# IEC TR 63434

Edition 1.0 2023-09

# TECHNICAL REPORT

## Low voltage switchgear and controlgear – Partial discharge voltages and PD-level in low voltage switchgear and controlgear



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# FOREWORD





IEC TR 63434 has been prepared by subcommittee 121A: Low voltage switchgear and controlgear, of IEC technical committee 121: Switchgear and controlgear and their assemblies for low-voltage. It is a Technical Report.

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

| Draft | Report on voting |
|---|---|
| 121A/549/DTR | 121A/556A/RVDTR |

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

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

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under 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- withdrawn,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

The application of this document is intended to provide awareness about partial discharge phenomena. Special emphasis is given to the electrical field stress through solid insulation as it relates to the risk of insulation failure.

IEC 60664-1[1] [1] is only providing requirements for partial discharge testing of solid insulation when the peak value of the operational voltage exceeds 700 V and the average field strength is higher than 1 kV/mm. However, in practice, partial discharge testing gives random results below 4 kV/mm, mainly because of the intrinsic fluctuation of PD inception voltage in gaps, the variations of the shape and size of the internal voids in solid materials, and the large influence of the temperature and humidity on the material characteristics. Therefore, this document is providing guidance related to the proper design of the insulation and the selection criteria of the material.



1 Numbers in square brackets refer to the Bibliography.

# LOW VOLTAGE SWITCHGEAR AND CONTROLGEAR –

# PARTIAL DISCHARGE VOLTAGES AND PD-LEVEL IN LOW VOLTAGE SWITCHGEAR AND CONTROLGEAR

## 1 Scope

This document is intended to provide awareness about partial discharge phenomena. This document gives guidance for some conditions when partial discharge can occur in low voltage switchgear and controlgear connected to networks of up to 1 000 V AC. Internal operational voltages can exceed these values. This document gives guidance on the design of conductors and dimensioning of insulation exposed to electrical fields.

This document explains the partial discharge phenomena considering electrical field stress, type of insulation material and other construction parameters, such as the voltage, frequency, temperature, humidity and the distances within the device.

This document does not cover:

- phenomena associated with semiconductor power switching by effects on equipment placed downstream of semiconductor power switching systems;
- partial discharge test procedures (see IEC 60270) [2];
- pure DC systems which are under consideration;
- selection of solid insulation material.



## 2 Normative references

There are no normative references in this document.



## 3 Terms and definitions

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

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

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

**3.1**
**homogeneous electric field**
electric field which has an essentially constant voltage gradient between electrodes, such as that between two spheres where the radius of each sphere is greater than the distance between them

Note 1 to entry: The homogeneous field condition is referred to as case B in IEC 60664-1[1].

[SOURCE: IEC 60050-442:2014[3], 442-09-02]

**3.2**
**inhomogeneous electric field**
electric field which does not have an essentially constant voltage gradient between electrodes

Note 1 to entry: The inhomogeneous field condition of a point-plane electrode configuration is the worst case with regard to voltage withstand capability and is referred to as case A in IEC 60664-1[1]. It is represented by a point electrode having a 30 μm radius and a plane of 1 m × 1 m.

Note 2 to entry: For frequencies exceeding 30 kHz, the field is considered to be inhomogeneous when the radius of curvature of the conductive parts is less than 20 % of the clearance.

[SOURCE: IEC 60050-442:2014[3], 442-09-03]

**3.3**
**partial discharge**
**PD**
electric discharge that only partially bridges the insulation between conductors

Note 1 to entry: A partial discharge may occur inside the insulation or adjacent to a conductor.

Note 2 to entry: Scintillations of low energy on the surface of insulating materials are often described as partial discharges but should rather be considered as disruptive discharges of low energy, since they are the result of local dielectric breakdowns of high ionization density, or small arcs, according to the conventions of physics.

[SOURCE: IEC 60050-212:2010[3], 212-11-39, modified — Addition of the synonym “PD”.]

**3.4**
**partial discharge intensity**
amount of partial discharge occurring under given conditions

Note 1 to entry: In practice the partial discharge intensity is usually expressed in picocoulombs or in joules.

[SOURCE: IEC 60050-212:2010[3], 212-11-40]



**3.5**
**partial discharge inception voltage**
$U_\mathrm{i}$
lowest peak value of the test voltage at which the apparent charge becomes greater than the specified discharge magnitude when the test voltage is increased above a low value for which no discharge occurs



Note 1 to entry: For AC tests the RMS value may be used.

[SOURCE: IEC 60050-212:2014[3], 212-11-41]

**3.6**
**partial discharge extinction voltage**
$U_\mathrm{e}$
highest voltage at which partial discharges are extinguished when the voltage applied is gradually decreased from a higher value at which such discharges are observed

[SOURCE: IEC 60050-212:2010[3], 212-11-42, modified – added abbreviation $U_\mathrm{e}$]

**3.7**
**impulse withstand voltage**
$U_\mathrm{imp}$
highest peak impulse voltage, of prescribed form and polarity, which does not cause breakdown under specified conditions of test

**3.8**
**internal partial discharge**
partial discharge inside an insulating material

[SOURCE: IEC 60050-212:2010[3], 212-11-43]

**3.9**
**working voltage**
highest RMS value of the AC or DC voltage across any particular insulation which can occur when the equipment is supplied at rated voltage

Note 1 to entry: Transient overvoltages are disregarded.

Note 2 to entry: Both open-circuit conditions and normal operating conditions are taken into account.

[SOURCE: IEC 60947-1:2020[4], 3.7.52]

**3.10**
**recurring peak voltage**
$U_{rp}$
maximum peak value of periodic excursions of the voltage waveform resulting from distortions of an AC voltage or from AC components superimposed on a DC voltage

Note 1 to entry: Random overvoltages, for example due to occasional switching, are not considered to be recurring peak voltages.

[SOURCE: IEC 60050-442:2014[3], 442-09-15]

**3.11**
**temporary overvoltage**
overvoltage at power frequency of relatively long duration



Note 1 to entry: A temporary overvoltage is undamped or weakly damped. In some cases, its frequency may be several times smaller or greater than power frequency.

[SOURCE: IEC 60947-1:2020[4], 3.7.53]

**3.12**
**transient overvoltage**
short duration overvoltage of a few milliseconds or less, oscillatory or non-oscillatory, usually highly damped



[SOURCE: IEC 60050-614:2016[3], 614-03-14, modified – “overvoltage with a duration” has been replaced with “short duration overvoltage” and the notes have been deleted.]

**3.13**
**glow discharge**
self-maintained gas conduction for which most of the charge carriers are electrons supplied by secondary-electron emission

[SOURCE: IEC 60050-121:1998[3], 121-13-13]

**3.14**
**electric breakdown**
abrupt change of all or part of an insulating medium into a conducting medium resulting in an electric discharge

[SOURCE: IEC 60050-614:2016[3], 614-03-15]

**3.15**
**electric strength**
quotient of the maximum voltage applied without breakdown, by the distance between conducting parts under prescribed test conditions

[SOURCE: IEC 60050-212:2010[3], 212-11-37]

**3.16**
**glass transition**
physical change in an amorphous material or in amorphous regions of a partially crystalline material from a viscous or rubbery condition to a hard one, or the reverse

[SOURCE: IEC 60050-212:2010[3], 212-12-28]

**3.17**
**glass transition temperature**
$\boldsymbol{T}_{\mathbf{g}}$
midpoint of a thermodynamic temperature range over which the glass transition takes place

[SOURCE: IEC 60050-212:2010[3], 212-12-29]

# 4 Basic information (physics)

## 4.1 Discharge phenomena

### 4.1.1 General

Partial discharges are well known in the field of high voltage applications and typical for inhomogeneous electrical field distributions.

Partial discharges in electromechanical switchgear can appear in different ways: through air directly (external PD), on surfaces of supporting parts (surface PD) and within voids of solid or liquid insulation components like phase separation walls (internal PD). Surface discharges in air have generally larger values than those inside of cavities of solid insulation [5].



NOTE In [6] a simulation is shown illustrating the potential locations of PD generation in a Motor Protection Switching Device (MPSD).

### 4.1.2 Homogeneous electric fields



The breakdown field strength or dielectric strength of an air gap of 1 mm distance with a homogeneous electric field – e.g. between parallel plane electrodes – is about 4 kV/mm (see Figure 4). In technical applications the size of the air gaps between electrodes and insulation material can be 1 mm or less.

NOTE For breakdown processes in homogeneous electric fields in air in general the Paschen-Law [7], [9] is valid.

The breakdown field strength $\hat{E}_{\mathrm{d}}$ is depending on the temperature $T$. The temperature correction is done by using equation (1) with $T_0$ = 293 K and the worst case temperature coefficient $\alpha$ = 0,8.[[7], p. 169], see Figure 1.

$$\hat{E}_{\mathrm{d}} = \hat{E}_{\mathrm{do}} \left( \frac{p / p_0}{T / T_0} \right)^{a} \tag{1}$$

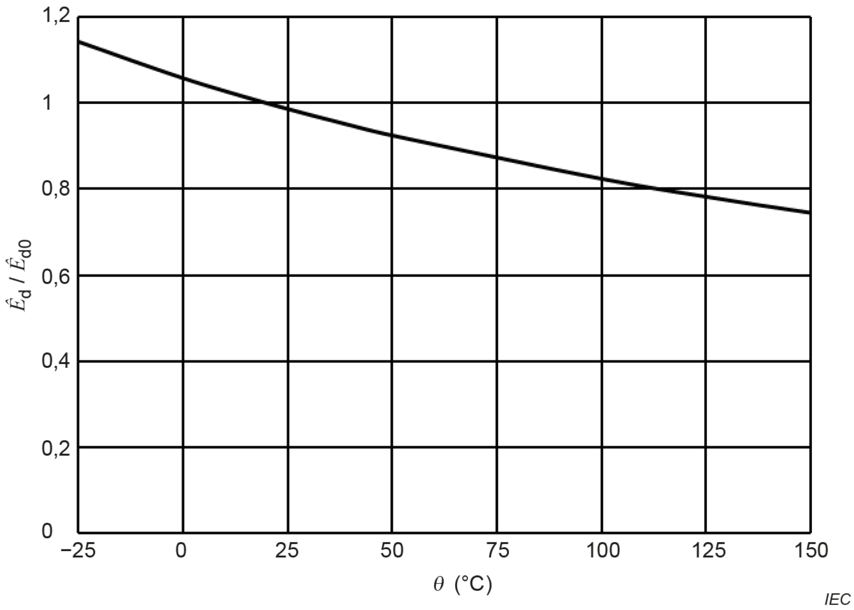


**Figure 1 – Temperature dependent variation of the breakdown field strength $\hat{E}_d$ of air per Equation (1), $\alpha$ = 0,8, $\theta$ = 20 °C, $p = p_0$ = 1 013 mbar**

For 130 °C this results in a dielectric strength of a 1 mm air gap with homogeneous field distribution $\hat{E}_d$ of 3,1 kV/mm (77,5 % of the 20 °C-value). This is the crest value of the field strength and related to the peak value of the applied voltage. The effective value of a corresponding sinusoidal voltage is reduced by the factor 1/√2.



### 4.1.3 Inhomogeneous electric fields

The PD inception voltage is related to inhomogeneous electrode distribution – like point to plane electrodes – with a degree of homogeneity or utilization factor $\eta$ lower as the limit of $\eta \approx 0,2$ [9]. This value gives the quotient of average field strength to maximum field strength for an electrode arrangement [5], [8]. Stable glow discharges in air can principally appear at field strength values of 2,5 kV/mm (see [9] and IEC 60664-1:2020, Figure A.1[1]). With a low utilization factor of 0,2 the PD inception peak voltage for an inhomogeneous electrode arrangement – like a point or edge electrode against a plane electrode – with an air gap of 1 mm is only about 800 $V_{peak}$ or 566 $V_{RMS.}$ according to the tables in [7].

NOTE 1 Because, in practice, partial discharge testing gives random results below 4 kV/mm, the threshold of 2,5 kV/mm is considered only for initial analysis purposes.

The utilization factor $\eta$ is dependent on the electrode distance $R$ and the electrode radius $r$ [5], [8]. A reference model in [8] shows the relation between radius $r$ and inception voltage $U_i$, expressed in RMS, based on real dimensions (see Table 1 and [8]).