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Edition 3.0 2018-08
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Insulating liquids – Determination of the breakdown voltage at power frequency – Test method

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Insulating liquids – Determination of the breakdown voltage at power frequency – Test method

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INSULATING LIQUIDS – DETERMINATION OF THE BREAKDOWN VOLTAGE AT POWER FREQUENCY – TEST METHOD

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 60156 has been prepared by IEC technical committee TC 10: Fluids for electrotechnical applications.

This third edition cancels and replaces the second edition published in 1995. This edition constitutes a technical revision and, mainly, confirms the content of the previous edition even if some advances are included. The test method has not been changed for practical reason due to the very large number of instrumentation disseminated around the world, although the use of stirring is now recommended.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
10/1061/FDIS	10/1065/RVD

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

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

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

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- withdrawn,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

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INTRODUCTION

As normally applied, breakdown voltage of insulating liquids is not a basic material property but an empirical test procedure intended to indicate the presence of contaminants such as water and solid suspended matter and the advisability of carrying out a drying and filtration treatment.

The AC breakdown voltage value of insulating liquids strongly depends on the particular set of conditions used in its measurement. Therefore, standardized testing procedures and equipment are essential for the unambiguous interpretation of test results.

The method described in this document applies to either acceptance tests on new deliveries of insulating liquids, or testing of treated liquids prior to or during filling into electrical equipment, or to the monitoring and maintenance of oil-filled apparatus in service. It specifies rigorous sample-handling procedures and temperature control that should be adhered to when certified results are required. For routine tests, especially in the field, less stringent procedures may be practicable and it is the responsibility of the user to determine their effect on the results.

Annex A (informative) describes, for comparison, an alternative test method which could be introduced in the future. Annex B (informative) describes special test methods, using cells which may include low volume samples. Annex C (informative) describes a reference material for a performance test and check according to IEC 60060-3[1][1].

[1] Numbers in square brackets refer to the Bibliography.

INSULATING LIQUIDS – DETERMINATION OF THE BREAKDOWN VOLTAGE AT POWER FREQUENCY – TEST METHOD

1 Scope

This document specifies the method for determining the dielectric breakdown voltage of insulating liquids at power frequency. The test ~~portion, contained~~ procedure is performed in a specified apparatus, where the oil sample is subjected to an increasing AC electrical field ~~by means of a constant rate of voltage rise~~ until breakdown occurs. The method applies to all types of insulating liquids of nominal viscosity up to 350 mm^2/s~~$^{-1}$~~ at 40 °C. It is appropriate both for acceptance testing on unused liquids at the time of their delivery and for establishing the condition of samples taken in monitoring and maintenance of equipment.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60052: 1960, *Recommendations for voltage measurement by means of sphere-gaps (one sphere earthed)*~~

~~IEC 60060, *High-voltage test techniques*~~

IEC 60475~~:1974~~, *Method of sampling insulating liquids ~~dielectrics~~*

3 Terms and definitions

No terms and definitions are listed in this document.

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

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

4 Electrical apparatus

4.1 General

The electrical apparatus consists of the following units:

1) voltage regulator,
2) step-up transformer,
3) switching system,
~~4) energy limiting devices.~~
4) current-limiting resistors,
5) measuring device.

Two or more of these units may be integrated in any equipment system.

4.2 Voltage regulator

~~Uniform increase of voltage with time by manual means is difficult and, for this reason, automatic control is essential.~~

~~Voltage control may be achieved by one of the following methods:~~

~~a) Variable ratio auto-transformer~~

~~b) Electronic regulator~~

~~c) Generator-field regulation~~

~~d) Induction regulator~~

~~e) Resistive type voltage divider~~

The test voltage shall be increased with an automatic control of the required uniform voltage rate of rise. The device should not introduce harmonics disturbances (< 3%) and the AC source should be free from harmonics.

4.3 Step-up transformer

The test voltage is obtained by using a step-up or resonant transformer supplied from an AC source using ~~(~~ 48 Hz to 62 Hz~~)~~ (sinusoidal waveform) ~~voltage source whose value is gradually increased~~. The voltage source value is constantly increased. The controls of the variable low-voltage source shall be capable of varying the test voltage smoothly, uniformly and without overshoots or transients. Incremental increases (produced, for example, by a variable auto-transformer or an amplifier) shall not exceed 2 % of the expected breakdown voltage.

~~The voltage applied to the electrodes of the liquid-filled cell shall have an approximately sinusoidal waveform, such that the peak factor is within the following limits: 1,41 ± 0,07.~~

The centre-point of the secondary winding of the transformer should be connected to earth.

4.4 Switching system

~~3.4.1 Basic requirements~~

The circuit shall be opened automatically if ~~an established~~ a sustained arc between the electrodes occurs and the voltage between the electrodes collapses to a voltage less than 500 V. The primary circuit of the step-up transformer shall be fitted with a circuit-breaker operated by the current sensing device, resulting from the breakdown of the sample and shall break the voltage within 10 ms. ~~The circuit may be opened manually if a transient spark (audible or visible) occurs between the electrodes.~~

~~NOTE~~ The sensitivity of the current or voltage sensing element depends on the energy-limiting device employed and only approximate guidance can be given. ~~Normally, triggering of cut-off by a current of 4 mA maintained for 5 ms is acceptable, while fast energy-limiting (see 3.4.2) triggering by a transient current of 1 A maintained for 1 µs has been found satisfactory.~~

A cut-off time of < 100 µs, as given in the previous edition of this document, is needed to perform multiple breakdowns on silicone liquids.

~~3.4.2 Special requirements for silicone liquids~~

~~Silicone liquids can give rise to solid decomposition products through the action of electric discharges, which may cause gross errors in the observed results. In such cases, all feasible steps shall be taken to minimize the energy available for dissipation in the breakdown discharge.~~

~~Whilst current limiting as above, combined with isolation of the step-up transformer primary within 10 ms, is adequate for hydrocarbons. More satisfactory performance for silicone liquids is obtained by short circuiting of the primary circuit of the transformer by a low-impedance or by use of a low-voltage device for detection of breakdown acting within a few microseconds. This device may be of either analogue (for example, modulating amplifier) or switching (for example, thyristor) type. By the use of this device, the output voltage of the step-up transformer shall be reduced to zero within 1 ms of detection of breakdown, and shall not thereafter increase again until the next step of the test sequence is commenced.~~

4.5 Current-limiting resistors

To protect the equipment and to avoid excessive decomposition ~~of the liquid~~ at the instant of breakdown of liquids such as silicone or ester liquids, a resistance limiting the breakdown current ~~may~~ shall be inserted in series with the test cell.

The short-circuit current of the transformer and associated circuits shall be within the range of 10 mA to 25 mA for all voltages higher than 15 kV. This may be achieved by a combination of resistors in either or both the primary and secondary circuits of the high-voltage transformer.

4.6 Measuring ~~device~~ system

For the purposes of this document, the magnitude of the test voltage is defined as its peak value divided by $\sqrt{2}$.

~~This voltage may be measured by means of a peak-voltmeter or by means of another type of voltmeter connected to the input or output side of the testing transformer, or to a special winding provided thereon; the instrument then used shall be calibrated against a standard up to the full voltage which it is desired to measure.~~

The output voltage of the step-up transformer may be measured by means of a measuring system consisting of a voltage divider or a measuring winding of the step-up transformer coupled with a peak-voltmeter. The measuring system shall be calibrated up to the upper scale voltage to be measured. A method of calibration which has been found satisfactory is the use of a transfer standard. This is an auxiliary measuring device which is connected in place of the test cell between the high-voltage terminals to which it presents ~~the same~~ an impedance ~~as the filled test cell~~ similar to the one of the sample liquid. The auxiliary device is separately calibrated against a primary standard~~, for example, a sphere gap in accordance with IEC 52 (see also IEC 60)~~ [2],[3].

5 Test assembly

5.1 General

The breakdown voltage test is performed following the method described herewith as a routine test.

5.2 Test cell

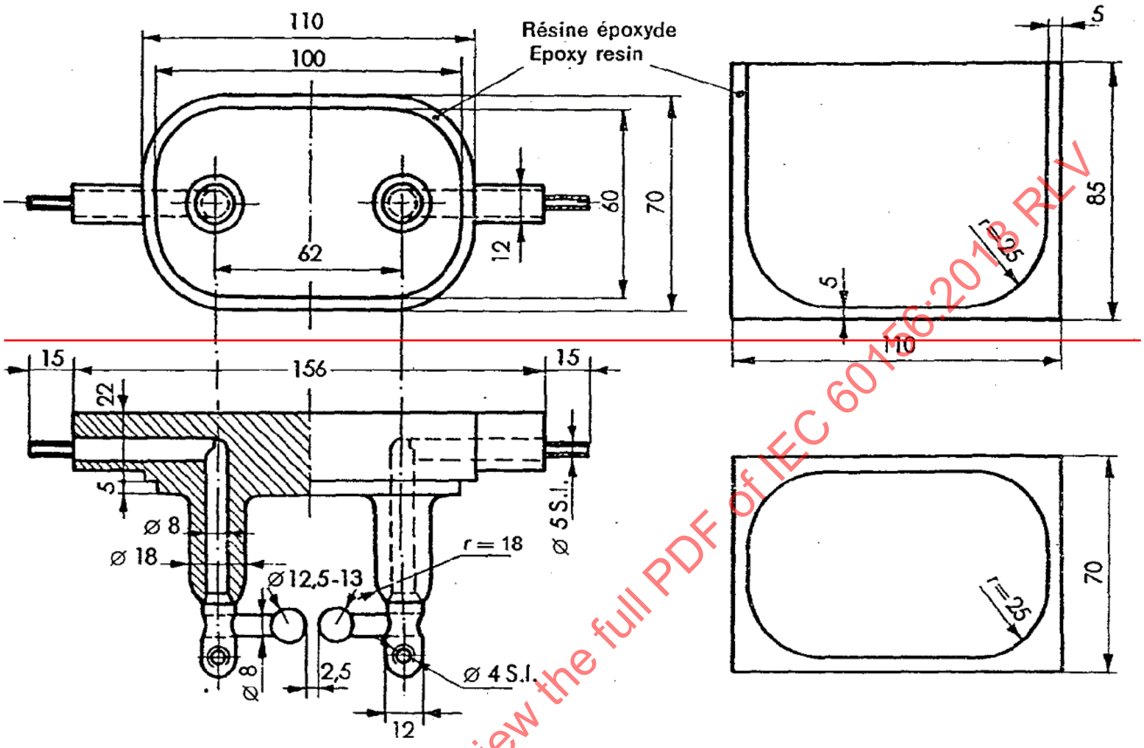
The volume of the cell shall be between 350 ml and 600 ml.

The cell shall be made from electrically insulating materials, that are not hygroscopic. The cell shall be transparent and chemically inert, resistant to the insulating liquid and to the cleaning agent~~s~~ that ~~may~~ shall be used. A glass cell is the preferred option.

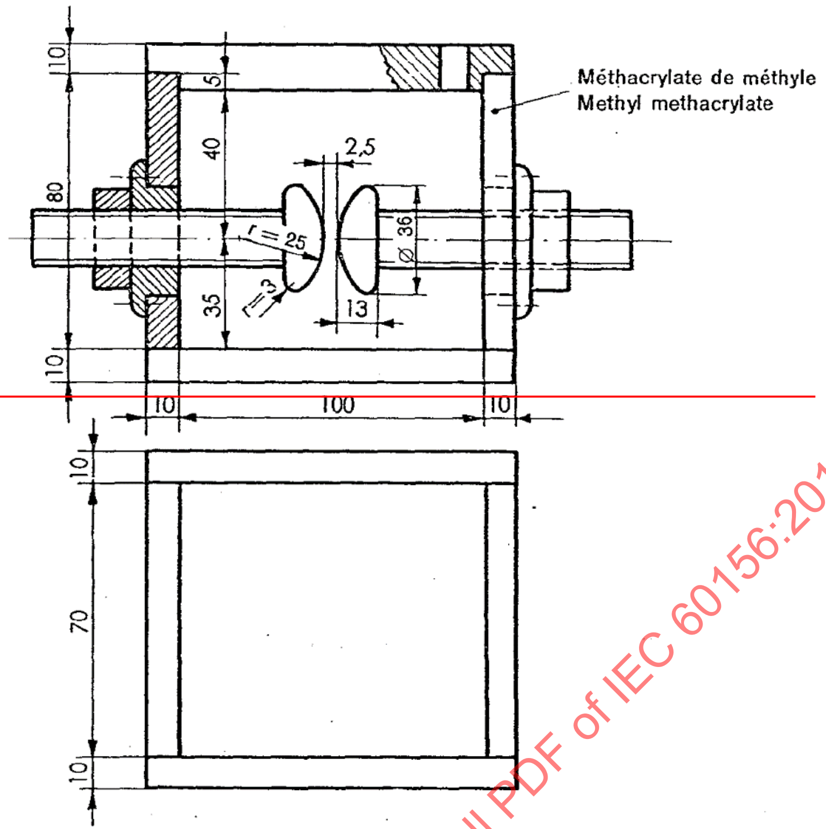
The cell shall be provided with a cover and shall be designed to permit easy removal of the electrodes for cleaning and maintenance. To improve homogenization of the test liquid, a rounded bottom shape of the cell is recommended. Containers and covers shall be cleaned by washing with a suitable solvent or clean insulating liquid to remove residues of an earlier sample. After cleaning, containers shall be immediately capped and kept closed until used again. Electrodes shall be stored in clean insulating liquids.

NOTE It is preferable, in the case of esters, to use similar liquid to store the electrodes.

Examples of suitable cell designs are given in Figures 1 and 2.

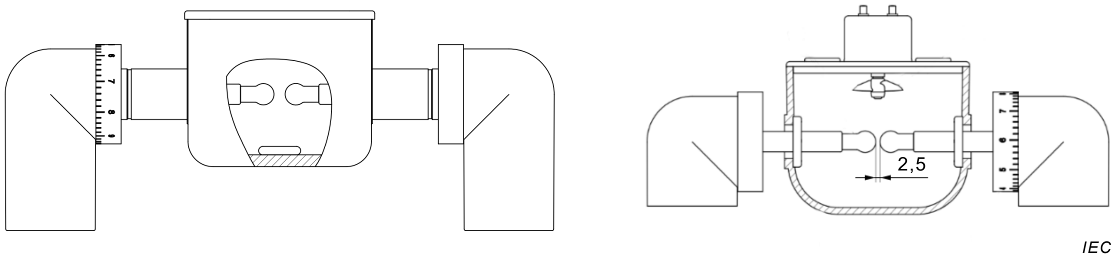


~~Figure 1 – Example of suitable cell and spherical electrodes~~



~~**Figure 2 – Example of suitable cell and partially spherical electrodes**~~

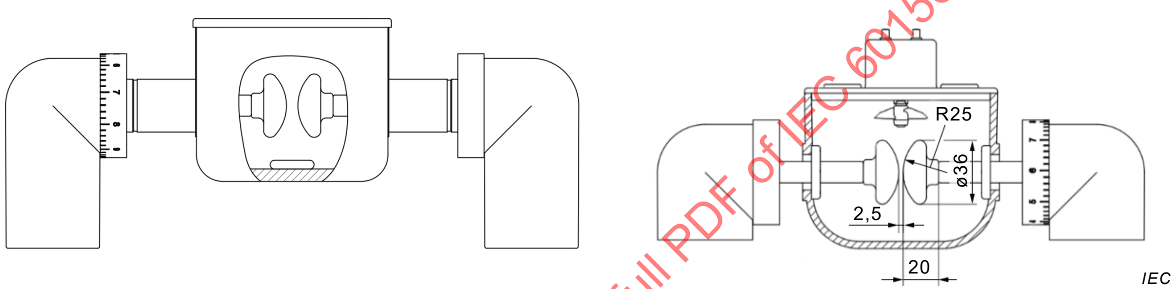
Dimensions in millimetres



NOTE The stirring device can be mounted on the top (right side figure) or on the bottom (left side figure). The stirring device position and Vernier shifter are reported only as reference.

Figure 1 – Examples of test cells with spherical electrodes 12,5 mm to 13,0 mm diameter

Dimensions in millimetres



NOTE The stirring device can be mounted on the top (right side figure) or on the bottom (left side figure). The stirring device position and Vernier shifter are reported only as reference.

Figure 2 – Examples of test cells with partially spherical electrodes with 25 mm radius and diameter of 36 mm

5.3 Electrodes

The electrodes shall be made either of brass, bronze or austenitic stainless steel. They shall be polished and, in shape, either spherical (12,5 mm to 13,0 mm diameter) as shown in Figure 1 or in partially spherical shape (25 mm ± 0,25 mm radius) as shown in Figure 2. The axis of the electrode system shall be horizontal and shall be at least 40 mm below the surface of the test liquid. ~~No part of the electrode shall be closer than 12 mm to the cell wall or stirrer.~~ Any part of the cell or stirrer shall not influence the electric field between the electrodes. The gap between the electrodes shall be 2,50 mm ± 0,05 mm.

The electrodes shall be examined frequently for pitting or other damage and shall be maintained or replaced as soon as such damage is observed.

NOTE The electrodes can be replaced or refurbished typically after 5 000 single breakdowns. The surface of the electrodes can be polished with a maximum grain diameter of 10 µm. The limit of the arithmetical mean deviation of the roughness profile of the electrodes can be Ra ≤ 0,5 µm, according to ISO 4287[4].

5.4 Stirring device ~~(optional)~~

~~The test may be conducted with or without stirring. Differences between tests with or without stirring have not been found statistically significant. A stirrer, however, may be convenient especially with apparatus capable of automatic operation.~~

~~Stirring may be achieved by means of a two-bladed impeller of effective diameter 20 mm to 25 mm, axial depth 5 mm to 10 mm, rotating at a speed of 250 r.p.m to 300 r.p.m. The impeller~~

~~shall not entrain air bubbles and preferably rotate in such a direction that the resulting liquid flow is directed downward. It shall be constructed so that it is easily cleaned.~~

~~Stirring by means of a magnetic bar (20 mm to 25 mm in length and 5 mm to 10 mm in diameter) is an acceptable alternative when there is no risk of removing magnetic particles.~~

~~The dimensions of the stirring device shall conform to the clearance requirements in 4.2.~~

The use of an automatic stirring device is recommended, to be used at all times throughout the test.

The stirrer shall be mounted in the test cell in order to maximize the homogenization of the liquid. It shall be designed so that it is easily cleaned. Stirring shall be achieved by means of a two-bladed or appropriate stirrer of effective diameter 25 mm to 35 mm, axial depth 5 mm to 10 mm, rotating at a speed of 200 r/min to 300 r/min. The stirrer shall not produce air bubbles. It shall be fully immersed in the liquid sample. Examples of stirring systems mounted in test cells are reported in Figures 1 and 2.

NOTE 1 To avoid bubbles between the electrodes the stirrer can rotate preferably in such a direction that bubbles can be removed [5].

NOTE 2 The stirring device can be mounted on the top or on the bottom. In Figures 1 and 2, the stirring device position is reported only as reference.

NOTE 3 A magnetic stirring device can be also used.

6 Preparation of electrodes

New electrodes~~, pitted electrodes, electrodes which have not been properly stored for a considerable time~~ shall be cleaned ~~by~~ and fulfil the requirements of 5.3. Preparation of the electrodes shall be according to the following procedure:

– clean all surfaces with a suitable volatile solvent and allow the solvent to evaporate;
– polish with fine abrasive powder (for example, jeweller's rouge) or abrasive paper or cloth, for example crocus cloth (see 5.3);
– after polishing, clean with petroleum spirit (reagent quality: boiling range of ~~60°C~~ about 40 °C to 80 °C) followed by acetone (reagent quality);
– assemble the electrodes in the cell, fill with a clean, unused insulating liquid of the type to be tested;
– before the first breakdown test, raise the voltage until breakdown 24 times.

This procedure shall be repeated after each cleaning or change of electrodes.

7 Test assembly preparation

It is recommended that a separate test cell assembly be reserved for ~~each~~ different insulating liquid types.

Test assemblies shall be stored in a dry place, covered and filled with dry insulating liquid of the type in regular use in the cell.

On change of the type of liquid under test, remove all residues of the previous liquid with an appropriate solvent, rinse the assembly with a clean, dry liquid of the same type as ~~that~~ the one to be tested, drain and refill.

8 Sampling

~~**7.1 Sample containers**~~

~~Sample size should be approximately three times the capacity of the test cell.~~

~~Appropriate sample containers shall comply with IEC 475. An amber glass bottle is the preferred container. Clear glass bottles may be used but they shall be shielded from direct light until ready to be tested. Plastic containers which are not attacked by the liquid to be tested may be used, but these shall not be used more than once. For sealing, screw caps with polyolefine or polytetrafluoroethylene insert are preferred.~~

~~Containers and caps shall be cleaned by washing with a suitable solvent to remove residues of an earlier sample. Containers shall next be rinsed with acetone, traces of which shall be removed by blowing with warm air.~~

~~After cleaning, containers shall be immediately capped and kept sealed until used.~~

~~**7.2 Sampling technique**~~

~~Sampling of new and used insulating liquids shall be carried out in full compliance with procedures detailed in IEC 475.~~

~~When sampling, containers should be almost filled with sample, leaving about 3 % of the container volume as free air space.~~

~~Breakdown voltage is extremely sensitive to the slightest contamination of the sample by water and particulate matters. Special reference is made to precautions necessary to avoid contamination of the sample and the need for trained personnel and experienced supervision.~~

~~Unless otherwise required, the sample is taken where the liquid is likely to be most contaminated, usually at the lowest point of the container holding it.~~

Sampling shall be carried out in accordance with IEC 60475.

NOTE Breakdown voltage is extremely sensitive to the slightest contamination of the sample by water and particulate matter. Special precautions can be implemented to avoid contamination of the sample and the need for trained personnel and experienced supervision. Unless otherwise required, the sample is taken where the liquid is likely to be most contaminated, usually at the lowest point of the container holding it.

~~**8 Condition of the sample**~~

The test is carried out, unless otherwise specified, on the sample as received without drying or degassing.

~~At the time of test, the temperatures of the test liquid and ambient air shall not differ by more than 5 °C and for referee tests the liquid temperature shall be 20 °C ± 5 °C.~~

9 Test procedure

9.1 Sample preparation

Immediately before filling the test cell, the sample container is gently agitated and turned over several times in such a way as to ensure, as far as possible, a homogeneous distribution of the impurities contained in the liquid without causing the formation of air bubbles.

~~Unnecessary exposure to the ambient air of the sample shall be avoided.~~

A possible method is an automatic rotation of the sample container horizontally for 1 min with a recommended speed of 30 r/min.

Equilibrate the sample to room temperature. Unnecessary exposure to the ambient air of the sample shall be avoided.

9.2 Filling of the cell

Immediately before commencing the test, drain the test cell and rinse the walls, electrodes and other component parts, with the test ~~sample~~ liquid. Drain and slowly fill with the test ~~sample~~ liquid avoiding the formation of air bubbles.

Measure and record the temperature of the liquid.

~~Position the cell in the test equipment and start the stirrer if used.~~

10 Application of the voltage

At the time of test, the temperatures shall be maintained at room temperature (20 °C ± 5 °C).

Adjust the electrode gap distance to 2,5 mm ± 0,05 mm with a vernier or other system and start the stirrer. The stirrer, if used, shall run continuously throughout the test.

Metallic gauges can damage the surface of the electrodes; hence, they have to be avoided.

The first application of voltage is started approximately 5 min after completion of filling and checking that no air bubbles are visible in the electrode gap. Apply voltage to the electrodes and uniformly increase voltage from zero at the rate of 2,0 kV/s ± 0,2 kV/s until breakdown occurs.

~~Apply voltage to the electrodes and uniformly increase voltage from zero at the rate of 2,0 kV s^{-1} ± 0,2 kV s^{-1} until breakdown occurs.~~ The breakdown voltage is the maximum voltage reached at the time the circuit is opened either automatically (established arc) or manually (visible or audible discharge detected).

Record the value in kilovolts.

Carry out six breakdowns on the same cell filling allowing a pause of at least 2 min after each breakdown before re-application of voltage. Check that no gas bubbles are present within the electrode gap. ~~If a stirrer is used, it shall run continuously throughout the test.~~

Calculate the mean value of the six breakdowns ~~in kilovolts~~, standard deviation and related coefficient of variation (ratio between standard deviation and mean breakdown voltage).

For insulating liquids having a nominal viscosity higher than 15 mm^2/s (40°C), the resting time before application of the voltage shall be increased in the range of 15 min to 30 min. In addition, the resting time between two consecutive shots shall also be increased accordingly.

11 Report

~~Report the mean value, in kilovolts, of the six breakdowns as the test result.~~

The report shall ~~also~~ include:

– sample identification, possibly including the type of insulating liquids;
– value of each individual breakdown in kilovolts;

– mean breakdown value;
– type of electrodes used;
– temperature of the liquid (in the test cell);
– coefficient of variation (%) (optional);
– frequency of the test voltage (optional);
– ~~the use of a stirrer (if any);~~
– stirring arrangement (optional).

In the case where the individual breakdown voltage is above the maximum equipment voltage capability, the result shall be reported as greater than the maximum voltage capability (example: > 80 kV).

12 Test data dispersion and reproducibility

~~The scatter of individual breakdown voltages has been found to be very dependent on the value of the result. The graphical representation of figure 3 indicates the values of standard deviation/mean ratio which have been found in a large body of test data in several laboratories using transformer oil.~~

~~The full line in the graph shows the distribution of the median value of SD/mean as a function of the value of the mean. The dotted lines indicate the expected 95 % range of values of SD/mean as a function of the value of the mean.~~

12.1 Test data dispersion

The graphical representation of Figure 3 indicates the values of the coefficient of variation and its mean value which have been found in a large body of test data in several laboratories using transformer liquids. The solid line in the graph shows the distribution of the coefficient of variation as a function of the mean breakdown value. The dotted lines indicate the expected 2,5 % (0,025) to 97,5 % (0,975) range of values of standard deviation (SD)/mean as a function of the value of the mean.

Typical coefficients of variation reported in Figure 3 are for information only and do not represent an acceptance criteria for the obtained results.

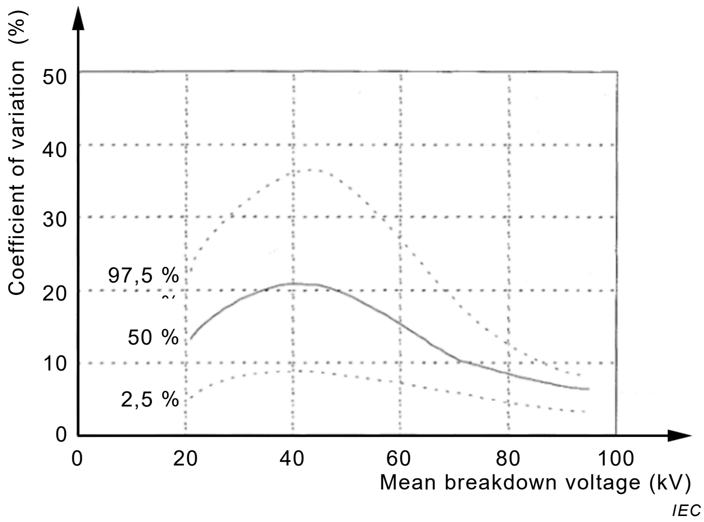


Figure 3 – Graphical representation of coefficient of variation ~~(standard deviation/mean ratio)~~ versus mean breakdown voltage

12.2 Reproducibility

Experience has shown that the reproducibility of individual dielectric breakdown values is in the range of ±30 %.

Annex A
(informative)

Improved test method

A.1 Test procedure for improved test method

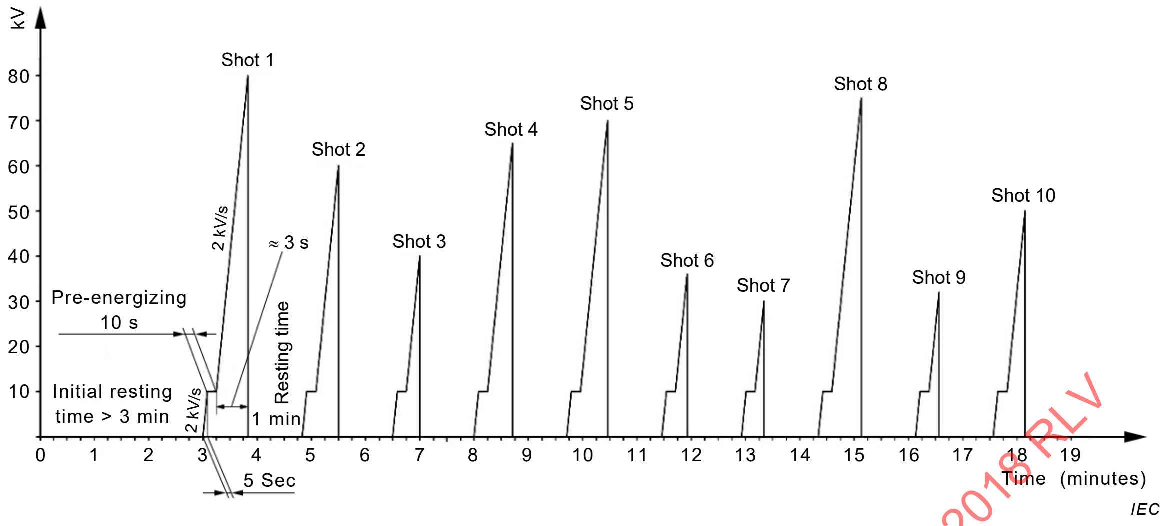
Annex A describes an improved test method, believed to be able to reduce the scatter of the results of breakdown voltage, which may be used [5],[6],[7]. The results obtained using both methods around the world during the following years will assist in a future choice when this document is revised.

Use the same instrument and prepare the test according to Clauses 4 to 9. Instead of the procedure described in Clause 10, follow the procedure described hereafter (Figure A.1):

NOTE The software of the device can be aligned with the procedure described in Annex A.

1) The first application of voltage is started at least 5 min after completion of filling and after checking that the liquid under test is free from air bubbles.
2) Apply voltage to the electrodes uniformly and increase the voltage from zero at the rate of 2 kV/s ± 0,2 kV/s until 10 kV is reached.
3) Maintain the 10 kV level for 10 s, then continue with a rate of voltage rise of 2 kV/s ± 0,2 kV/s until a breakdown occurs.
4) The breakdown voltage shall be recorded at the maximum voltage reached.
5) Carry out 10 breakdowns on the same filling, allowing a pause of at least 1 min after each breakdown before re-application of the test voltage. Record each single breakdown. Calculate the test results as the average and coefficient of variation (ratio between standard deviation and mean breakdown voltage) of the remaining six results after disregarding the two highest and two lowest results.
6) When the coefficient of variation of the test result (mean breakdown voltage) exceeds the upper limit (Figure 3), the test procedure should proceed for the other 10 breakdowns, repeating the procedure from 2) to 6) with the same sample liquid. Record also the results of these additional breakdowns. Calculate the test results as the average and coefficient of variation of the remaining 12 results after disregarding the four highest and four lowest results.

For insulating liquids having a nominal viscosity higher than 15 mm^2/s (40°C), the resting time before application of the voltage shall be increased in the range of 15 min to 30 min. In addition, the resting time between two consecutive shots shall also be increased accordingly.



In the average calculation, the results of four outliers (two highest and two lowest values) have to be discarded (in this example, shots 1 and 8 are the highest and shots 7 and 9 are the lowest).

Figure A.1 – Example of a sequence of breakdown shots for determination of the breakdown voltage

A.2 Report

See Clause 11.

Annex B
(informative)

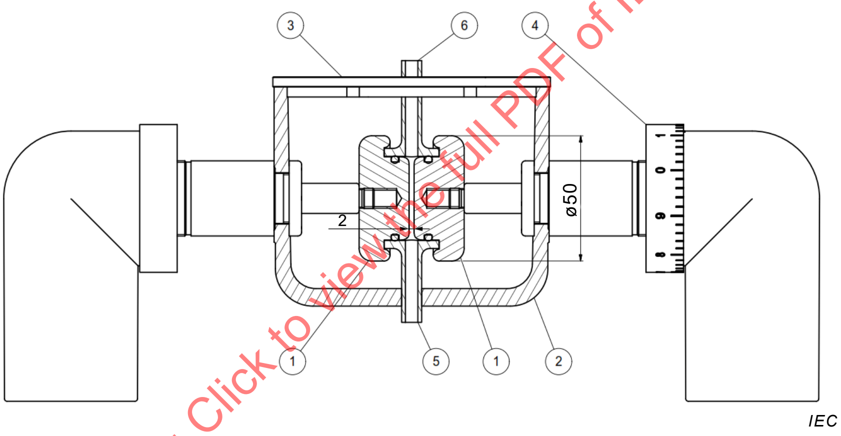
Special test methods for low volume samples

B.1 Low volume sample test

The special test method reported in this annex is suggested for use with low sample volumes. A limited body of data has shown that the results obtained are comparable to the results obtained from the method described in the main body of this document. Examples of the reduced volume test cell are shown in Figures B.1 and B.2.

A fast test on-site may require small portable testers, able to measure the breakdown voltage of insulating liquids (in either direct current or alternating current). An example of such instruments is a Cockcroft-Walton generator, which utilizes a small electrode gap cell and measuring instrumentation. The cell in such an instrument also requires very small quantities of test liquid.

NOTE The results obtained with such portable instruments cannot be used for diagnostic purposes. Results can differ significantly unless comparability has been established.



Key

1 partially spherical electrodes, rounded disk electrode, 50 mm diameter, 2 mm gap

2 oil filled cup, test cell HV insulation

3 cover

4 electrode distance control

5 sample inlet

6 sample outlet

Figure B.1 – Example of low volume test cell, fixed electrode distance of 2 mm with 2 ml active volume under dielectric stress

Dimensions in millimetres

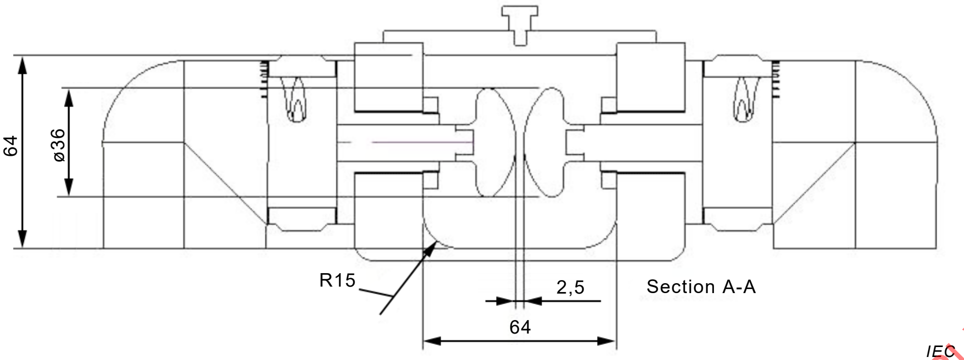


Figure B.2 – Example of low volume test cell, fixed electrode distance of 2,5 mm (150 ml to 200 ml)

Annex C
(informative)

Representative material for a performance test

The reference analysis may be used as a performance check to prove that the test system is fit for use according to IEC 60060-3.

The representative material shall be unused, filtered and degassed mineral, silicone or ester liquids. The minimum quality requirement of the liquid shall be according to IEC relevant standards.

If the test result does not reach the required > 70 kV value, check the functionality of the equipment, or prepare a fresh representative material sample and carry out a new performance check.

Bibliography

[1] IEC 60060-3, *High-voltage test techniques – Part 3: Definitions and requirements for on-site testing*

[2] IEC 60052:2002, *Voltage measurement by means of standard air gaps*

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IEC 60156

Edition 3.0 2018-08

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Insulating liquids – Determination of the breakdown voltage at power frequency – Test method

Isolants liquides – Détermination de la tension de claquage à fréquence industrielle – Méthode d'essai

IEC 60156:2018-08(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INSULATING LIQUIDS – DETERMINATION OF THE BREAKDOWN VOLTAGE AT POWER FREQUENCY – TEST METHOD

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60156 has been prepared by IEC technical committee TC 10: Fluids for electrotechnical applications.

This third edition cancels and replaces the second edition published in 1995. This edition constitutes a technical revision and, mainly, confirms the content of the previous edition even if some advances are included. The test method has not been changed for practical reason due to the very large number of instrumentation disseminated around the world, although the use of stirring is now recommended.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
10/1061/FDIS	10/1065/RVD

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

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

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

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

INTRODUCTION

As normally applied, breakdown voltage of insulating liquids is not a basic material property but an empirical test procedure intended to indicate the presence of contaminants such as water and solid suspended matter and the advisability of carrying out a drying and filtration treatment.

The AC breakdown voltage value of insulating liquids strongly depends on the particular set of conditions used in its measurement. Therefore, standardized testing procedures and equipment are essential for the unambiguous interpretation of test results.

The method described in this document applies to either acceptance tests on new deliveries of insulating liquids, or testing of treated liquids prior to or during filling into electrical equipment, or to the monitoring and maintenance of oil-filled apparatus in service. It specifies rigorous sample-handling procedures and temperature control that should be adhered to when certified results are required. For routine tests, especially in the field, less stringent procedures may be practicable and it is the responsibility of the user to determine their effect on the results.

Annex A (informative) describes, for comparison, an alternative test method which could be introduced in the future. Annex B (informative) describes special test methods, using cells which may include low volume samples. Annex C (informative) describes a reference material for a performance test and check according to IEC 60060-3[1][1].

1 Numbers in square brackets refer to the Bibliography.

INSULATING LIQUIDS – DETERMINATION OF THE BREAKDOWN VOLTAGE AT POWER FREQUENCY – TEST METHOD

1 Scope

This document specifies the method for determining the dielectric breakdown voltage of insulating liquids at power frequency. The test procedure is performed in a specified apparatus, where the oil sample is subjected to an increasing AC electrical field until breakdown occurs. The method applies to all types of insulating liquids of nominal viscosity up to 350 mm^2/s at 40 °C. It is appropriate both for acceptance testing on unused liquids at the time of their delivery and for establishing the condition of samples taken in monitoring and maintenance of equipment.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60475, *Method of sampling insulating liquids*

3 Terms and definitions

No terms and definitions are listed in this document.

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

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

4 Electrical apparatus

4.1 General

The electrical apparatus consists of the following units:

1) voltage regulator,
2) step-up transformer,
3) switching system,
4) current-limiting resistors,
5) measuring device.

Two or more of these units may be integrated in any equipment system.

4.2 Voltage regulator

The test voltage shall be increased with an automatic control of the required uniform voltage rate of rise. The device should not introduce harmonics disturbances (< 3%) and the AC source should be free from harmonics.

4.3 Step-up transformer

The test voltage is obtained by using a step-up or resonant transformer supplied from an AC source using 48 Hz to 62 Hz (sinusoidal waveform). The voltage source value is constantly increased. The controls of the variable low-voltage source shall be capable of varying the test voltage smoothly, uniformly and without overshoots or transients. Incremental increases (produced, for example, by a variable auto-transformer or an amplifier) shall not exceed 2 % of the expected breakdown voltage.

The centre-point of the secondary winding of the transformer should be connected to earth.

4.4 Switching system

The circuit shall be opened automatically if a sustained arc between the electrodes occurs and the voltage between the electrodes collapses to a voltage less than 500 V. The primary circuit of the step-up transformer shall be fitted with a circuit-breaker operated by the current sensing device, resulting from the breakdown of the sample and shall break the voltage within 10 ms.

The sensitivity of the current or voltage sensing element depends on the energy-limiting device employed and only approximate guidance can be given.

A cut-off time of < 100 μs, as given in the previous edition of this document, is needed to perform multiple breakdowns on silicone liquids.

4.5 Current-limiting resistors

To protect the equipment and to avoid excessive decomposition at the instant of breakdown of liquids such as silicone or ester liquids, a resistance limiting the breakdown current shall be inserted in series with the test cell.

The short-circuit current of the transformer and associated circuits shall be within the range of 10 mA to 25 mA for all voltages higher than 15 kV. This may be achieved by a combination of resistors in either or both the primary and secondary circuits of the high-voltage transformer.

4.6 Measuring system

For the purposes of this document, the magnitude of the test voltage is defined as its peak value divided by $\sqrt{2}$.

The output voltage of the step-up transformer may be measured by means of a measuring system consisting of a voltage divider or a measuring winding of the step-up transformer coupled with a peak-voltmeter. The measuring system shall be calibrated up to the upper scale voltage to be measured. A method of calibration which has been found satisfactory is the use of a transfer standard. This is an auxiliary measuring device which is connected in place of the test cell between the high-voltage terminals to which it presents an impedance similar to the one of the sample liquid. The auxiliary device is separately calibrated against a primary standard [2],[3].

5 Test assembly

5.1 General

The breakdown voltage test is performed following the method described herewith as a routine test.

5.2 Test cell

The volume of the cell shall be between 350 ml and 600 ml.

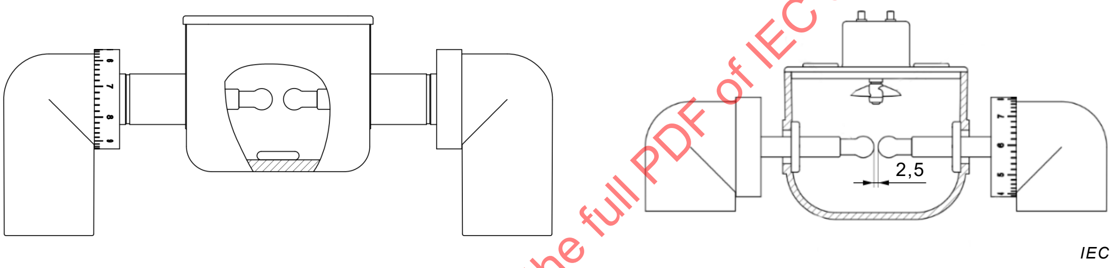
The cell shall be made from electrically insulating materials, that are not hygroscopic. The cell shall be transparent and chemically inert, resistant to the insulating liquid and to the cleaning agent that shall be used. A glass cell is the preferred option.

The cell shall be provided with a cover and shall be designed to permit easy removal of the electrodes for cleaning and maintenance. To improve homogenization of the test liquid, a rounded bottom shape of the cell is recommended. Containers and covers shall be cleaned by washing with a suitable solvent or clean insulating liquid to remove residues of an earlier sample. After cleaning, containers shall be immediately capped and kept closed until used again. Electrodes shall be stored in clean insulating liquids.

NOTE It is preferable, in the case of esters, to use similar liquid to store the electrodes.

Examples of suitable cell designs are given in Figures 1 and 2.

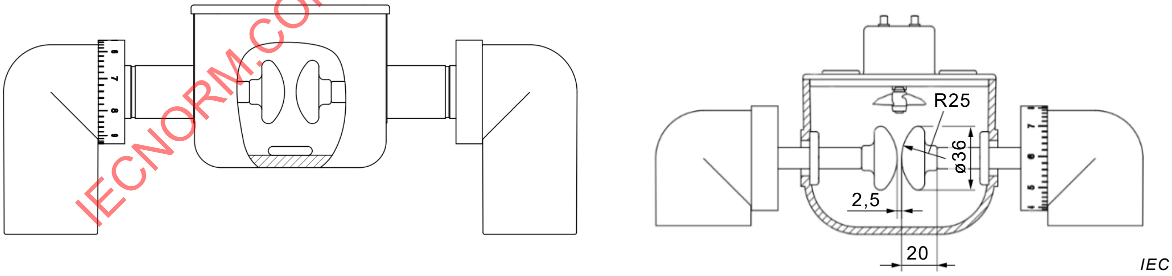
Dimensions in millimetres



NOTE The stirring device can be mounted on the top (right side figure) or on the bottom (left side figure). The stirring device position and Vernier shifter are reported only as reference.

Figure 1 – Examples of test cells with spherical electrodes 12,5 mm to 13,0 mm diameter

Dimensions in millimetres



NOTE The stirring device can be mounted on the top (right side figure) or on the bottom (left side figure). The stirring device position and Vernier shifter are reported only as reference.

Figure 2 – Examples of test cells with partially spherical electrodes with 25 mm radius and diameter of 36 mm

5.3 Electrodes

The electrodes shall be made either of brass, bronze or austenitic stainless steel. They shall be polished and, in shape, either spherical (12,5 mm to 13,0 mm diameter) as shown in Figure 1 or in partially spherical shape (25 mm ± 0,25 mm radius) as shown in Figure 2. The axis of the electrode system shall be horizontal and shall be at least 40 mm below the surface of the test liquid. Any part of the cell or stirrer shall not influence the electric field between the electrodes. The gap between the electrodes shall be 2,50 mm ± 0,05 mm.

The electrodes shall be examined frequently for pitting or other damage and shall be maintained or replaced as soon as such damage is observed.

NOTE The electrodes can be replaced or refurbished typically after 5 000 single breakdowns. The surface of the electrodes can be polished with a maximum grain diameter of 10 µm. The limit of the arithmetical mean deviation of the roughness profile of the electrodes can be Ra ≤ 0,5 µm, according to ISO 4287[4].

5.4 Stirring device

The use of an automatic stirring device is recommended, to be used at all times throughout the test.

The stirrer shall be mounted in the test cell in order to maximize the homogenization of the liquid. It shall be designed so that it is easily cleaned. Stirring shall be achieved by means of a two-bladed or appropriate stirrer of effective diameter 25 mm to 35 mm, axial depth 5 mm to 10 mm, rotating at a speed of 200 r/min to 300 r/min. The stirrer shall not produce air bubbles. It shall be fully immersed in the liquid sample. Examples of stirring systems mounted in test cells are reported in Figures 1 and 2.

NOTE 1 To avoid bubbles between the electrodes the stirrer can rotate preferably in such a direction that bubbles can be removed [5].

NOTE 2 The stirring device can be mounted on the top or on the bottom. In Figures 1 and 2, the stirring device position is reported only as reference.

NOTE 3 A magnetic stirring device can be also used.

6 Preparation of electrodes

New electrodes shall be cleaned and fulfil the requirements of 5.3. Preparation of the electrodes shall be according to the following procedure:

– clean all surfaces with a suitable volatile solvent and allow the solvent to evaporate;
– polish with fine abrasive powder (for example, jeweller's rouge) or abrasive paper or cloth, for example crocus cloth (see 5.3);
– after polishing, clean with petroleum spirit (reagent quality: boiling range of about 40 °C to 80 °C) followed by acetone (reagent quality);
– assemble the electrodes in the cell, fill with a clean, unused insulating liquid of the type to be tested;
– before the first breakdown test, raise the voltage until breakdown 24 times.

This procedure shall be repeated after each cleaning or change of electrodes.

7 Test assembly preparation

It is recommended that a separate test cell assembly be reserved for different insulating liquid types.

Test assemblies shall be stored in a dry place, covered and filled with dry insulating liquid of the type in regular use in the cell.

On change of the type of liquid under test, remove all residues of the previous liquid with an appropriate solvent, rinse the assembly with a clean, dry liquid of the same type as the one to be tested, drain and refill.

8 Sampling

Sampling shall be carried out in accordance with IEC 60475.

NOTE Breakdown voltage is extremely sensitive to the slightest contamination of the sample by water and particulate matter. Special precautions can be implemented to avoid contamination of the sample and the need for trained personnel and experienced supervision. Unless otherwise required, the sample is taken where the liquid is likely to be most contaminated, usually at the lowest point of the container holding it.

The test is carried out, unless otherwise specified, on the sample as received without drying or degassing.

9 Test procedure

9.1 Sample preparation

Immediately before filling the test cell, the sample container is gently agitated and turned over several times in such a way as to ensure, as far as possible, a homogeneous distribution of the impurities contained in the liquid without causing the formation of air bubbles.

A possible method is an automatic rotation of the sample container horizontally for 1 min with a recommended speed of 30 r/min.

Equilibrate the sample to room temperature. Unnecessary exposure to the ambient air of the sample shall be avoided.

9.2 Filling of the cell

Immediately before commencing the test, drain the test cell and rinse the walls, electrodes and other component parts, with the test liquid. Drain and slowly fill with the test liquid avoiding the formation of air bubbles.

Measure and record the temperature of the liquid.

10 Application of the voltage

At the time of test, the temperatures shall be maintained at room temperature (20 °C ± 5 °C).

Adjust the electrode gap distance to 2,5 mm ± 0,05 mm with a vernier or other system and start the stirrer. The stirrer, if used, shall run continuously throughout the test.

Metallic gauges can damage the surface of the electrodes; hence, they have to be avoided.

The first application of voltage is started approximately 5 min after completion of filling and checking that no air bubbles are visible in the electrode gap. Apply voltage to the electrodes and uniformly increase voltage from zero at the rate of 2,0 kV/s ± 0,2 kV/s until breakdown occurs.

The breakdown voltage is the maximum voltage reached at the time the circuit is opened either automatically (established arc) or manually (visible or audible discharge detected).

Record the value in kilovolts.

Carry out six breakdowns on the same cell filling allowing a pause of at least 2 min after each breakdown before re-application of voltage. Check that no gas bubbles are present within the electrode gap.

Calculate the mean value of the six breakdowns, standard deviation and related coefficient of variation (ratio between standard deviation and mean breakdown voltage).

For insulating liquids having a nominal viscosity higher than 15 mm^2/s (40°C), the resting time before application of the voltage shall be increased in the range of 15 min to 30 min. In addition, the resting time between two consecutive shots shall also be increased accordingly.

11 Report

The report shall include:

– sample identification, possibly including the type of insulating liquids;
– value of each individual breakdown in kilovolts;
– mean breakdown value;
– type of electrodes used;
– temperature of the liquid (in the test cell);
– coefficient of variation (%) (optional);
– frequency of the test voltage (optional);
– stirring arrangement (optional).

In the case where the individual breakdown voltage is above the maximum equipment voltage capability, the result shall be reported as greater than the maximum voltage capability (example: > 80 kV).

12 Test data dispersion and reproducibility

12.1 Test data dispersion

The graphical representation of Figure 3 indicates the values of the coefficient of variation and its mean value which have been found in a large body of test data in several laboratories using transformer liquids. The solid line in the graph shows the distribution of the coefficient of variation as a function of the mean breakdown value. The dotted lines indicate the expected 2,5 % (0,025) to 97,5 % (0,975) range of values of standard deviation (SD)/mean as a function of the value of the mean.

Typical coefficients of variation reported in Figure 3 are for information only and do not represent an acceptance criteria for the obtained results.

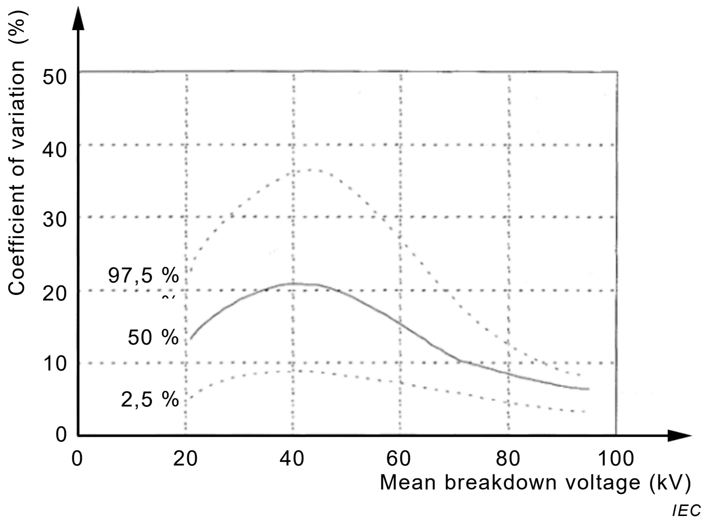


Figure 3 – Graphical representation of coefficient of variation versus mean breakdown voltage

12.2 Reproducibility

Experience has shown that the reproducibility of individual dielectric breakdown values is in the range of ±30 %.

Annex A
(informative)

Improved test method

A.1 Test procedure for improved test method

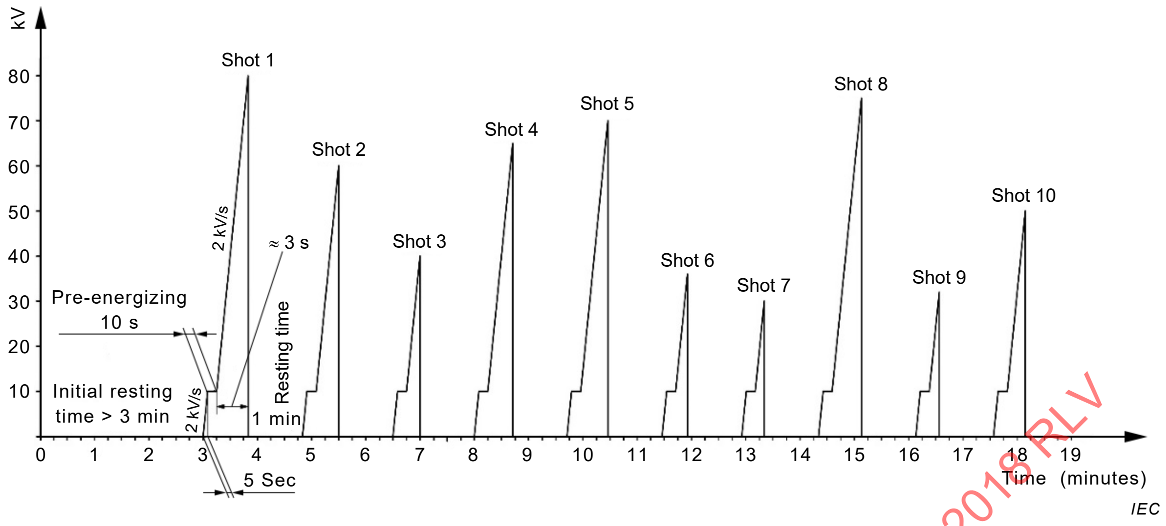
Annex A describes an improved test method, believed to be able to reduce the scatter of the results of breakdown voltage, which may be used [5],[6],[7]. The results obtained using both methods around the world during the following years will assist in a future choice when this document is revised.

Use the same instrument and prepare the test according to Clauses 4 to 9. Instead of the procedure described in Clause 10, follow the procedure described hereafter (Figure A.1):

NOTE The software of the device can be aligned with the procedure described in Annex A.

1) The first application of voltage is started at least 5 min after completion of filling and after checking that the liquid under test is free from air bubbles.
2) Apply voltage to the electrodes uniformly and increase the voltage from zero at the rate of 2 kV/s ± 0,2 kV/s until 10 kV is reached.
3) Maintain the 10 kV level for 10 s, then continue with a rate of voltage rise of 2 kV/s ± 0,2 kV/s until a breakdown occurs.
4) The breakdown voltage shall be recorded at the maximum voltage reached.
5) Carry out 10 breakdowns on the same filling, allowing a pause of at least 1 min after each breakdown before re-application of the test voltage. Record each single breakdown. Calculate the test results as the average and coefficient of variation (ratio between standard deviation and mean breakdown voltage) of the remaining six results after disregarding the two highest and two lowest results.
6) When the coefficient of variation of the test result (mean breakdown voltage) exceeds the upper limit (Figure 3), the test procedure should proceed for the other 10 breakdowns, repeating the procedure from 2) to 6) with the same sample liquid. Record also the results of these additional breakdowns. Calculate the test results as the average and coefficient of variation of the remaining 12 results after disregarding the four highest and four lowest results.

For insulating liquids having a nominal viscosity higher than 15 mm^2/s (40°C), the resting time before application of the voltage shall be increased in the range of 15 min to 30 min. In addition, the resting time between two consecutive shots shall also be increased accordingly.



In the average calculation, the results of four outliers (two highest and two lowest values) have to be discarded (in this example, shots 1 and 8 are the highest and shots 7 and 9 are the lowest).

Figure A.1 – Example of a sequence of breakdown shots for determination of the breakdown voltage

A.2 Report

See Clause 11.

Annex B
(informative)

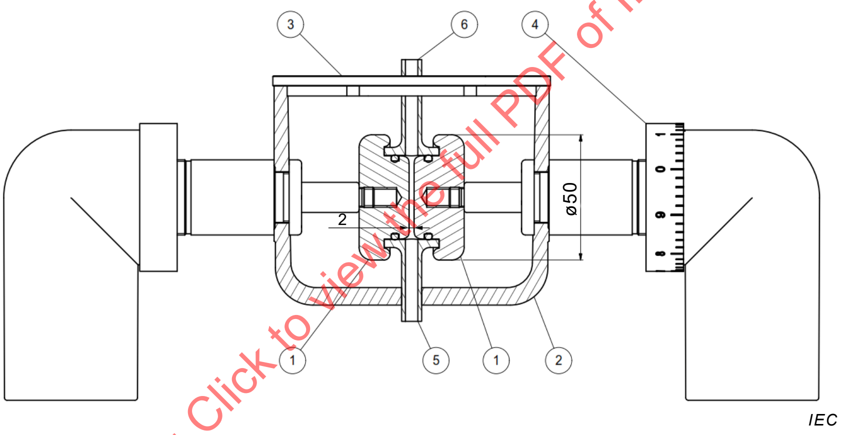
Special test methods for low volume samples

B.1 Low volume sample test

The special test method reported in this annex is suggested for use with low sample volumes. A limited body of data has shown that the results obtained are comparable to the results obtained from the method described in the main body of this document. Examples of the reduced volume test cell are shown in Figures B.1 and B.2.

A fast test on-site may require small portable testers, able to measure the breakdown voltage of insulating liquids (in either direct current or alternating current). An example of such instruments is a Cockcroft-Walton generator, which utilizes a small electrode gap cell and measuring instrumentation. The cell in such an instrument also requires very small quantities of test liquid.

NOTE The results obtained with such portable instruments cannot be used for diagnostic purposes. Results can differ significantly unless comparability has been established.



Key

1 partially spherical electrodes, rounded disk electrode, 50 mm diameter, 2 mm gap

2 oil filled cup, test cell HV insulation

3 cover

4 electrode distance control

5 sample inlet

6 sample outlet

Figure B.1 – Example of low volume test cell, fixed electrode distance of 2 mm with 2 ml active volume under dielectric stress

Dimensions in millimetres

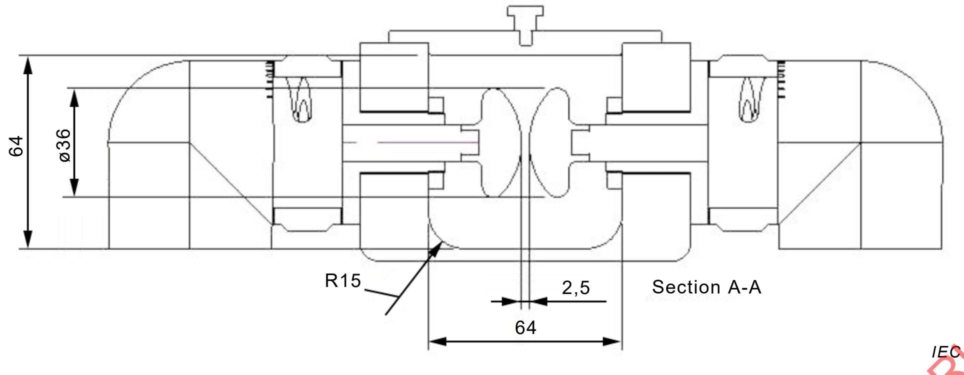


Figure B.2 – Example of low volume test cell, fixed electrode distance of 2,5 mm (150 ml to 200 ml)

Annex C
(informative)

Representative material for a performance test

The reference analysis may be used as a performance check to prove that the test system is fit for use according to IEC 60060-3.

The representative material shall be unused, filtered and degassed mineral, silicone or ester liquids. The minimum quality requirement of the liquid shall be according to IEC relevant standards.

If the test result does not reach the required > 70 kV value, check the functionality of the equipment, or prepare a fresh representative material sample and carry out a new performance check.

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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ISOLANTS LIQUIDES – DÉTERMINATION DE LA TENSION DE CLAQUAGE À FRÉQUENCE INDUSTRIELLE – MÉTHODE D'ESSAI

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La Norme internationale IEC 60156 a été établie par le comité d'études 10 de l'IEC: Fluides pour applications électrotechniques.

Cette troisième édition annule et remplace la deuxième édition parue en 1995. Cette édition constitue une révision technique et valide essentiellement le contenu de l'édition précédente même si elle comporte certaines améliorations. La méthode d'essai n'a pas été modifiée pour des raisons pratiques et du fait du très grand nombre de dispositifs de mesure utilisés au niveau international, même si l'emploi de l'agitateur est maintenant recommandé.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
10/1061/FDIS	10/1065/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 internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Le comité a décidé que le contenu de ce document 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 au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

INTRODUCTION

La tension de claquage des isolants liquides, telle qu'elle est généralement appliquée, n'est pas une propriété fondamentale du matériau, mais une procédure d'essai empirique destinée à révéler la présence de produits contaminants comme l'eau ou des matières solides en suspension, et permettre ainsi de décider de l'opportunité d'effectuer un traitement de séchage et de filtration.

La valeur de la tension de claquage sous courant alternatif des isolants liquides dépend beaucoup de l'ensemble des conditions particulières appliquées pour son mesurage. En conséquence, des procédures d'essai et un équipement normalisés sont essentiels pour interpréter sans ambiguïté les résultats d'essai.

La méthode décrite dans le présent document s'applique soit aux essais de réception de nouvelles livraisons d'isolants liquides, soit aux essais de liquides traités, avant ou pendant le remplissage de matériels électriques, soit à la surveillance et à la maintenance des appareils remplis d'huile en service. Elle spécifie des méthodes rigoureuses de manipulation des échantillons et de vérification des températures auxquelles il convient de se conformer quand des résultats certifiés sont exigés. Pour les essais de routine, notamment sur le terrain, des procédures moins rigoureuses peuvent être appliquées et il revient alors à l'utilisateur de déterminer leurs effets sur les résultats obtenus.

L'Annexe A (informative) décrit, à titre de comparaison, une autre méthode d'essai qui pourrait être adoptée à l'avenir. L'Annexe B (informative) décrit des méthodes d'essai spéciales utilisant des cellules qui peuvent contenir des échantillons de faible volume. L'Annexe C (informative) décrit un matériau de référence pour un essai de détermination des caractéristiques ou un contrôle de caractéristiques conformément à l'IEC 60060-3[1][1].

[1] Les chiffres entre crochets renvoient à la Bibliographie.

ISOLANTS LIQUIDES – DÉTERMINATION DE LA TENSION DE CLAQUAGE À FRÉQUENCE INDUSTRIELLE – MÉTHODE D'ESSAI

1 Domaine d'application

Le présent document spécifie la méthode de détermination de la tension de claquage diélectrique des isolants liquides à fréquence industrielle. La procédure d'essai est réalisée dans un appareil spécifié dans lequel l'échantillon d'huile est soumis à un champ électrique alternatif croissant jusqu'à l'obtention du claquage. La méthode est applicable à tous les types d'isolants liquides de viscosité nominale allant jusqu'à 350 mm^2/s à 40 °C. Elle convient aussi bien pour les essais de réception de liquides neufs à la livraison que pour définir l'état des échantillons prélevés lors de la surveillance et de la maintenance des matériels.

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. 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 60475, *Méthode d'échantillonnage des liquides isolants*

3 Termes et définitions

Aucun terme n'est défini dans le présent document.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

4 Appareillage électrique

4.1 Généralités

L'appareillage électrique se compose des éléments suivants:

1) régulateur de tension,
2) transformateur élévateur,
3) disjoncteur,
4) résistances de limitation de courant,
5) dispositif de mesure.

Deux de ces éléments ou plus peuvent être réunis dans un système de mesure intégré.

4.2 Régulateur de tension

La tension d'essai doit être augmentée à l'aide d'un réglage automatique de la vitesse uniforme exigée de montée en tension. Il convient que le dispositif ne crée pas de perturbations harmoniques (< 3 %) et que la source de tension alternative soit exempte d'harmonique.

4.3 Transformateur élévateur

La tension d'essai est obtenue au moyen d'un transformateur élévateur ou à résonance alimenté à partir d'une source de tension alternative dans la plage de fréquences comprise entre 48 Hz et 62 Hz (forme d'onde sinusoïdale). La valeur de la source de tension est augmentée de façon continue. Les commandes de la source basse tension variable doivent être capables de faire varier la tension d'essai sans à-coups, d'une manière uniforme, et sans oscillations ni transitoires de tension. L'incrémentation (obtenue, par exemple, à l'aide d'un autotransformateur variable ou d'un amplificateur) ne doit pas dépasser 2 % de la tension de claquage attendue.

Il convient que le point milieu de l'enroulement secondaire du transformateur soit relié à la terre.

4.4 Disjoncteur

Le circuit doit être automatiquement ouvert quand un arc maintenu se produit entre les électrodes et quand la tension entre les électrodes chute jusqu'à une valeur inférieure à 500 V. Le circuit primaire du transformateur élévateur doit être équipé d'un disjoncteur fonctionnant sous l'action du détecteur du courant qui résulte du claquage de l'échantillon et doit couper la tension en moins de 10 ms.

La sensibilité des dispositifs détecteurs de courant ou de tension dépend du dispositif de limitation d'énergie utilisé et seules des recommandations approximatives peuvent être fournies.

Un temps de coupure < 100 µs, tel qu'indiqué dans l'édition précédente du présent document, est nécessaire pour réaliser plusieurs claquages sur les liquides silicones.

4.5 Résistances de limitation de courant

Afin de protéger le matériel et pour éviter une décomposition excessive au moment du claquage des liquides (par exemple, liquides silicones ou esters), une résistance de limitation du courant de claquage doit être insérée en série avec la cellule d'essai.

Le courant de court-circuit du transformateur et de ses circuits associés doit être compris entre 10 mA et 25 mA pour toutes les tensions supérieures à 15 kV. Ce résultat peut être obtenu par une combinaison de résistances placées dans l'un ou l'autre des circuits primaire ou secondaire du transformateur haute tension ou dans les deux circuits.

4.6 Système de mesure

Dans le cadre du présent document, l'amplitude de la tension d'essai est définie par sa valeur de crête divisée par $\sqrt{2}$.

La tension de sortie du transformateur élévateur peut être mesurée au moyen d'un système de mesure comprenant un diviseur de tension ou un enroulement de mesure du transformateur élévateur relié à un voltmètre de crête. Le système de mesure doit être étalonné jusqu'à la tension maximale à mesurer. L'utilisation d'un étalon de transfert est une méthode d'étalonnage qui s'est révélée satisfaisante. Il s'agit d'un dispositif de mesure auxiliaire placé entre les bornes haute tension, à la place de la cellule d'essai, et présentant une impédance identique à celle du liquide en essai. Ce dispositif auxiliaire est étalonné séparément à partir d'un étalon primaire [2],[3].