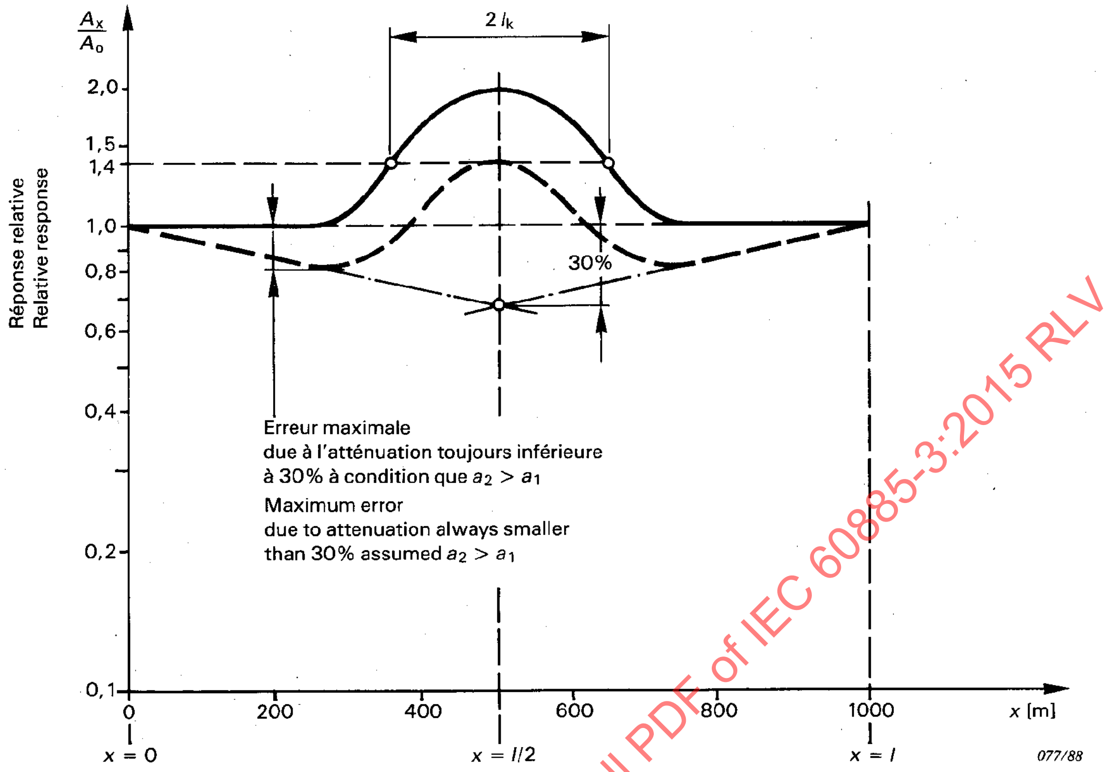


Figure 15 – Maximum attenuation error, both cable ends connected together

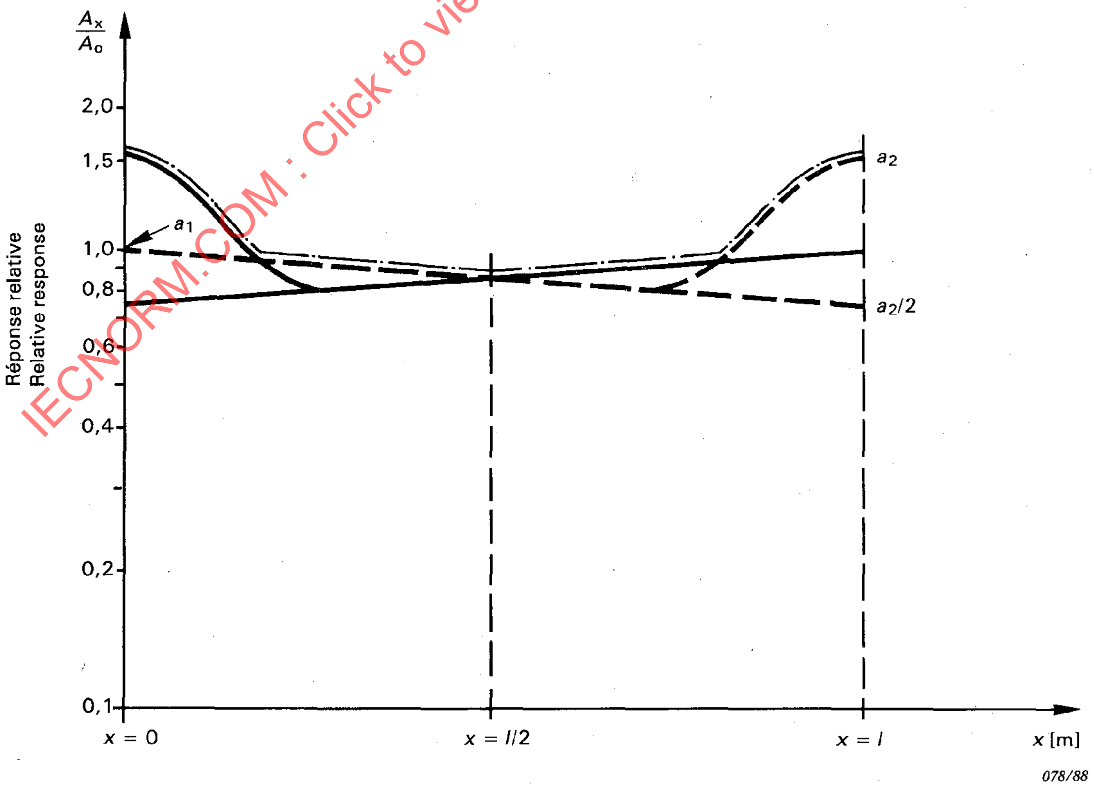
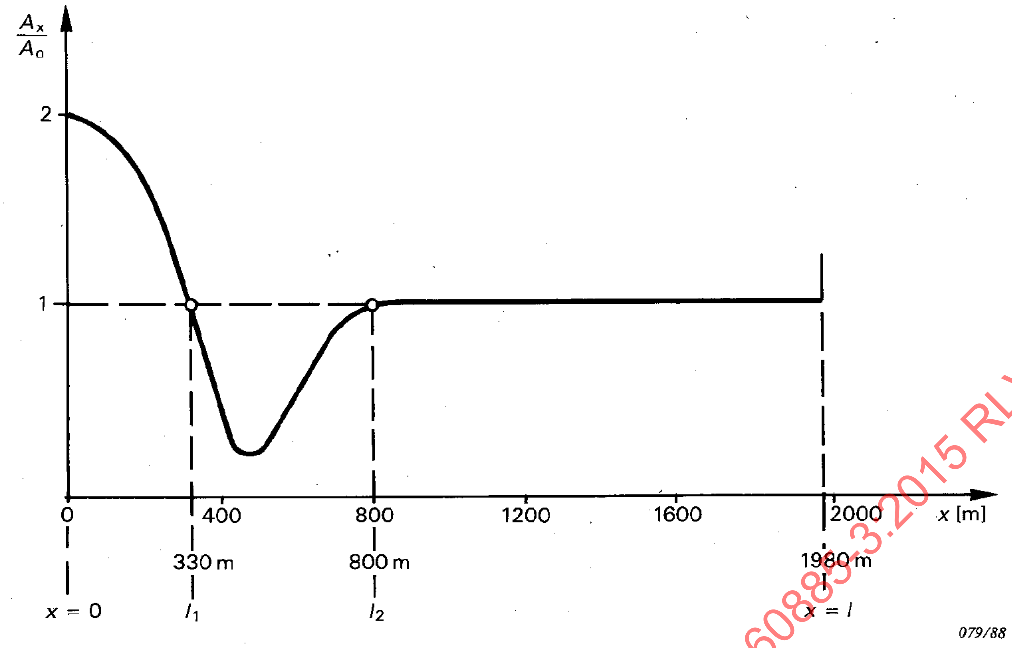
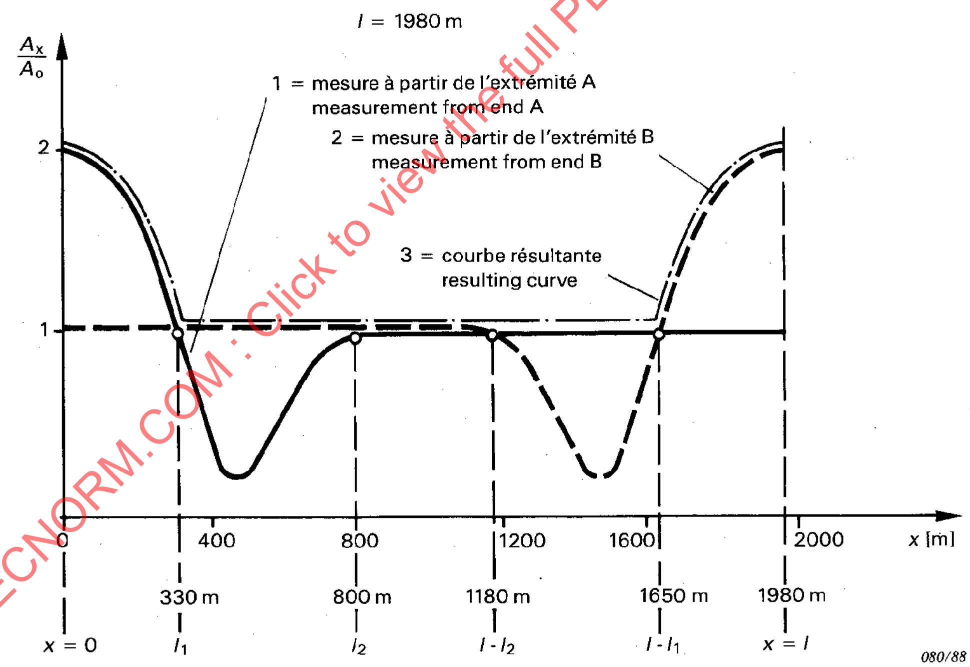


Figure 16 – Maximum attenuation error at the centre of the cable
if measurements are made from both ends



~~Figure 17 – Double pulse diagram type 2.~~
~~Negative superposition between l_1 and l_2 (forbidden length).~~



~~Figure 18 – Measurement from both ends to avoid negative error~~

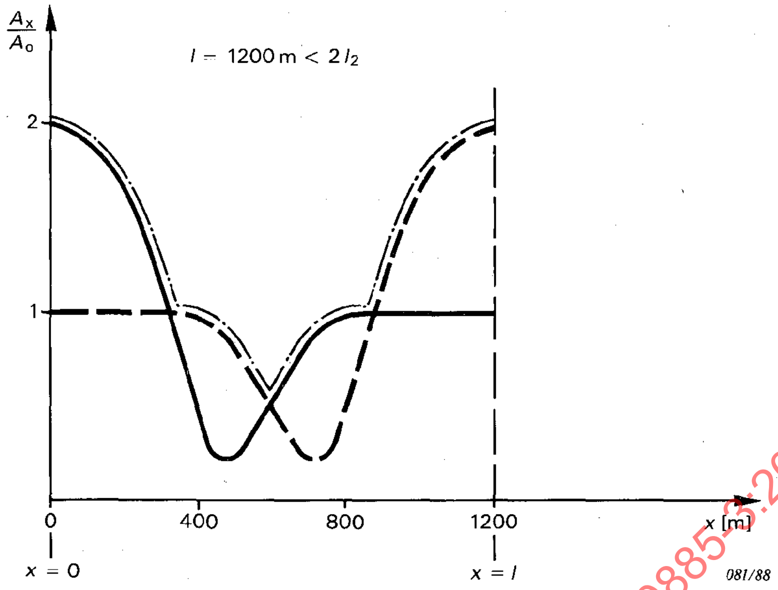


Figure 19 – Negative superposition for $2l_1 < l < 2l_2$

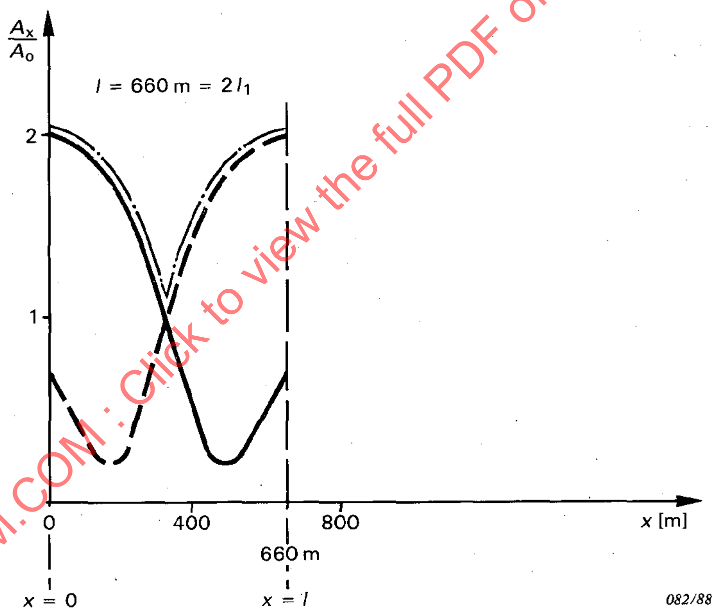


Figure 20 – Only positive superposition for $l < 2l_1$

IEC 60885-3

Edition 2.0 2015-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Electrical test methods for electric cables –
Part 3: Test methods for partial discharge measurements on lengths of extruded power cables**

**Méthodes d'essais électriques pour les câbles électriques –
Partie 3: Méthodes d'essais pour la mesure des décharges partielles sur des longueurs de câbles de puissance extrudés**

IEC 60885-3:2015-03(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRICAL TEST METHODS FOR ELECTRIC CABLES –

Part 3: Test methods for partial discharge measurements on lengths of extruded power cables

FOREWORD

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International Standard IEC 60885-3 has been prepared by IEC technical committee 20: Electric cables.

This second edition of IEC 60885-3 cancels and replaces the first edition, published in 1988 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- The definition of sensitivity as twice the background noise level has been removed and replaced by a practical assessment of sensitivity based on the minimum level of detectable discharge.
- References to measurements of pulse heights in mm on an oscilloscope have been replaced by measurements of partial discharge magnitude in pC.

- The order of the clauses has been revised in line with the general numbering scheme of IEC standards and to provide clarity in order to facilitate its practical use. Section 3 of the first edition (Application guide) has been removed as it is considered that background information is better obtained from the original references as listed in the bibliography.

The text of this standard is based on the following documents:

FDIS	Report on voting
20/1560/FDIS	20/1587/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60885 series, published under the general title *Electrical test methods for electric cables*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

ELECTRICAL TEST METHODS FOR ELECTRIC CABLES –

Part 3: Test methods for partial discharge measurements on lengths of extruded power cables

1 Scope

This part of IEC 60885 specifies the test methods for partial discharge (PD) measurements on lengths of extruded power cable, but does not include measurements made on installed cable systems.

Reference is made to IEC 60270 which gives the techniques and considerations applicable to partial discharge measurements in general.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60270:2000, *High-voltage test techniques – Partial discharge measurements*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60270 apply.

3.2 Symbols used in Figures 1 to 14

a_1 discharge magnitude measured with the calibrator at the end near to the detector

a_2 discharge magnitude measured with the calibrator at the end remote from the detector

C_{cal} calibrator

C_K coupling capacitor

C_x power cable

D detector

I double pulse generator

l length of the power cable

M coaxial signal cable

Q discharge magnitude

$R_1 R_2$ matching resistors

RS reflection suppressor

v propagation velocity of partial discharge

V voltage indicator

W power supply

Z impedance/filter

Z_A input unit

Z_W terminal impedance

4 Overview

4.1 General

Partial discharge measurements shall be carried out using the test techniques specified in IEC 60270.

4.2 Object

The object of the test is to determine the discharge magnitude, or to check that the discharge magnitude does not exceed a specified value, at a specified voltage and a declared minimum sensitivity.

4.3 Problem of superposition of travelling waves for long lengths

Short lengths of cable behave in the same way as a single capacitor in that the discharge magnitude can be measured directly by considering the cable as a single capacitor. However longer cables behave like a transmission line and PD pulses travel away from their source in both directions along the cable, in the form of a wave. On reaching the remote end from the measuring equipment, the pulse will be reflected with the same polarity if the end is open circuit. The reflected pulse will then travel back along the length of cable and arrive at the detector at a time after the directly received pulse. If the time between the arrival of the two pulses is short (the time difference depending on the length of the cable) then the detection instrument may give a false response, indicating either a larger or smaller magnitude of discharge than was actually the case. The methods detailed in this standard allow correct measurement of partial discharges under these conditions.

Figures 1 to 4 illustrate the behaviour of travelling waves and possible superposition effects.

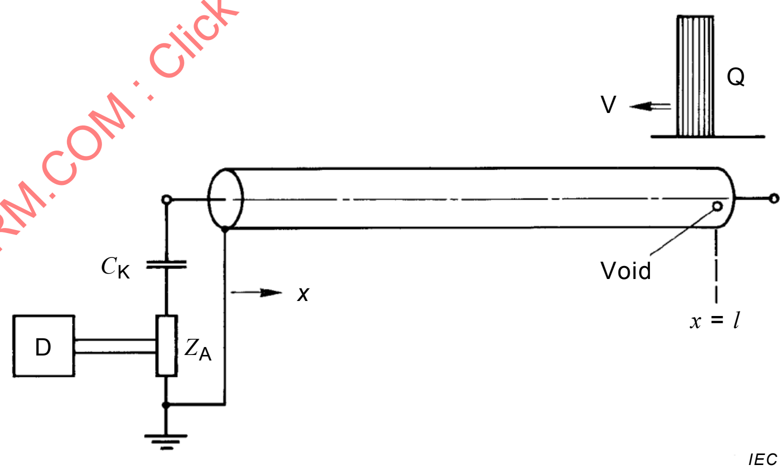


Figure 1 – Discharge site exactly at the cable end remote from the detector ($x = l$)

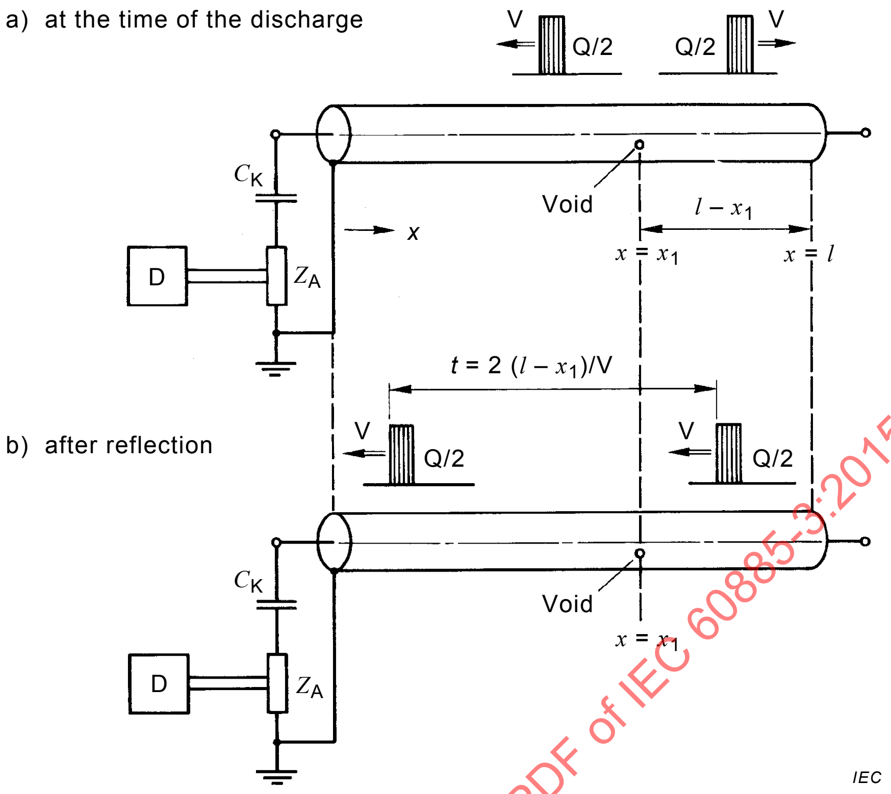


Figure 2 – Discharge site at a distance $x = x_1$ – Travelling waves

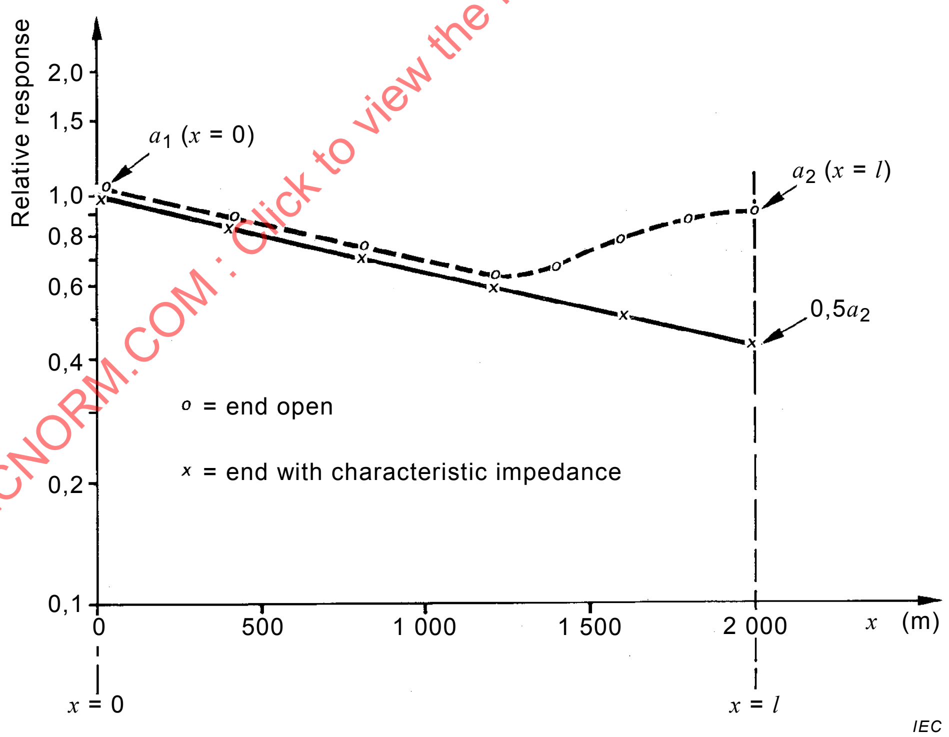
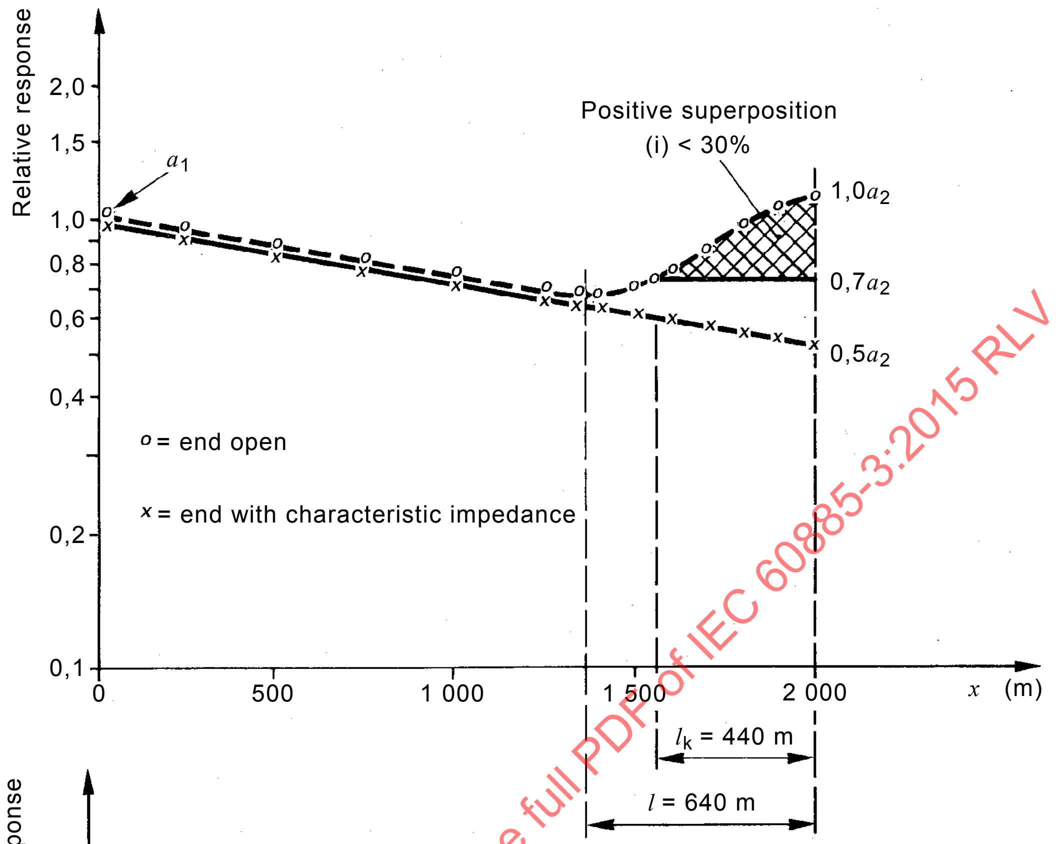
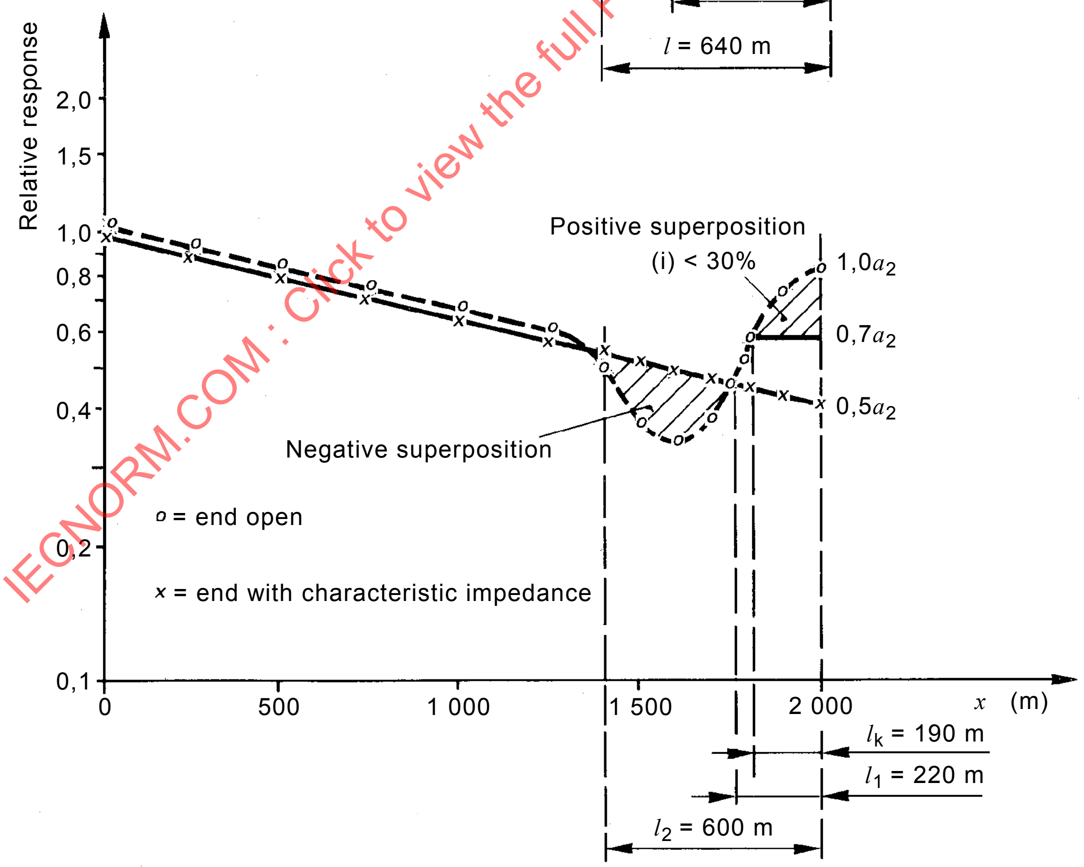


Figure 3 – Attenuation of PD pulses along the cable

a)



b)



IEC

Figure 4 – Superposition and attenuation of PD pulses

5 Partial discharge tests

5.1 Test apparatus

5.1.1 Equipment

The equipment consists of a high-voltage alternating voltage supply having a rating adequate to energise the length of cable under test, a voltmeter for high voltages, a measuring circuit, a discharge calibrator, a double pulse generator and, where applicable, a terminal impedance or reflection suppressor. All components of the test equipment shall have a sufficiently low noise level to achieve the required sensitivity. The frequency of the test supply shall be in the range 45 Hz to 65 Hz with a waveshape approximating to a sinusoid with the ratio of peak to r.m.s. values being equal to $\sqrt{2}$ with a maximum tolerance of 5 %.

5.1.2 Test circuit and instruments

The test circuit includes the high voltage power supply, test object, the coupling capacitor and the HV and PD measuring equipment. The measuring circuit consists of the measuring impedance (input impedance of the measuring instrument and the input unit which is selected to match the cable impedance), the connecting lead and the measuring instrument. The measuring instrument or detector includes a suitable amplifying device, an oscilloscope, or other instrument to indicate the existence of partial discharges and to measure the apparent charge. The measuring system shall comply with IEC 60270.

5.1.3 Double pulse generator

A double pulse generator is an instrument producing two equal pulses (with the same apparent charge) following each other within a time interval which can be varied between 0,2 µs to 100 µs. The rise time of the pulses shall not exceed 20 ns (10 % to 90 % of peak value); the time between 10 % values of the front and the tail shall not exceed 150 ns. The pulses may be synchronized with the power frequency.

5.1.4 Terminal impedance

A terminal impedance is an impedance, equal in value to the characteristic impedance of the test object, which is connected to the open end of the cable remote from the detector. It may be a combination of resistance and capacitance (R & C) or resistance, capacitance and inductance (R, C & L). The components shall be suitable for operation at the test voltage to be applied to the cable under test. Additional requirements are specified in section 5.6.

5.1.5 Reflection suppressor

This is an electronic switch which is designed to block the input of the measuring instrument from pulses reflected from the open end of the cable. This is achieved by blocking the input for a fixed time after the first pulse is received.

5.2 Setting up the test circuit

5.2.1 Determination of characteristic properties of the test circuit

The characteristic properties of the test circuit should be determined under the conditions to be used. The test circuits normally used for connections to a single cable end are those shown in Figures 5, 6, 7, 8 and 9. Similar test circuits are also applicable when both ends of the cable conductor are connected together; in this case the two ends of the metal cable screen shall also be connected together.

5.2.2 Terminal impedance

If a terminal impedance is connected to the remote end of the cable under test, with an impedance value equal to the characteristic impedance of the cable then the cable will behave as if it is of infinite length and there will be no reflected wave. The circuit for connection of a terminal impedance is shown in Figure 8. The values (RC and L where applicable) of the components of the terminal impedance and its suitability for the type of cable under test should be demonstrated using the procedure described in 5.6. This check should be carried out when the test circuit is set up and also when any changes are made to the circuit.

5.2.3 Determination of superposition of travelling waves

If a terminal impedance is not used, it is necessary to determine the properties of the test circuit with respect to superposition of travelling waves. A double pulse generator is connected according to Figure 10 and a double pulse diagram is plotted (see 5.5 and Figures 11, 12 and 13). This check should be carried out when the test circuit is set up and also when any changes are made to the circuit.

5.2.4 Reflection suppressor

The purpose of using a reflection suppressor is to obtain a double pulse diagram of Type 1 corresponding to Figure 11. Using the arrangement shown in Figure 14, the efficiency of the reflection suppressor should be checked by plotting a double pulse diagram (see 5.5 and Figures 11, 12 and 13), when the test circuit is set up and also when any changes are made to the circuit.

5.2.5 Calibration of the measuring system in the complete test circuit

Calibration of the measuring system in the complete test circuit shall be carried out in accordance with Clause 5 of IEC 60270:2000. The calibrator used shall comply with IEC 60270. For long lengths of cable (> 100 m) there is an additional requirement that the calibrating capacitance shall be not greater than 150 pF.

5.2.6 Sensitivity

The sensitivity of the measuring system is defined as the minimum detectable discharge pulse, q_{min} (in picocoulombs – pC) that can be observed in the presence of background noise.

Value of q_{min} shall be determined by evaluation of the background noise level and shall be no more than twice the apparent noise level, h_{n} (h_{n} is the noise reading on the measuring instrument).

Therefore:

$$q_{\text{min}} = x \times k \times h_{\text{n}}$$

where k is the scale factor and x is the ratio of the minimum detectable discharge to the background noise. The maximum allowed value of x is 2. Typically values of x of between 1,25 and 1,5 should be achievable.

The maximum values of sensitivity shall be determined according to 5.4.

5.3 Measurement procedures

5.3.1 General

The selection of the test circuit depends on whether the cable sample may be considered as a short length (see 5.3.2) or a long length (see 5.3.3, 5.3.4 and 5.3.5). The test circuit shall be discharge free in order to achieve the required sensitivity (see 5.2.6). Calibration does not necessarily have to be done with the HV supply on (see 5.2.5). During the partial discharge measurement, individual pulses clearly identifiable as interference may be disregarded.

5.3.2 Short cable lengths including type test lengths

5.3.2.1 Requirements

For short lengths the cable may be considered similar to a lumped capacitance. The limitation on length where this is not acceptable depends upon the test circuit used, however it may be assumed that cable lengths of up to 50 m (or 100 m, if both ends of the cable are connected together) behave as a lumped capacitance and therefore superposition of reflected waves need not be taken into account. For longer lengths whether they can be treated as a lumped capacitance shall be determined using the double pulse diagram as described in 5.5. The maximum length which can be considered as a lumped capacitance is defined as $l_{k;}$ This may be as low as 100 m or even greater than 1 000 m, depending on the particular measuring system in use.

The test circuits normally used are those in Figures 5, 6 and 7.

5.3.2.2 Verification of sensitivity

The determination of the scale factor k for the measurement of the apparent charge shall be carried out in accordance with Clause 5 of IEC 60270:2000. Therefore the partial discharge calibrator shall be connected in parallel with the cable at the end remote from the detector.

5.3.2.3 Test procedure

The measurement shall be made only at one end of the cable.

The test parameters shall be selected according to 5.4.

5.3.3 Long cable lengths tested without a terminal impedance

5.3.3.1 General

For long cable lengths (>50 m or >100 m with ends connected), tested without a terminal impedance, it is necessary to plot a double pulse diagram.

5.3.3.2 Requirements

For cable lengths in excess of l_k it may still be possible to test without a terminal impedance provided superposition and attenuation phenomena are taken into account.

A double pulse generator is connected according to Figure 10 and a double pulse diagram is plotted (see 5.5 and Figures 11, 12 and 13). This shall be carried out when the test circuit is set up and also when any changes are made to the circuit.

A test without terminal impedance is permitted where the double pulse diagram is either

– type 1 (Figure 11), or
– type 2 and type 3 (Figures 12 and 13) but where the cable length, l, lies outside the limits $2l_1 \leq l \leq 2l_2$.

(See 5.5 for the determination of l_1 and l_2.)

For lengths inside these limits an alternative test circuit should be used or the procedures described in 5.3.4 or 5.3.5 should be adopted.

The test circuits normally used are those shown in Figures 5, 6, 7 and 9.

5.3.3.3 Verification of sensitivity

The determination of the scale factor k for the measurement of the apparent charge shall be carried out in accordance with Clause 5 of IEC 60270:2000. Therefore the partial discharge calibrator shall be connected in parallel with the cable at the end near to the detector.

For the determination of the attenuation correction factor, the partial discharge calibrator shall be connected to each end in turn in parallel with the cable with the same setting of the amplifier and calibration charge. The following values shall be recorded:

– a_1 discharge magnitude measured with the calibrator at the end near to the detector;
– a_2 discharge magnitude measured with the calibrator at the end remote from the detector.

a_1 and a_2 are used to determine a correction factor F to allow for attenuation. It is given by:

$$F = 1 \qquad \text{if } a_2 \geq a_1$$

$$F = \sqrt{\frac{a_1}{a_2}} \qquad \text{if } a_2 < a_1$$

5.3.3.4 Test procedure

The measurement shall be made twice by connecting the high voltage end of the coupling capacitor to each end of the cable in turn. The measured discharge magnitudes A_1 and A_2 shall be determined and the higher value A_{max} (pC) selected. With the correction factor F, the discharge magnitude q(pC) is:

$$q = A_{max} \times F$$

The voltage levels used when measuring the highest discharge magnitude A_{max} shall be selected according to 5.4.

NOTE Only if the double pulse diagram is of type 1 (see Figure 11) and $a_2 \geq a_1$, a measurement of A(pC) is sufficient when both cable ends are connected together (see 5.3.2). The discharge magnitude is then: $q = A$.

5.3.4 Long cable lengths tested with a terminal impedance

5.3.4.1 General

For long cable lengths (>50 m or >100 m with ends connected), tested with a terminal impedance, it is not necessary to plot a double pulse diagram.

5.3.4.2 Requirements

To eliminate superposition errors, cables of length greater than l_k may be tested with a terminal impedance as shown in Figure 8. This method may be used with all detectors and all cable lengths provided that the impedance Z_w meets the requirements specified in 5.6. The suitability of the impedance for the cable under test shall be demonstrated using the procedure described in 5.6.

5.3.4.3 Verification of sensitivity

The partial discharge calibrator shall be connected to each end in turn in parallel with the cable with the same setting of the amplifier and calibration charge. The following values shall be recorded:

– a_1 (pC) the discharge magnitude measured with the calibrator at the end near to the detector. This need not be measured if the procedure in 5.3.4.4 b) is sufficient;

– a_2 (pC) the discharge magnitude measured with the calibrator at the end remote from the detector.

For the determination of the scale factor k for the measurement of the apparent charge in accordance with Clause 5 of IEC 60270:2000, the value a_2 (pC) with the partial discharge calibrator connected in parallel with the cable at the end remote from the detector shall be used.

5.3.4.4 Test procedure

The test procedure is as follows.

a) When it is required to determine the value of the partial discharge magnitude as closely as possible, the high voltage end of the coupling capacitor shall be connected to each end of the cable in turn and both measured discharge magnitudes A_1(pC) and A_2 (pC) determined. The discharge magnitude q (pC) is given by:

$$q = q_{\text{cal}} \times \sqrt{\frac{A_1 \times A_2}{a_1 \times a_2}}$$

where q_{cal} is the calibration discharge magnitude (pC).

b) When it is sufficient to check that the discharge magnitude does not exceed a specified value, the measurement may be made with the high voltage end of the coupling capacitor connected to one end of the cable only. In this case the calibration pulse is injected only at the end of the cable connected to the terminal impedance remote from the detector (a_2). With the measured discharge magnitude $A1$ (pC) and the scale factor k_2 the discharge magnitude q (pC) is given by:

$$q = k_2 \times A_1$$

The voltage levels used when measuring the discharge magnitudes A_1 and if necessary A_2 shall be selected according to 5.4.

5.3.5 Long cable lengths tested with a reflection suppressor

5.3.5.1 General

For long cable lengths (>50 m or >100 m with ends connected), tested with a reflection suppressor, it is necessary to plot a double pulse diagram.

The connection of the reflection suppressor is shown in Figure 9.

A double pulse generator is connected according to Figure 10 and a double pulse diagram is plotted (see 5.5 and Figures 11, 12 and 13). This shall be carried out when the test circuit is set up and also when any changes are made to the circuit.

5.3.5.2 Requirements

When using a reflection suppressor the double pulse diagram shall be type 1 (see Figure 11).

5.3.5.3 Verification of sensitivity

See 5.3.2.2.

5.3.5.4 Test procedure

See 5.3.2.3.

5.4 Voltage levels/partial discharge limits

The test voltages, partial discharge sensitivity and partial discharge limits shall be determined in accordance with the requirements in the standard for the type of cable.

5.5 Double pulse behaviour and plotting the double pulse diagram

The double pulse plot is affected by variations in each circuit component. It is important that the double pulse plot be obtained for the precise conditions to be used in the high voltage test.

NOTE The test cable is not connected whilst the double pulse plot is being plotted, the double pulse plot depends solely on the measuring system and test circuit, excluding the cable.

The power cable is replaced by a resistive load having the maximum characteristic impedance for extruded cables (generally R_{max} = 40 Ω). The double pulses are injected in the same position as the calibration pulses for the various test circuits shown in Figures 5, 6 and 7. Figure 10 shows, as an example, the double pulse generator connected to the test circuit of Figure 5.

The following conditions should apply:

a) The double pulse generator should satisfy the requirements of 5.1.3. In some cases the dials of the double pulse generator may have numeric (e.g. 0 to 9) markings for pulse separation, in which case it will be necessary to use a suitable oscilloscope to calibrate these scales in terms of µs; the required accuracy is ±3 % or 50 ns whichever is the greater. The overall output impedance should approximately match the characteristic impedance of the cable, which is typically in the range of 20 Ω to 40 Ω. To achieve this it may be necessary to add external resistors in parallel to or in series with the output.

   Experience has shown that the double pulse plot may be reliably obtained in the following ways:

   – The simplest method is to connect the double pulse generator across the high voltage capacitor C_K and the measuring impedance Z_A with wires not longer than 3 m.

   – For longer connections a coaxial cable should be used (see Figure 10). In this case two adapter resistors R_1 and R_2 are necessary to ensure that the system approximately matches the characteristic impedance of the cable, which is typically in the range of 20 Ω to 40 Ω.

b) The capacitor C_K and the other high voltage components of the test circuit should be the same and have the same connections as those used in the high voltage test.

c) The matching unit or detector impedance Z_A to be used in the high voltage test should be used to obtain the double pulse plot.

d) The detector amplifier D should be used with the gain setting and amplifier frequency response selected for the high voltage test. For accurate measurement of the changes in pulse magnitude caused by superposition distortions, the output of the detector amplifier D should be displayed on an external oscilloscope (for example the oscilloscope used in 5.5 a)).

   The time interval of the double pulse generator should be set to 100 µs and the discharge magnitude of the partial discharge detector to the two pulses A_{100} should be measured. The time interval should then be reduced from 100 µs to 0,2 µs; for different values of an interval t measured between maximum peaks of the two pulses, the maximum discharge magnitude A_t should be measured. Particular attention should be given to areas of positive and negative superposition. Values of A_t/A_{100} should then be plotted as a function of t to obtain the double pulse diagram. Examples of diagrams are in Figures 11 to 13.

   The value t_k where A_t/A_{100} = 1,4 on the initial positive superposition should be determined from the plot. Times t_1 and t_2 where $A_t/A_{100} \leq 1,0$ at all areas of negative superposition should be determined. Taking into account the errors of measurement, areas of negative superposition with a maximum magnitude up to –10 % may be ignored.

The cable lengths l_k, l_1 and l_2 corresponding to t_k, t_1 and t_2 should be calculated using the formula $l = 0,5 \times t \times v$. The mean propagation velocity is v and typical values for most extruded cable lie between 150 m/µs and 170 m/µs. On request the propagation rate shall be measured by injecting a calibration pulse into a cable not having a terminal impedance and measuring the time delay between incident and reflected pulse.

The cable lengths $l < l_k$ can be considered as short lengths. These may be as low as 100 m and even higher than 1 000 m.

Lengths between $2l_1$ and $2l_2$ have to be tested with a terminal impedance (see 5.3.4.2) or under modified conditions of the test circuit (for example D, Z_A, C_K) to alter l_1 and l_2 to more suitable values. Alternatively, it is possible to effectively double the value of l_k by connecting both ends of the cable together.

5.6 Requirements for the terminal impedance

5.6.1 General

The terminal impedance Z_w, shown in Figure 8 comprises either RC or RLC elements which are selected on the basis of experimental evaluation.

5.6.2 RC element

The following measurement shall be used to prove the suitability of the terminal capacitor C_w.

The RC element shall be connected in parallel with the cable across the end remote from the detector. The capacitive component shall be short-circuited and the ohmic component shall be adjusted to correspond to the characteristic impedance of the cable. Subsequently the calibrator shall also be connected to the end remote from the detector and the measured discharge magnitude a_2 shall be determined.

With the same amplifier setting, the short circuit of the capacitive component of the terminal impedance shall be removed.

The removal of the short circuit of the capacitor (C_w) shall not change the discharge magnitude a_2 by more than ±15 %.

For PD detectors having a cut-off frequency lower than 2 MHz, a reasonable estimate for the value of the capacitance C_w (high voltage coupling capacitor of Z_w) may be obtained using the following formula:

$$C_w \geq 0,5 \frac{1}{R_w \times f_m}$$

where

R_w is the ohmic component of the terminal impedance (corresponding approximately to the characteristic impedance of the cable);

f_m is the mean measuring frequency of the detector (arithmetic mean of the upper and lower limiting frequencies of the detector).

For PD measuring instruments having a wide-band amplifier with an upper cut-off frequency more than 2 MHz in connection with an electronic integrator unit, C_w can be estimated on the basis of the relation:

$$C_w \geq \frac{3\, T_J}{R_w}$$

T_J is the time duration of the original PD pulse (in general smaller than 0,2 µs).

5.6.3 RLC element series resonance circuit

The following measurement shall be used for proving the suitability of the resonant circuit at the respective measuring frequency.

With the terminal impedance removed an ohmic resistor corresponding to the characteristic impedance of the cable shall be connected to the end remote from the detector in parallel with the cable. Furthermore the calibrator shall be connected to the end remote from the detector, and the measured discharge magnitude a_2 shall be determined.

Then the ohmic resistor shall be removed — with the setting of the amplifier kept constant — and replaced by the terminal impedance, consisting of RLC.

At the measuring frequency the ohmic component of the terminal impedance shall correspond to the resistance R_w.

The measured discharge magnitude a_2 shall not change by more than ±15 % when the terminal impedance is connected.

Reasonable estimates of the values of the capacitance C_w and the inductance L_w may be obtained by using the following formulas:

$$C_w \geq \frac{\Delta f}{2\pi \times f_m^2 \times R_w}$$

$$L_w \geq \frac{1}{(2\pi \times f_m)^2 \times C_w}$$

where

R_W is the ohmic component of the terminal impedance (corresponding approximately to the characteristic impedance of the cable);

f_m is the mean measuring frequency of the detector (arithmetic mean of the upper and lower limiting frequencies of the detector);

Δf is the bandwidth of the detector (upper limiting frequency minus the lower limiting frequency of the detector).

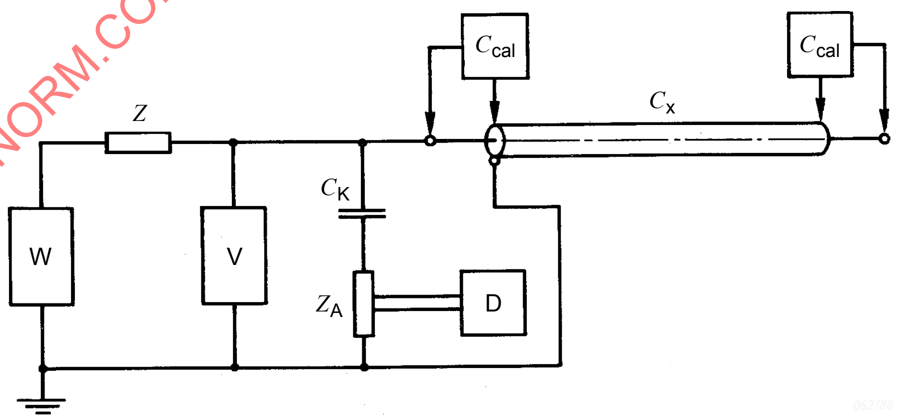


Figure 5 – Input unit Z_A connected in series with the coupling capacitor, C_K

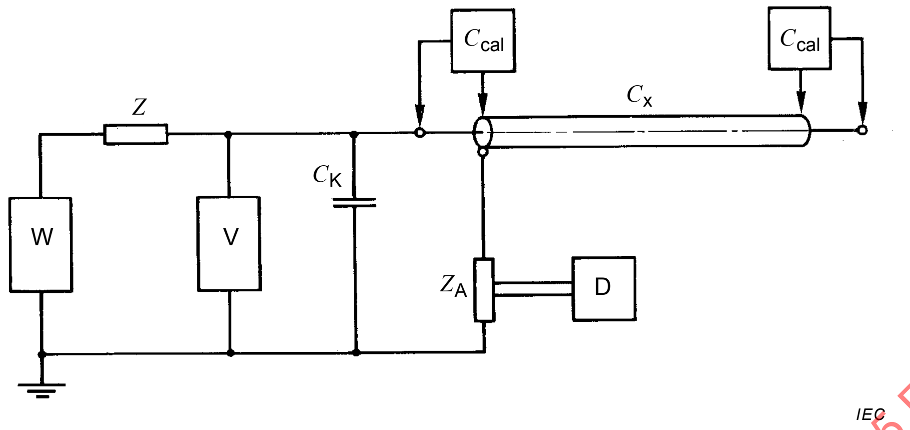


Figure 6 – Input unit Z_A connected in series with the cable, C_x

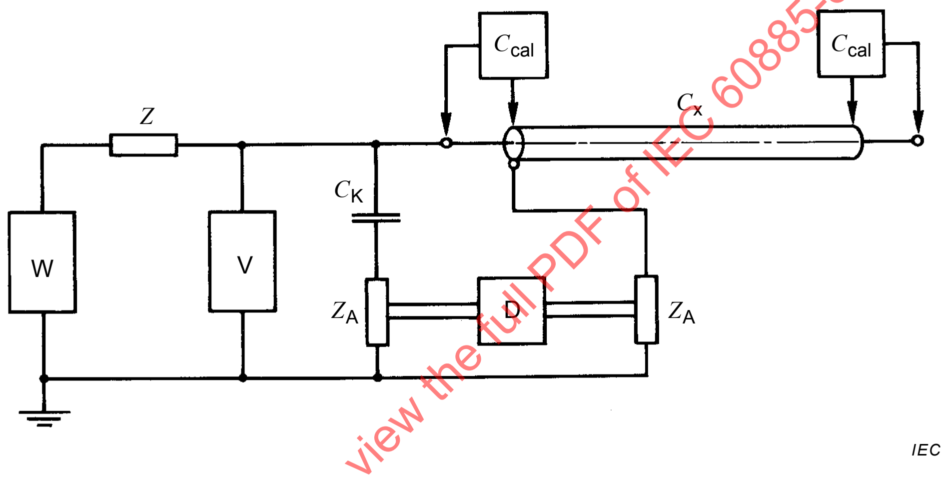


Figure 7 – Bridge circuit

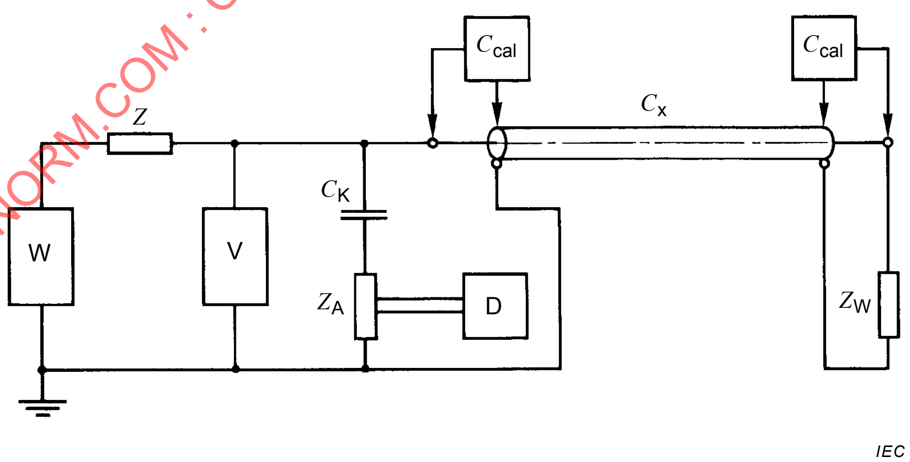


Figure 8 – Connection of the terminal impedance Z_w

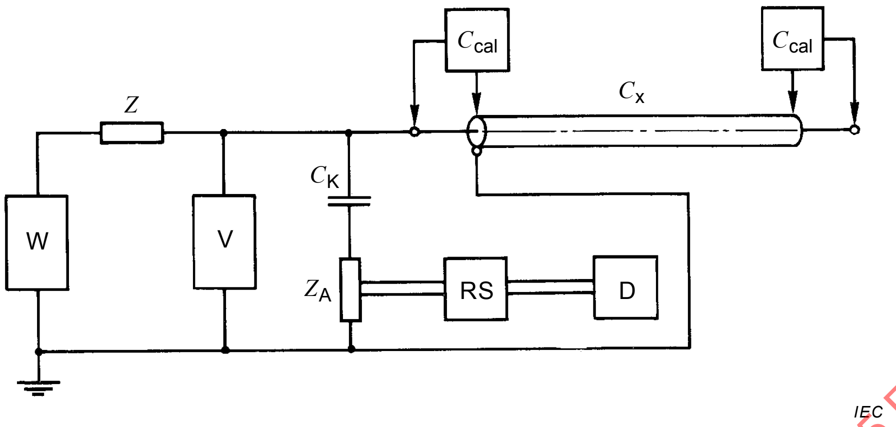
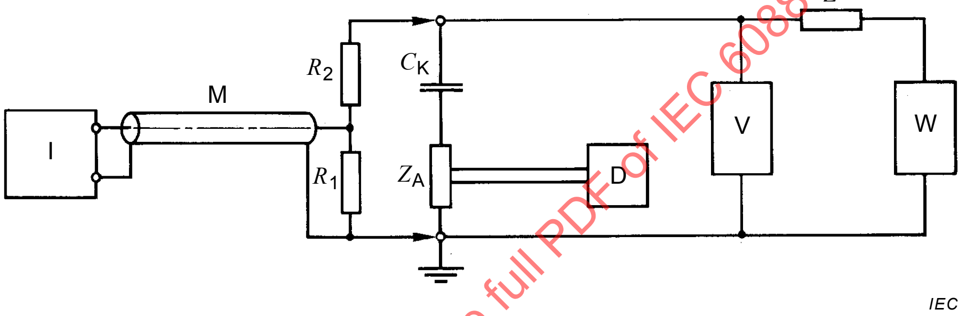


Figure 9 – Connection of the reflection suppressor, RS



Key

R_1 matching resistor with a value corresponding to the characteristic impedance of the coaxial signal cable M

R_2 matching resistor with a value $R_2 = R - \frac{R_1}{2}$ (load resistance R is typically 20 Ω to 40 Ω)

Figure 10 – Connection of the double pulse generator into the measuring circuit in Figure 5

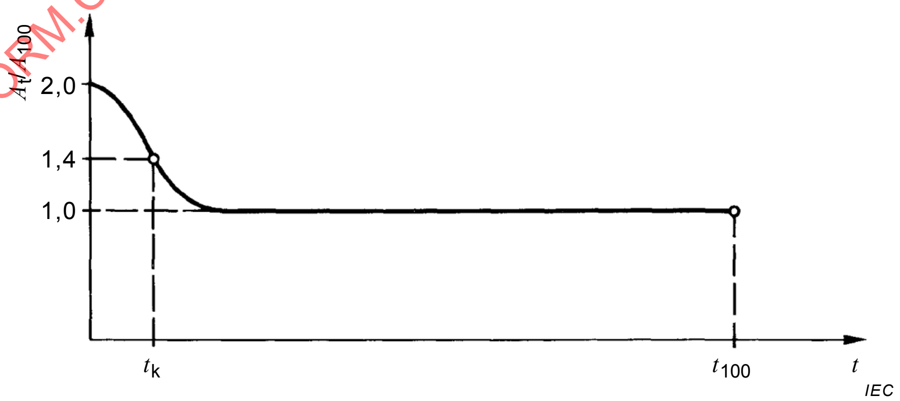
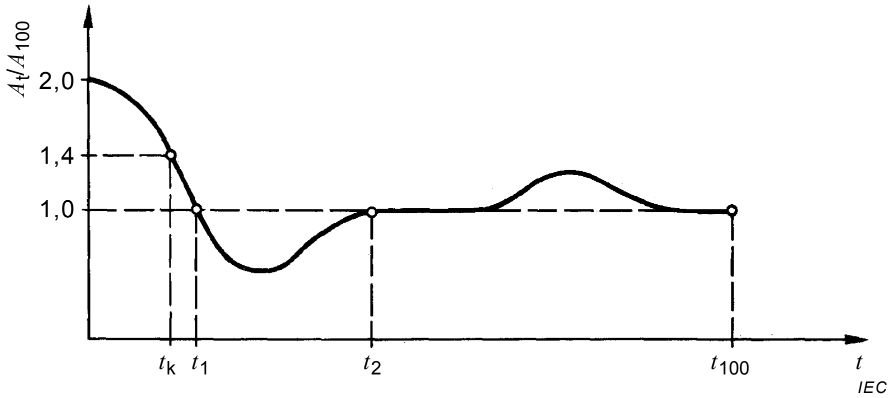


Figure 11 – Double pulse diagram type 1 without negative superposition



NOTE The influence of the positive superposition between t_2 and t_{100} is negligible.

Figure 12 – Double pulse diagram type 2 with negative superposition between t_1 and t_2

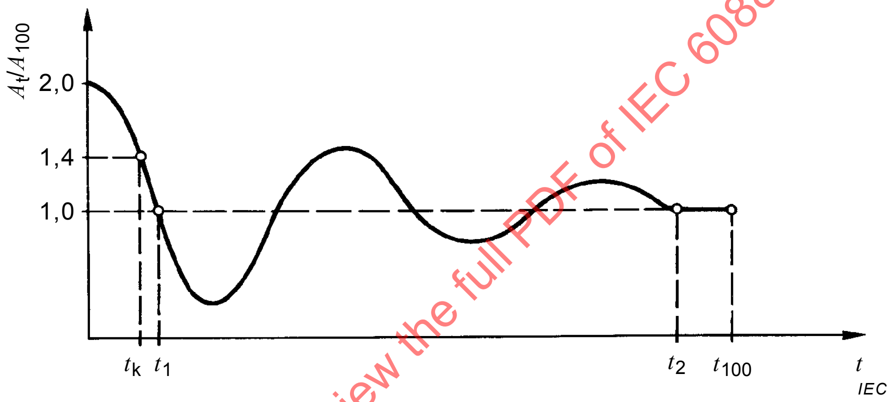


Figure 13 – Double pulse diagram type 3 with negative and positive superpositions between t_1 and t_2

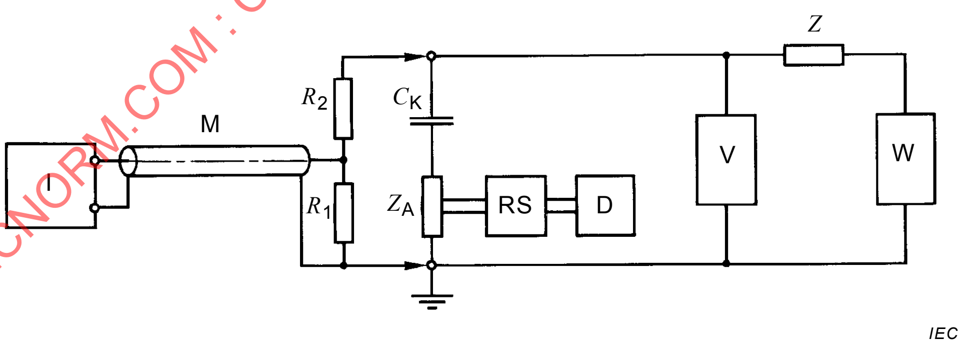


Figure 14 – Connection of the double pulse generator for the test circuit in Figure 9 with the reflection suppressor

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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MÉTHODES D'ESSAIS ÉLECTRIQUES POUR LES CÂBLES ÉLECTRIQUES –

Partie 3: Méthodes d'essais pour la mesure des décharges partielles sur des longueurs de câbles de puissance extrudés

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La Norme internationale IEC 60885-3 a été établie par le comité d'études 20 de l'IEC: Câbles électriques.

Cette deuxième édition de l'IEC 60885-3 annule et remplace la première édition parue en 1988. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- La définition de la sensibilité considérée comme le double du niveau de bruit de fond a été supprimée et remplacée par une évaluation pratique de la sensibilité en fonction du niveau minimum de décharge détectable.

- Les références aux mesures des hauteurs d'impulsions en mm sur un oscilloscope ont été remplacées par des mesures de la grandeur de la décharge partielle en pC.
- L'ordre des articles a été révisé pour reprendre le schéma de numérotation général des normes de l'IEC et pour clarifier le texte pour en faciliter l'utilisation pratique. La Section 3 de la première édition (Guide d'application) a été supprimée car il est considéré que les références originales telles qu'énumérées dans la bibliographie fournissent des informations de meilleure qualité sur l'environnement technique.

Le texte de la présente norme est issu des documents suivants:

FDIS	Rapport de vote
20/1560/FDIS	20/1587/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Cette publication a été rédigée selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60885, publiées sous le titre général *Méthodes d'essais électriques pour les essais électriques*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de cette publication ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives à la publication recherchée. A cette date, la publication sera

- reconduite,
- supprimée,
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- amendée.

MÉTHODES D'ESSAIS ÉLECTRIQUES POUR LES CÂBLES ÉLECTRIQUES –

Partie 3: Méthodes d'essais pour la mesure des décharges partielles sur des longueurs de câbles de puissance extrudés

1 Domaine d'application

La présente partie de l'IEC 60885 spécifie les méthodes d'essai pour les mesures des décharges partielles sur des longueurs de câbles de puissance extrudés, mais ne traite pas des mesures effectuées sur des systèmes de câbles installés.

Il est fait référence à l'IEC 60270 qui donne les techniques et considérations générales applicables aux mesures des décharges partielles.

2 Références normatives

Les documents suivants sont cités en référence de manière normative, en intégralité ou en partie, dans le présent document et sont indispensables pour son application. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60270:2000, *Techniques des essais à haute tension – Mesures des décharges partielles*

3 Termes, définitions et symboles

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'IEC 60270 s'appliquent.

3.2 Symboles utilisés dans les Figures 1 à 14

a_1 grandeur de décharge mesurée avec le dispositif d'étalonnage à l'extrémité proche du détecteur

a_2 grandeur de décharge mesurée avec le dispositif d'étalonnage à l'extrémité éloignée du détecteur

C_{cal} dispositif d'étalonnage (calibrator)

C_K condensateur de couplage (coupling capacitor)

C_x câble de puissance (power cable)

D détecteur (detector)

I générateur à double impulsion (double pulse generator)

l longueur du câble de puissance (length of the power cable)

M câble de liaison coaxial (coaxial signal cable)

Q grandeur de décharge

$R_1 R_2$ résistances d'adaptation (matching resistors)

RS suppresseur de réflexion (reflection suppressor)

v vitesse de propagation de la décharge partielle

V	indicateur de tension (voltage indicator)
W	alimentation de puissance (power supply)
Z	impédance/filtre (impedance/filter)
Z_A	unité d'entrée (input unit)
Z_W	impédance terminale (terminal impedance)

4 Vue d'ensemble

4.1 Généralités

Les mesures des décharges partielles doivent être réalisées en utilisant les techniques d'essai spécifiées dans l'IEC 60270.

4.2 Objet

L'objet de l'essai est de déterminer la grandeur des décharges ou de vérifier que la grandeur des décharges ne dépasse pas une valeur spécifiée à une tension spécifiée et une sensibilité minimale déclarée.

4.3 Problème de superposition des ondes progressives pour de grandes longueurs

De courtes longueurs de câble se comportent de la même façon qu'un condensateur unique dans la mesure où la grandeur de la décharge peut être mesurée directement en considérant le câble comme un seul condensateur. Cependant, des câbles plus longs se comportent comme une ligne de transmission et les impulsions de décharges partielles se déplacent à partir de leur source dans les deux directions le long du câble, sous la forme d'une onde. À son arrivée à l'extrémité éloignée de l'équipement de mesure, l'impulsion sera réfléchie avec la même polarité, si l'extrémité est en circuit ouvert. Ensuite, l'impulsion réfléchie repartira en sens inverse le long de la longueur du câble et arrivera au niveau du détecteur après l'impulsion reçue directement. Si le temps écoulé entre l'arrivée des deux impulsions est court (la différence de temps étant fonction de la longueur du câble), l'instrument de détection peut donner une réponse fausse, indiquant une grandeur supérieure ou inférieure de la décharge par rapport à sa valeur réelle. Les méthodes détaillées dans la présente norme permettent une mesure correcte des décharges partielles dans ces conditions.

Les Figures 1 à 4 illustrent le comportement des ondes progressives et les éventuels effets de superposition.

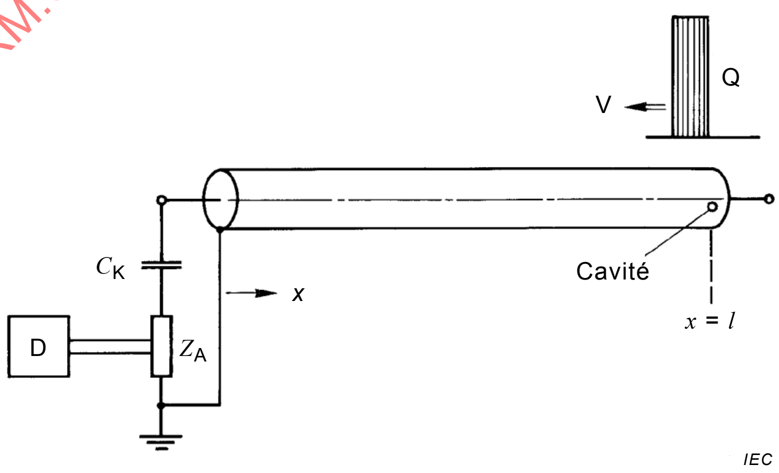

Figure 1 – Décharge située exactement à l'extrémité du câble éloignée du détecteur ($x = l$)

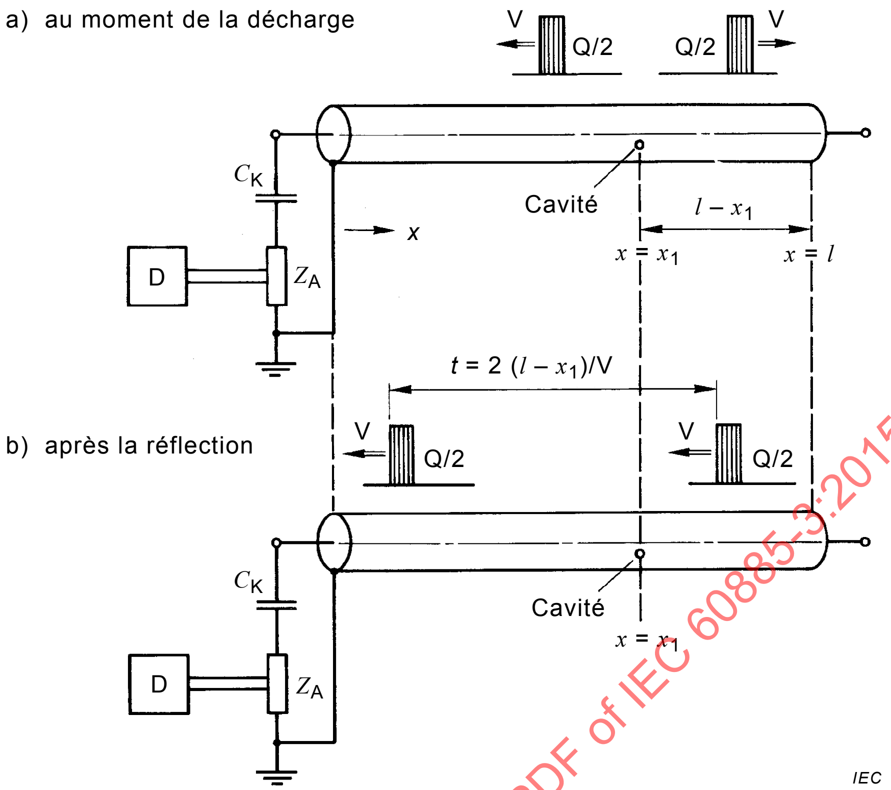

Figure 2 – Décharge située à une distance $x = x_1$ – Ondes progressives

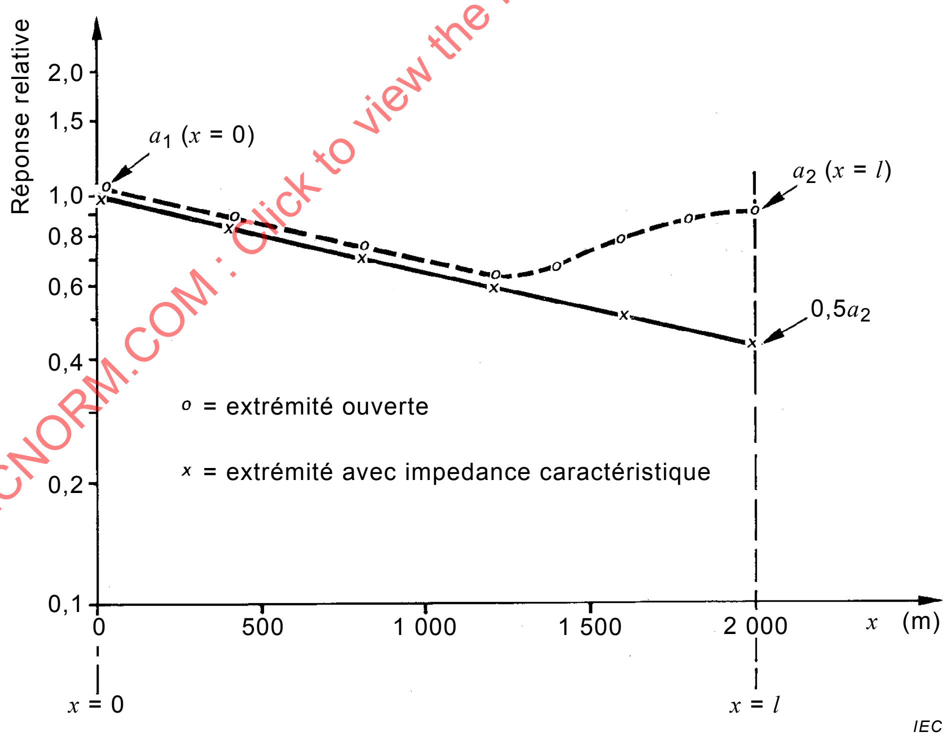

Figure 3 – Atténuation des impulsions de décharges partielles le long du câble