भारतीय मानक

Indian Standard

IS/IEC 60034-18-41 : 2024

Superseding IS 15999 (Part 18 /Sec 41) : 2018

विद्युत घूर्णिय मशीनें

भाग 18 आंशिक डिस्चार्ज मुक्त विद्युत इन्सुलेशन सिस्टम (टाइप I) वोल्टेज कन्वर्टर्स से संचालित रोटेटिंग इलेक्ट्रिकल मशीनों में उपयोग किया जाता है

अनुभाग 41 योग्यता और गुणवत्ता नियंत्रण परीक्षण

Rotating Electrical Machines

Part 18 Partial Discharge free Electrical Insulation Systems (Type I) used in Rotating Electrical Machines Fed from Voltage Converters

Section 41 Qualification and Quality Control Tests

ICS 29.160.01

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NATIONAL FOREWORD

This Indian Standard (Part 18/Sec 41) which is identical to IEC 60034-18-41 : 2014+AMD1 : 2019 CSV Rotating electrical machines — Part 18-41 : Partial discharge free electrical insulation systems (Type I) used in rotating electrical machines fed from voltage converters — Section 1 Qualification and quality control tests ' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Rotating Machinery Sectional Committee and approval of the Electrotechnical Division Council.

IS 15999 (Part 18/Sec 41) was first published in 2018. This publication has been brough out to align it with the latest version of IEC 60034-18-41 : 2014+AMD1 : 2019 CSV. This standard supersedes IS 15999 (Part 18/Sec 41) : 2018.

This standard is published in various parts. Other parts in this series are:

Part 5	Degrees of protection provided by the integral design of rotating electrical machines (IP Code) — Classification
Part 8	Terminal markings and direction of rotation (*third revision*)
Part 27 Section	Winding insulation of rotating electrical machines, Section 4 Measurement of insulation resistance and polarization index

The text of the IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appears referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to International Standards for which Indian Standards also exists. The corresponding Indian Standards, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC/TS 60034-18-42 Rotating electrical machines — Part 18-42: Qualification and acceptance tests for partial discharge resistant electrical insulation systems (Type II) used in rotating electrical machines fed from voltage converters	IS 15999 (Part 18/Sec 42) : 2018/IEC 60034-18-42 : 2008 Rotating electrical machines: Part 18 Qualification and acceptance tests for partial discharge resistant electrical insulation systems (Type II), Section 42 Used in rotating electrical machines fed from voltage converters	Identical
IEC 60172 Test procedure for the determination of the temperature index of enamelled winding wires	IS 5825 : 2024/IEC 60172 : 2020 Test procedure for the determination of the temperature index of enamelled and tape wrapped winding wires (*third revision*)	Identical

(*Cointuned on third cover*)

CONTENTS

INTRODUCTION

The approval of electrical insulation systems for use in rotating electrical machines driven from voltage converters is set out in two IEC documents. They divide the systems into those which are not expected to experience partial discharge activity within specified conditions in their service lives (Type I) and those which are expected to withstand partial discharge activity in any part of the insulation system throughout their service lives (Type II). For both Type I and Type II insulation systems, the drive system integrator (the person responsible for co-ordinating the electrical performance of the entire drive system) shall inform the machine manufacturer what voltage will appear at the machine terminals in service. The machine manufacturer will then decide upon the severity of the tests appropriate for qualifying the insulation system. The severity is based on the impulse rise time, the peak to peak voltage and, in the case of Type II systems, the impulse repetition rate. After installation of the converter/machine system, it is recommended that the drive system integrator measures the phase/phase and phase/ground voltages between the machine terminals and ground to check for compliance.

IEC 60034-18-41

The Type I systems are dealt with in this standard. They are generally used in rotating machines rated at 700 V r.m.s. or less and tend to have random wound windings. The procedures described here are directed at:

– Qualification of the insulation system.

– Type and routine testing of the complete windings of service machines.

Before undertaking any testing, the machine manufacturer shall decide upon the level of severity that the system will be required to withstand. The severity is based on how large the voltage overshoot and how short the impulse rise time will be at the machine terminals. The machine designer then makes a choice from a table in which the range of expected overshoot voltage is divided into bands. Testing is performed at the extreme value of each band. A default value of 0,3 μs is attributed to the impulse rise time. Other values of impulse rise time or voltage overshoot are dealt with as special cases.

In qualification testing, the insulation system is used to construct various representative test objects. These are subjected to the range of tests described in IEC 60034-18-21 or IEC 60034-18-31 with the addition of a high frequency voltage test and a partial discharge test. For the latter, it may be necessary to use impulse test equipment, as described in IEC/TS 61934. If the test object is partial discharge free under the specified test conditions at the end of the sequence of testing, the insulation system is qualified for the severity band that has been selected.

Type and optional routine tests are performed on complete windings to demonstrate that they are partial discharge free under sinewave or impulse voltage conditions (as appropriate) for the band of severity that the manufacturer has chosen. An impulse voltage insulation class is then assigned to the machine. A mechanism is described for dealing with special cases.

IEC/TS 60034-18-42

The tests for qualification and acceptance of electrical insulation systems chosen for Type II rotating electrical machines are described in this technical specification. These insulation systems are generally used in rotating machines and tend to have form-wound coils, mostly rated above 700 V r.m.s. The qualification procedure is completely different from that used for Type I insulation systems and involves destructive ageing of insulated test objects under accelerated conditions. The rotating machine manufacturer requires a life curve for the insulation system that can be interpreted to provide an estimate of life under the service conditions with converter drive. Great importance is attached to the qualification of any stress grading system that is used and testing here should be performed under repetitive impulse conditions. If the insulation system can be shown to provide an acceptable life under the appropriate ageing conditions, it is qualified for use. Acceptance testing is performed on coils made using this insulation system when subjected to a voltage endurance test.

Indian Standard

ROTATING ELETRICAL MACHINES

PART 18 PARTIAL DISCHARGE FREE ELECTRICAL INSULATION SYSTEMS TYPE I USED IN ROTATING ELECTRICAL MACHINES FED FROM VOLTAGE CONVERTERS

SECTION 41 QUALIFICATION AND QUALITY CONTROL TESTS

1 Scope

This part of IEC 60034 defines criteria for assessing the insulation system of stator/rotor windings which are subjected to voltage-source pulse-width-modulation (PWM) drives. It applies to stator/rotor windings of single or polyphase AC machines with insulation systems for converter operation.

It describes qualification tests and quality control (type and routine) tests on representative samples or on completed machines which verify fitness for operation with voltage source converters.

This standard does not apply to:

– rotating machines which are only started by converters;

– rotating electrical machines with rated voltage ≤ 300 V r.m.s.;

– rotor windings of rotating electrical machines operating at ≤ 200 V (peak).

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 60034-18-1:2010, *Rotating electrical machines – Part 18-1: Functional evaluation of insulation systems – General guidelines*

IEC 60034-18-21, *Rotating electrical machines – Part 18-21: Functional evaluation of insulation systems – Test procedures for wire-wound windings – Thermal evaluation and classification*

IEC 60034-18-31, *Rotating electrical machines – Part 18-31: Functional evaluation of insulation systems – Test procedures for form-wound windings – Thermal evaluation and classification of insulation systems used in rotating machines*

IEC/TS 60034-18-42, *Rotating electrical machines – Part 18-42: Qualification and acceptance tests for partial discharge resistant electrical insulation systems (Type II) used in rotating electrical machines fed from voltage converters*[1]

IEC/TS 60034-25:2007, *Rotating electrical machines – Part 25: Guidance for the design and performance of a.c. motors specifically designed for converter supply*

[1] This TS is in the process of being transformed into an IS.

IEC/TS 60034-27, *Rotating electrical machines – Part 27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines*

IEC 60172, *Test procedure for the determination of the temperature index of enamelled winding wires*

IEC 60664-1, *Insulation co-ordination for equipment within low voltage systems – Part 1: Principles, requirements and tests*

IEC/TS 61800-8, *Adjustable speed electrical power drive systems – Part 8: Specification of voltage on the power interface*

IEC/TS 61934, *Electrical insulating materials and systems – Electrical measurement of partial discharges (PD) under short rise time and repetitive voltage impulses*

3 Terms and definitions

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

3.1
partial discharge
PD
electric discharge that only partially bridges the insulation between electrical conductors

Note 1 to entry: It may occur inside the insulation or adjacent to an electrical conductor.

3.2
partial discharge inception voltage
PDIV
lowest voltage at which partial discharges are initiated in the test arrangement when the voltage applied to the test object is gradually increased from a lower value at which no such discharges are observed

Note 1 to entry: With sinusoidal applied voltage, the PDIV is defined as the r.m.s. value of the voltage. With impulse voltages, the PDIV is defined as the peak to peak voltage.

3.3
partial discharge extinction voltage
PDEV
voltage at which partial discharges are extinguished in the test arrangement when the voltage applied to the test object is gradually decreased from a higher value at which such discharges are observed

Note 1 to entry: With sinusoidal applied voltage, the PDEV is defined as the r.m.s. value of the voltage. With impulse voltages, the PDEV is defined as the peak to peak voltage.

3.4
peak (impulse) voltage
U_p
maximum numerical value of voltage reached during a unipolar voltage impulse (e.g. U_p in Figure 1)

Note 1 to entry: For bi-polar voltage impulses, it is half the peak to peak voltage (see Figure 2).

Note 2 to entry: The definition of peak to peak voltage is clarified in Clause 4.

3.5
steady state impulse voltage magnitude
U_a
final magnitude of the voltage impulse (see Figure 1)

3.6
voltage overshoot
U_b
magnitude of the peak voltage in excess of the steady state impulse voltage (see Figure 1)

3.7
peak to peak impulse voltage
$U'_{pk/pk}$
peak to peak voltage at the impulse repetition rate (see Figure 2)

3.8
peak to peak voltage
$U_{pk/pk}$
peak to peak voltage at the fundamental frequency (see Figure 2)

3.9
repetitive partial discharge inception voltage
RPDIV
minimum peak-to-peak impulse voltage at which more than five PD pulses occur on ten voltage impulses of the same polarity

Note 1 to entry: This is a mean value for the specified test time and a test arrangement where the voltage applied to the test object is gradually increased from a value at which no partial discharges can be detected.

3.10
unipolar impulse
voltage impulse, the polarity of which is either positive or negative

Note 1 to entry: The term impulse is used to describe the transient stressing voltage applied to the test object and the term pulse is used to describe the partial discharge signal.

3.11
bipolar impulse
voltage impulse, the polarity of which changes alternately from positive to negative or vice versa

3.12
impulse voltage repetition rate
f
inverse of the average time between two successive impulses of the same polarity, whether unipolar or bipolar

3.13
impulse rise time
t_r
time for the voltage to rise from 10 % to 90 % of its final value (see Figure 1)

3.14
electrical insulation system
insulating structure containing one or more electrical insulating materials together with associated conducting parts employed in an electrotechnical device

3.15
formette
special test model used for the evaluation of the electrical insulation systems for form-wound windings

3.16
motorette
special test model used for the evaluation of the electrical insulation systems of random-wound windings

3.17
(electric) stress
electric field in volts/mm

3.18
rated voltage
$\boldsymbol{U}_{\mathbf{N}}$
voltage assigned by the manufacturer for a specified power frequency operating condition of a machine and indicated on its rating plate

3.19
impulse voltage insulation class
IVIC
<for Type I insulation systems> peak to peak voltage classes A, B, C, D, S for reliable operation, assigned by the manufacturer in relation to the rated voltage for a specified converter-driven machine and indicated in its documentation and, if applicable, on its rating plate

3.20
fundamental frequency
first frequency, in the spectrum obtained from a Fourier transform of a periodic time function, to which all the frequencies of the spectrum are referred.

Note 1 to entry: For the purposes of this standard, the fundamental frequency of the machine terminal voltage is the one defining the speed of the converter fed machine.

3.21
impulse duration
impulse width
interval of time between the first and last instants at which the instantaneous value of an impulse reaches a specified fraction of its impulse magnitude or a specified threshold.

3.22
jump voltage
$\boldsymbol{U}_{\mathbf{j}}$
change in voltage at the terminals of the machine occurring at the start of each impulse when fed from a converter (see Figure 3)

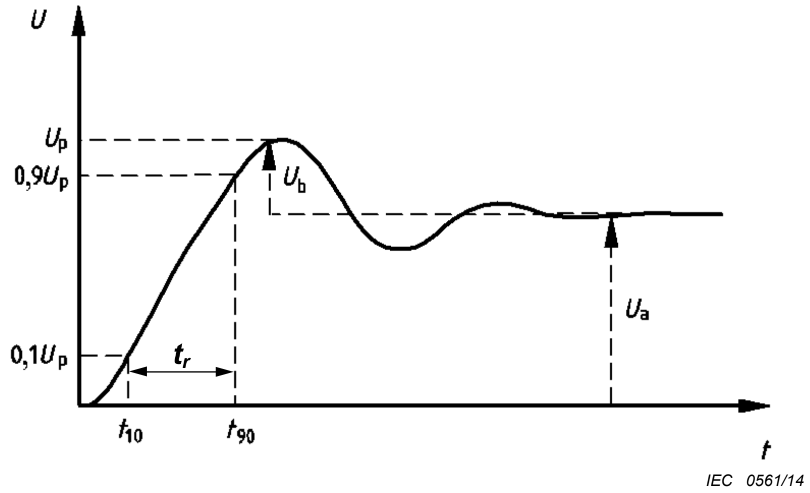
3.23
DC bus voltage
$\boldsymbol{U}_{\mathbf{dc}}$
voltage of the intermediate circuit of the voltage converter (dc-link-circuit)

Note 1 to entry: For a two level converter U_{dc} is equal to U_a in Figure 1.

Note 2 to entry: For a multilevel converter, U_{dc} is equal to ½ Upk/pk minus the overshoot in Figure 2.

3.24
overshoot factor
ratio of the voltage appearing at the machine terminals and the voltage at the converter for each converter level

3.25
power drive system
complete drive module and rotating machine together with the connecting cable if necessary



Key

U voltage
t time

Figure 1 – Voltage impulse waveshape parameters

3.26
maximum allowable terminal voltage
U_{IVIC}
maximum allowable peak to peak phase to ground voltage in service, according to the IVIC specification

3.27
test voltage factor
TVF
maximum allowable peak to peak phase to ground voltage in service in units of U_N, divided by $2\sqrt{2}$

4 Machine terminal voltages arising from converter operation

Modern converter output voltage rise times may be in the 0,05 μs – 2,0 μs range due to power semiconductor switching characteristics. The voltage appearing at the terminals of a converter driven machine may be calculated using IEC/TS 61800-8 and depends upon several characteristics of the power drive system, such as,

a) operating line voltage of the converter;
b) architecture and control regime of the converter;
c) filters between the converter and machine;
d) length and type of cable between them;
e) design of the machine winding;
f) design and configuration of the installation.

In order to apply this Standard to the qualification and testing of the insulation system of a winding, it is necessary to specify the required parameters of the voltage appearing at the machine terminals (Clause 7).

The amplitude and rise time of the voltage at the machine terminals depend upon the grounding system, various design aspects of the cable, the machine surge impedance and the presence of any filters that increase the impulse rise time. Common ranges of characteristics of converter impulses at the machine terminals are given in Table 1.

Table 1 – Common ranges of characteristics of the terminal voltages of converter fed machines

Characteristics	Range of values (depending on ratings, characteristics and service conditions of the drive system)
Peak/peak voltage	0,5 kV – 7 kV
Impulse rise time	0,05 µs – 2,0 µs
Impulse voltage repetition rate	100 Hz – 20 000 Hz
Impulse duration	10 µs – 10 000 µs
Shape	Rectangular
Polarity	Unipolar or bipolar
Fundamental frequency	5 Hz – 1 000 Hz
Mean time between impulses	≥ 0,6 µs

For the purpose of this standard, the symbols in Table 2 are used.

Table 2 – Definition of symbols

Symbol	Parameter	Units	Type of feed
U_{line}	Phase to phase (rated) voltage	V r.m.s.	Line
U_{phase}	Phase to neutral voltage	V r.m.s.	Line
$U_{max} = \sqrt{2}\,U_{phase}$	Maximum phase/neutral voltage	V	Line
$U_{pk/pk}$	Peak to peak voltage	V	Converter
U_{dc}	DC bus voltage	V	Converter

In the case of 2-level or other U converters, depending on the rise time of the voltage impulse at the converter output and on the cable length and machine impedance, the impulses generate voltage overshoots at the machine terminals (typically U_p up to $2U_{dc}$ between phases). The voltage overshoot is created by reflected waves at the interface between cable and machine or converter terminals due to surge impedance mismatch. It is fully explained by transmission line and travelling wave theory.

Figure 2 shows the voltage that appears (during one period at the fundamental frequency) at the machine terminals when fed from a 3-level converter.

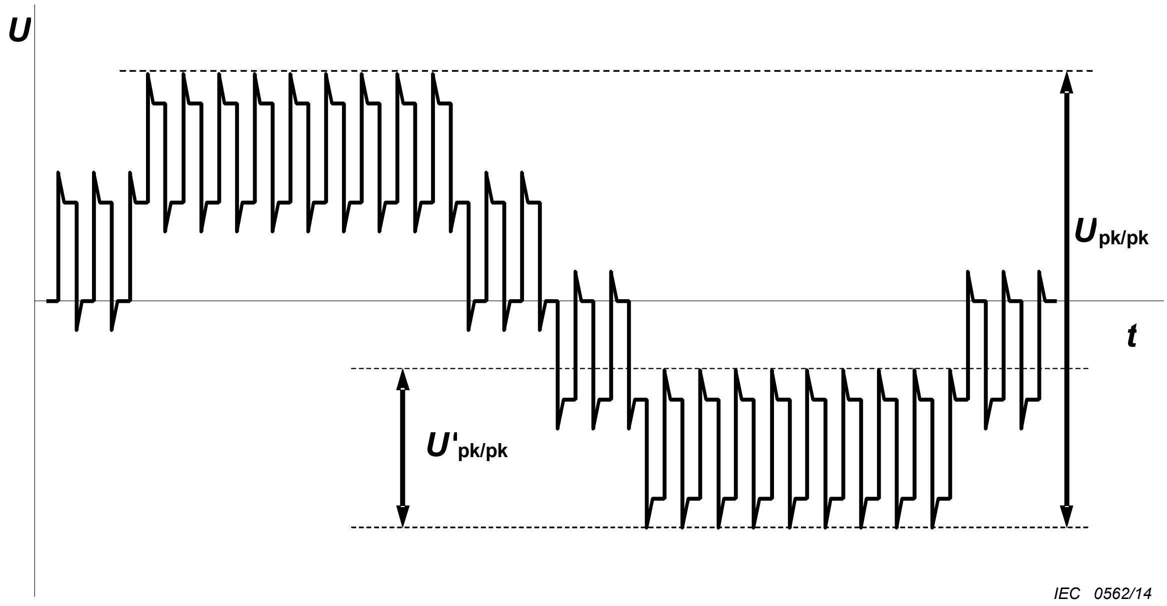


Figure 2 – Five step phase to phase voltage at the terminals of a machine fed by a 3-level converter

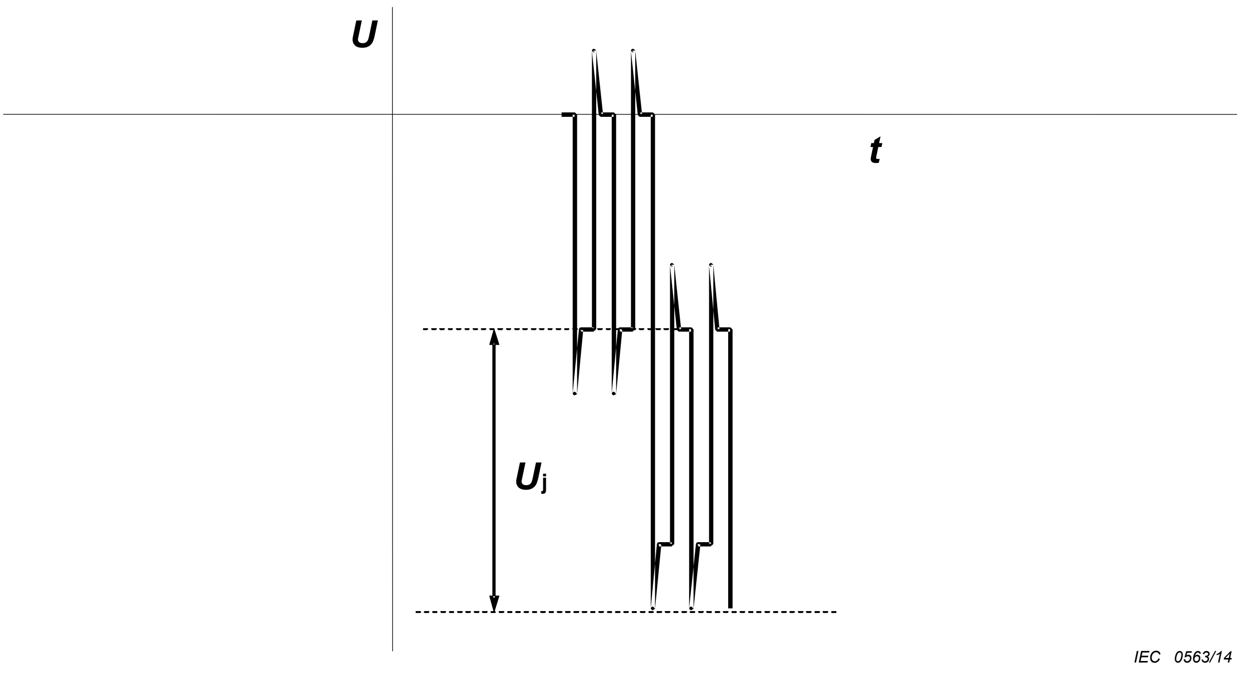


Figure 3 – Jump voltage (U_j) at the machine terminals associated with a converter drive

The maximum change in voltage, U_j, at the impulse frequency is shown in Figure 3. This parameter is important in defining the voltage enhancement that can occur across the first or last coil in the winding. A double jump transition is possible but it is the duty of the drive system integrator to ensure that the software controlling the converter drive prevents this from happening.

For an “n” level converter, the phase/phase voltage can be estimated as follows:

Peak/peak fundamental frequency voltage = $2(U_{dc} + U_b)$ (1)

Peak/peak impulse frequency voltage = $U_{dc}/(n-1) + 2U_b$

The phase/ground values are estimated as follows:

Peak/peak fundamental frequency voltage = $0,7 \times 2(U_{dc} + U_b)$ (2)

Peak/peak impulse frequency voltage = $0,7(U_{dc}/(n-1) + 2U_b)$

The jump voltage is given by $0,7(U_{dc}/(n-1) + U_b)$ (3)

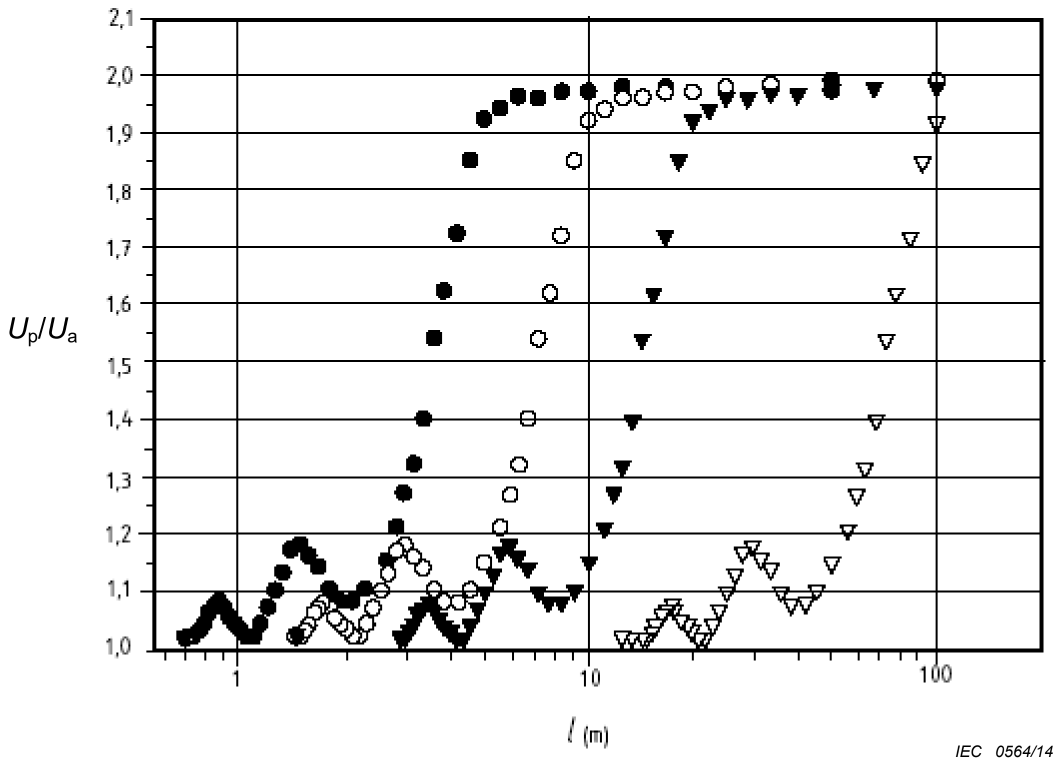
The proportion of jump voltage appearing across the first turn is obtained from Figure 7.

The value of U_b in these formulae is the value shown in Figure 1 for the phase/phase voltage on the machine terminals. The values of the phase/ground voltages estimated from these formulae may be higher or lower in practice, depending upon the grounding system, converter control regime and other factors. It is known that a sudden rise can occur in the machine ground voltage level with respect to the d.c. zero point in the converter. The theoretical rise is determined capacitively to be 1/3 which gives a residual effect of about 0,7. This would apply to simple systems where only travelling wave theory determines the factor, i.e. stress categories A, B and C (see Clause 7).

Examples of the enhancement that is produced for various rise times and cable lengths in the case of a motor driven from a converter are given in Figure 4. In this case, the enhancement to the voltage for an impulse rise time of 1,0 µs is insignificant below about 15 m and only exceeds 1,2 when the cable length is greater than about 50 m.

Voltages above $2U_{dc}$ can be produced at the terminals of the machine by drive double transition and by a converter fed drive algorithm that does not allow a minimum time between successive pulses. Double transition occurs, for example, when one phase switches from minus to plus d.c. bus voltage at the same instant that another phase switches from plus to minus. This generates a $2U_{dc}$ voltage wave which travels to the machine and can then increase in magnitude when reflected at the machine terminals. If there is no minimum impulse time control in the drive and if the time between two impulses is matched with the time constant of the cable between the converter and the machine, an over voltage $>2U_{dc}$ can be generated at the machine terminals. The reflection can be reduced or prevented by using a filter in the converter, at the machine terminals or both.

In the event of an earth fault on one of the phases of a system where the neutral star point is not grounded, the machine may be permitted by the manufacturer to run for a period of several hours until a suitable outage can be arranged for repairs. In this case, the voltage stress on the turn to ground insulation in the other phases will increase.



Key

t_r = 0,05 µs t_r = 0,1 µ t_r = 0,2 µs ∇ t_r = 1,0 µs

l (m) cable length

U_p/U_a ratio of peak voltages at the machine and at the converter terminals

Figure 4 – Voltage enhancement at the terminals of a motor due to reflection as a function of cable length for various impulse rise times

5 Electrical stresses in the insulation system of machine windings

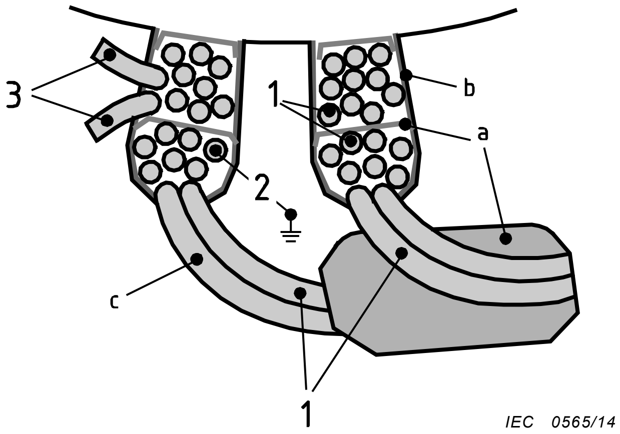
5.1 General

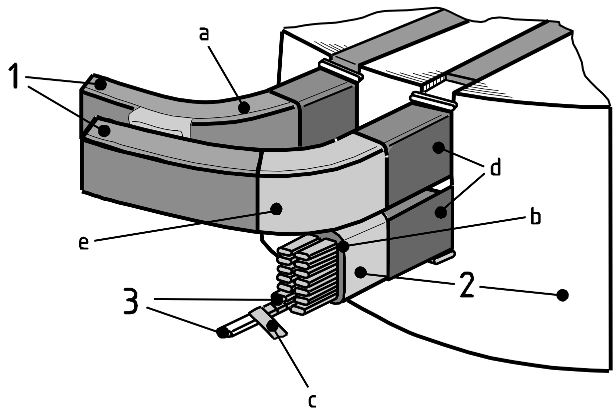
If a winding experiences short rise time voltage impulses of significant magnitude, high voltage stresses will be created, for example, in the following locations (Figures 5 and 6):

- between conductors in different phases,
- between a conductor and ground,
- between adjacent turns in the line-end coil.

Due to space and surface charge creation within the insulation components, the electric stress is not only defined by the instantaneous voltage itself but also by the peak voltages that have been stressing the insulation previously. Generally, it has been shown by experience that, within certain limits valid for drive systems, the stressing parameter is the peak/peak voltage. This is also the reason why a unipolar voltage produces the same stress as a bi-polar voltage having a peak/peak voltage of the same value [1][2].

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





Key

a	phase insulation / overhang insulation	1	phase to phase
b	mainwall insulation	2	phase to ground
c	turn insulation	3	turn to turn
d	slot corona protection		
e	overhang corona protection (stress grading)		

Figure 5 – Example of a random wound design **Figure 6 – Example of a form-wound design**

5.2 Voltages stressing the phase/phase insulation

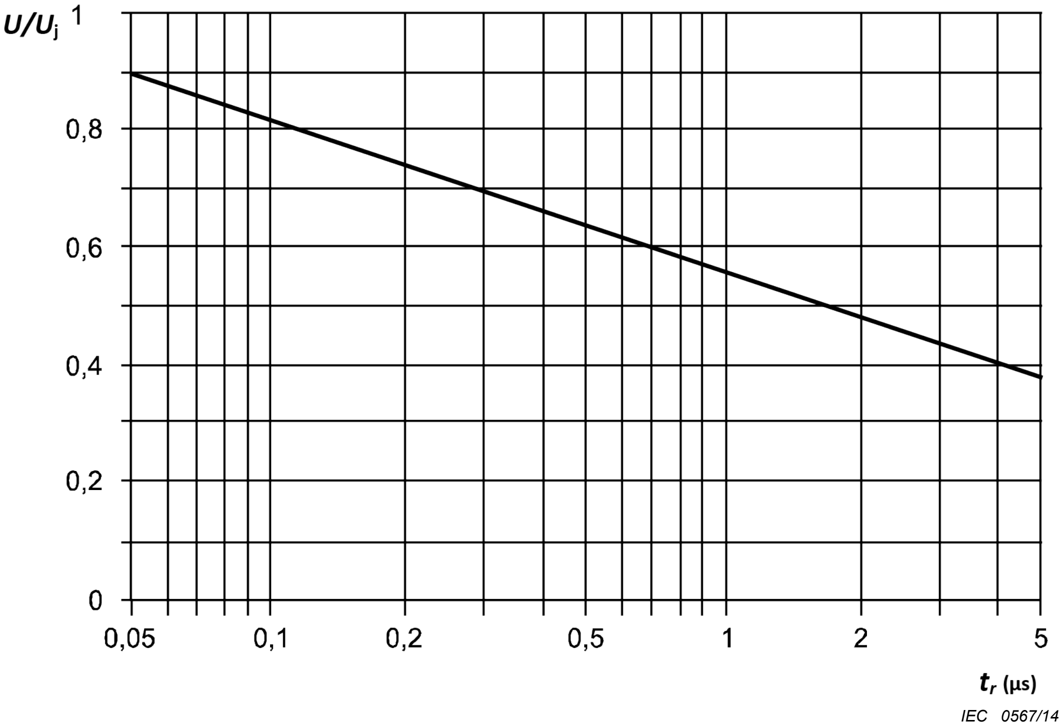
The maximum voltage stress on the phase/phase insulation is determined by the design of the winding and by the characteristics of the phase/phase voltage.

5.3 Voltages stressing the phase/ground insulation

The maximum voltage stress on the phase/ground insulation is determined by the design of the winding and by the characteristics of the phase/ground voltage.

5.4 Voltages stressing the turn and strand insulation

The electrical stress within the winding insulation is determined by the jump value of the phase/ground voltage and the impulse rise time of this voltage at the machine terminals. For random windings, the distribution of the transient voltage depends upon the relative position of the individual turns in the slots. Short rise time impulses result in the voltage being unevenly distributed throughout the coils, with high levels of stress present across the first turn or turns (depending upon the winding design) of the individual winding phase. In practice, the first and last turn can be adjacent to each other, in which case the turn/turn voltage can be almost equal to the voltage drop across the coil. Figure 7 shows the worst case voltage stressing the turn-to-turn-insulation in a variety of stators as a function of impulse rise time. The voltage is shown as a proportion of the phase/ground jump voltage. The data has been obtained from a combination of figures provided in References [2], [3] and [4]. If the distribution of voltage within the coils as a function of rise time is known by the manufacturer for a particular design of rotating machine, the data may be used to calculate the fraction of jump voltage stressing the interturn insulation in the worst case instead of Figure 7. This is referred to in Table B.6. The jump voltage occurs at both the rising and falling edges of the phase/ground voltage. The turn/turn voltage experiences the same effect at each edge where there is either a positive or a negative peak (See Clause B.4.).



Key

U/U_j Fraction of jump voltage stressing the turn/turn insulation

t_r Impulse rise time

NOTE 1,0 is the peak phase/ground jump voltage at the machine terminals.

Figure 7 – Worst case voltage stressing the turn/turn insulation in a variety of random wound stators as a function of the rise time of the impulse

5.5 Mechanisms of insulation degradation

In a low voltage, random or form-wound winding, the conductor insulation has a small thickness and there is often some air surrounding the wire. Additionally, in a random wound winding the first and last turns of one or more coils may be adjacent. With sufficient electric stress between turns, or to ground or to another phase, the air between the wires or to ground may experience electrical breakdown (that is, a spark) in the air. Since the insulation itself does not break down, this spark is called a partial discharge (PD). The electrons and ions created by the discharge in air bombard the wire, ground or phase insulation. In random wound windings, conventional wire insulation is a thin organic film. This film is eventually eroded by the PD, leading to insulation failure and a shorted coil. Pitting of the wire insulation and white powders are typical observable indications that PD has occurred in service. The ground insulation of high voltage windings may be attacked by PD but the designer can allow for the presence of partial discharges by incorporating materials that are resistant to deterioration by them.

A further factor which may influence the life of the insulation is the effect upon dielectric heating of the higher frequencies associated with the converter waveform. If the coils have slot corona protection and stress grading, high frequency currents in this material, caused by the drive, can lead to overheating and deterioration. Both the repetition frequency and the frequency associated with the rise time of the leading edge will create extra heating through the dielectric losses in the insulation materials. The most critical regions are the main wall insulation, the turn/turn insulation and phase to phase insulation.

6 Types of machine insulation

Two types of winding insulation are defined in IEC 60034-18-41 and IEC 60034-18-42. Type I winding insulation (Figure 5) is not expected to experience PD activity during its life in any parts of its electrical insulation. Type II winding insulation (Figure 6) is likely to have to withstand PD during its life in some part of its electrical insulation and should therefore contain materials that resist PD. Machines with a rated voltage ≤ 700 V r.m.s. may have either Type I or Type II winding insulation. Above 700 V r.m.s., the winding insulation is usually Type II. Manufacturers typically assign a rated voltage to a machine based on power frequency. This assumes that voltage from the power supply is 50 Hz or 60 Hz sinusoidal. In the case of machines driven from converters, the conventional definition of voltage rating is no longer applicable for the insulation system of the winding, although the manufacturer may still assign a rated voltage for 50 Hz/60 Hz operation and put it on the rating plate of the machine. In order to address this problem, a new definition of impulse voltage insulation class is introduced. This is to be specified additionally in the documentation and on the rating plate as described in Annex C. The insulation classification of Type I is determined by the absence of partial discharges in service or when subjected to the test procedures described in this standard.

7 Stress categories for Type I insulation systems used in converter fed machines

In order to achieve sufficient reliability of the power drive systems, the electrical stress and the strength of its machine winding insulation systems need to be co-ordinated. Either:

- a system supplier takes responsibility for this co-ordination if he supplies a complete power drive system and thereby ensures component compatibility, or
- the drive system integrator shall specify to the machine designer the voltages that will appear at the machine terminals, to ensure its fitness for this purpose, or
- the machine manufacturer shall indicate the voltages for which the winding insulation system has been designed to operate reliably under specific converter conditions.

This information should be included in the purchase specification or in the offer documentation of the manufacturer, in addition to the traditional features such as rated voltage, thermal class, humidity, etc. Providing all the necessary information on the machine, converter and connecting cable is available, the characteristics of the voltages seen at the machine terminals may be calculated using the methodology described in IEC/TS 61800-8. Specifically, the limiting values shall be defined for the following parameters of the voltage that appear at the machine terminals. Repetition frequency is not considered a critical parameter in the qualification of Type I insulation systems.

a) The peak impulse voltage (0 to peak) that is expected to occur at the machine terminals (U_p for a 2-level converter as in Figure 1).

b) The rise time, t_r, of the impulses.

Table 3 gives an indication of the degree to which the components of a Type I insulation system are affected by each of these features of the converter waveform. Note that the critical influence on turn/turn insulation is a combination of impulse rise time and the jump in impulse voltage which takes place, ΔV.

Table 3 – Influence of features of the machine terminal voltage on components of Type I insulation systems

Insulation component	Fundamental frequency	Impulse voltage repetition rate	Peak/peak impulse voltage (Fundamental frequency)	Peak/peak impulse voltage (Impulse voltage repetition rate)	Jump voltage	Impulse rise time
Turn to turn insulation						
Main wall insulation						
Phase/phase insulation						
NOTE Less significant More significant						

Experience has shown that there are only a few combinations of voltage overshoot and impulse rise time which are required in practice to satisfy most applications. There are four overshoot stress categories (Table 4). For the rise time, a default value of 0,3 µs is specified. While the categories are partly arbitrary in nature, they help to qualify insulation systems for converter operation in voltage classes, similar to the qualification of insulation systems for temperature classes, according to IEC 60034-18-21 and IEC 60034-18-31. Where the application of the machine is unknown, a stress category C is recommended. The treatment of special cases is described in Clause C.2.

Table 4 – Stress categories for Type I insulation systems based on a 2-level converter

Stress category	Overshoot factor (OF) U_p/U_a	Impulse rise time t_r µs
A – Benign	OF ≤ 1,1	0,3
B – Moderate	1,1 < OF ≤ 1,5	
C – Severe	1,5 < OF ≤ 2,0	
D – Extreme	2,0 < OF ≤ 2,5	

The benign level of overshoot factor given in Table 4 relates to the case of a converter directly connected to the machine or through a short cable. However, it is recognised that in practice a theoretical value of 1,0 for U_p/U_{dc} cannot generally be met as it would require there to be no overshoot at all in the voltage appearing at the machine terminals. In order to allow for this practical consideration, the value for stress category A has been raised by 10 % to 1,10. The value of 2,0 arises from the condition for a converter connected to the machine through a long cable. The band from 1,1 to 2,0 has been split into two parts for practical purposes. A limit of 2,5 has been applied to the most extreme conditions likely to be experienced in service. Examples of when this may arise are if regenerative breaking can occur or in specific crane applications where the earthing arrangement of the converter may introduce oscillations in the grounding of the converter signal when a single d.c. system is driving several converters in an extended complex drive system [2]. In Table A.1, the use of these factors is demonstrated in the calculation of maximum peak voltages for various overshoot factors.

The qualification and type testing for a particular combination of stress categories should be performed at the most severe value for the overshoot factor. The tolerance in the value of the rise time is specified in Clause B.2.

8 Design qualification and type tests for Type I insulation systems

8.1 General

There are two stages to the testing of electrical insulation for machines to be fed from converter drives. The first stage is qualification of the materials, insulation system design and manufacturing technique. For Type I insulation systems, it is carried out using motorettes or formettes that undergo thermal cycling and conditioning procedures which include mechanical vibration, moisture exposure and high voltage. Diagnostic tests are performed on these samples and also on complete windings with the aim of assessing the absence of PD. The second stage is a type test performed on the complete winding or machine.

On the basis of these qualification and type test results, a machine is assigned an impulse voltage insulation class, which defines the maximum allowable voltage in units of U_N stressing the parts of the insulation system in converter-fed service (see Annex C).

8.2 Design qualification test

For the purposes of this standard, a qualification test is used to investigate the capability to withstand various stresses. For Type I insulation systems, it is based on PDIV tests before and after thermal cycling and other tests as defined in IEC 60034-18-21 and IEC 60034-18-31, as well as voltage stressing at one of the stress category levels defined in Clause 7, with the voltage increased by the appropriate enhancement factor described in Clause B.3. It is only necessary to perform thermal ageing at any one of the three ageing temperatures specified in IEC 60034-18-21 or IEC 60034-18-31 if the thermal class for the insulation system has already been determined through testing according to these two standards.

8.3 Type test

In the case of Type I insulation systems, PD tests are undertaken to demonstrate the absence of partial discharges [5][6]. The complete winding or machine is subjected to the voltage appropriate to the selected stress category (Table 4), enhanced by a factor (Table B.2). For example, if the application is for a machine which is to be driven by a voltage where the overshoot factor at the terminals is 1,3 (moderate) the stress factors to be used in calculating the test voltage are 1,5 (overshoot) and 0,3 μs (rise time see Clause B.1).

9 Test equipment

9.1 PD measurement at power frequency

A conventional laboratory PD measurement device, using either a high voltage coupling capacitor or a radio frequency current transformer, can be used when the applied voltage to the test object is a sinusoidal 50 Hz or 60 Hz waveform. Details of the test equipment and methods are presented in IEC/TS 60034-27. Use of 50 Hz or 60 Hz applied voltages together with the PD test method described in IEC/TS 60034-27 should be reserved for capacitive test objects such as individual coils, formettes and motorettes.

9.2 PD measurement during voltage impulses

Conventional PD test devices for use with 50 Hz/60 Hz voltages, such as described in IEC/TS 60034-27, cannot generally be used when the applied voltage is a short rise time voltage impulse. A rise time of 0,1 μs has a harmonic content with frequencies of more than 3 MHz. This means that the voltage impulse will have components within the pass band of most IEC/TS 60034-27 style detectors, resulting in a displayed signal that may be hundreds of times the magnitude of the partial discharge pulses. For this reason, it is important to ensure that the partial discharge pulses are distinguished from the high frequency components of the voltage impulses. In addition, the voltage impulses may be of sufficiently high magnitude to destroy the electronics of the partial discharge detector.

To distinguish the partial discharges from the short rise time components of the voltage impulses, a different type of PD detector is needed. The detector should reduce all frequency components from the impulse voltage to less than the high frequency components associated with the partial discharges. The display can be a standard oscilloscope or a pulse magnitude analyser. Guidance is given in IEC/TS 61934 on the method and equipment to be used. It is essential that the PD caused by short rise time impulses are separated from any residue of the impulse voltage. Note that PD remote from the PD sensor may not be detected.

9.3 Voltage impulse generators

Partial discharge tests under impulse voltage conditions require an impulse generator. To simulate properly the impulses for the relevant stress category, the voltage impulse generator should be capable of producing a rise time that is equal to 0,3 μs ± 0,2 μs. A larger tolerance may be acceptable for high capacitance windings (see Clause B.2). The impulse generator should have a controllable output magnitude from zero volt to the highest voltage required for the winding voltage rating. When reporting results, the following shall be provided.

a) The PD sensitivity level, background noise level and detection system noise level as defined in IEC/TS 61934.
b) The applied impulse voltage under load (test object) and confirmation of compliance with Figures B.1 and B.2.
c) A photographic or digital record of the impulse waveform at the machine terminals.
d) The presence or absence of the rotor for tests on complete stator windings.

Reporting of the peak/peak voltage of the impulse generator output and whether it is unipolar or bipolar is advisable.

9.4 Sensitivity

In general, the sensitivity of a partial discharge detector falls as the impedance of the load decreases (or its capacitance increases). As a guide, the sensitivity expected for qualification and type tests covered in this standard should be 1 pC per nF of capacitive load at 50 Hz/60 Hz, with a minimum sensitivity of 1 pC. A measurement system capable of achieving this degree of sensitivity is considered to be sufficiently sensitive to undertake PD tests on inductive loads when equating impedances.

9.5 PD tests

9.5.1 Power frequency voltage

For the purpose of this standard, partial discharge freedom is defined as being less than 5 pC for turn/turn samples and for motorettes and formettes when measurements are made at 50 Hz/60 Hz. These values are also the maximum noise levels permitted during measurements. The PD test is performed according to the procedures in IEC/TS 60034-27.

9.5.2 Impulse excitation

PD tests with impulse voltages are performed according to IEC/TS 61934. The background noise level is given in mV. This background noise level and the sensitivity according to IEC/TS 61934 shall be reported.

10 Qualification of the design of Type I insulation systems

10.1 General

For Type I systems, tests are not carried out to achieve failure by electrical breakdown. The test samples are subjected to thermal and mechanical cycling as described in IEC 60034-18-21 and IEC 60034-18-31 together with various electrical withstand tests. After each sub-cycle, the test objects are given a partial discharge diagnostic test and the end of test occurs when the PD inception voltage falls below the specified test voltage for the chosen stress category.

Qualification is by comparison with the performance of a reference system as defined in 4.3 of IEC 60034-18-1:2010 which has been qualified under the conditions in 10.4. The candidate shall endure the same, or more, ageing cycles than the reference system without PD occurring below the specified test value. The inception voltage is the lowest voltage at which partial discharges can be detected. In the case of power frequency, measurements are made according to IEC/TS 60034-27, within the limit of sensitivity described in 9.4. In the case of the PD measurement by impulse voltage, tests are performed according to IEC/TS 61934, which describes the sensitivity checks and reporting requirements.

Successful service experience may have enabled a manufacturer to assign a stress category to a machine using a specific design of insulation system. In this case and with the agreement of the purchaser, this experience may be used as an alternative way to qualify the insulation system for converter-fed applications.

10.2 Approach

10.2.1 General

Type I insulation systems are intended for use in the absence of partial discharge activity throughout their lifetime. It is essential to measure whether partial discharge occurs at the specified test voltage (see Clause B.6). The allowable voltage waveshapes for the different insulation system components are shown in Table 5 and Figures B.1 and B.2. The test samples are to be made using the materials and manufacturing methods applicable to production. They may represent either part of the insulation system or the insulation system in total.

10.2.2 Twisted pair or equivalent arrangement

Twisted pairs or parallel adjacent conductors, in the case of flat wires, may be used for testing turn/turn behaviour in order to establish the voltage stress level to be used between parallel conductors during the motorette/formette test. Sine and impulse voltages are assumed to give equivalent results in terms of PD inception voltage because the voltage distribution experienced in a complete winding is not represented. Consequently, either voltage waveform may be used in testing for PD inception. The voltage stress shall be raised above the average stress per turn expected in service to account for the stress concentration described in 5.4. The test levels specified in Annex B are peak/peak.

10.2.3 Motorette (random wound) or formette (form-wound)

These models may be used to represent phase/phase and phase/ground insulation. Turn/turn insulation may also be represented by the use of parallel conductors, when sinewave voltage may be used. This model arrangement should be tested according to Table 5. The applied voltages stressing the model insulation components should reproduce the voltage stresses occurring within the complete machine in service.

10.2.4 Complete windings

This allows phase/phase and phase/ground insulation to be tested. Turn/turn insulation in conventional windings should be tested by the use of impulse voltage. The advantage of an impulse wave shape for testing is that all areas of the winding can be stressed in a representative way, even if the star point is connected. Nevertheless, it is important to take account of the voltage distribution within the winding. Tests should be performed on impregnated samples where the service machine is to have impregnated windings.

When the test object is a complete winding and the capacitance between the winding and ground is large, the rise time of the impulse voltage applied to the test object may become longer than the original rise time of the impulse generator. This phenomenon may occur when the impulse generator cannot provide enough capacitive current for the test object to generate a steep-fronted voltage rise. It may be overcome by improvements to the current capacity and output impedance of the impulse generator. In recognition of the difficulty in achieving the required rise time when testing large machines using commercially available impulse generators, the tolerance on the rise time of the waveform is relaxed for larger machines as described in Clause B.2.

Sinewave testing of PD activity is allowed if a special winding is prepared in which pairs of wires are used and the maximum voltage that is expected to develop across two neighbouring turns is applied between them. The occasions where sinewave or impulse voltage shall be used are given in Table 5.

Table 5 – Allowable voltage waveforms for testing system components

Component to be tested	Design qualification tests				Type test	
	Twisted pair or equivalent		Motorette or formette or complete winding		Complete winding	
	Sine	Impulse	Sine	Impulse	Sine	Impulse
Turn/turn	✓	✓	*	✓	*	✓
Phase/phase	No	No	✓	✓	✓	✓
Phase/ground	No	No	✓	✓	✓	✓

* A special test winding is required in which the turn/turn insulation is simulated by at least two electrically isolated conductors wound in parallel, one of which is grounded and the other is energised.

10.3 Preparation of test objects

10.3.1 General

The test samples should be as close as possible to the designs described in IEC 60034-18-21 for random wound samples and IEC 60034-18-31 for form-wound samples or to the production winding.

10.3.2 Turn/turn insulation samples

In the turn/turn test, the PDIV or RPDIV is measured on a simple twisted pair sample (see IEC 60172) or equivalent arrangement. This test may be the basis for establishing the voltage stress level to be used between parallel conductors during the motorette/formette test.

Partial discharge tests on impregnated twisted pair samples may not be used to assess the impregnation resin and manufacturing route used in motorettes or formettes or a complete winding. For that evaluation, only motorettes/formettes or complete windings are allowed.

10.3.3 Motorette/formette test samples or complete windings

The samples are made using the same materials and processes that are applied to service coils. Where phase/phase insulation is to be used, as in the case of two coils of different phases occupying the same slot, the model or complete winding shall reproduce this design feature. Tests should be performed on impregnated samples where the service machine is to have impregnated windings. The phase-to-phase and main wall insulation should replicate all creepage distances and clearances (phase to phase) found within the production winding. The samples should replicate production insulating materials and thicknesses for each type of insulation to be tested. In the case of testing with complete windings, the procedures given in 11.2 and 11.3 shall be followed.

10.4 Design qualification tests

10.4.1 General

The aim is to perform thermal ageing tests on the components and related parts of the insulation system, according to IEC 60034-18-21 or IEC 60034-18-31, and to determine at what point PD inception occurs below the specified test voltage. The stress category for which the system is to be qualified (Clause 7), the ageing procedure and diagnostic data shall be reported at the conclusion of the test. The candidate insulation system design is deemed to be qualified if it endures the same or more ageing cycles (without the PD inception occurring below the specified test values) than a reference system with proven service experience. There shall be at least five samples on which PD tests are performed in order to achieve a statistically valid outcome to the test, except in the case of complete windings where one sample is adequate.

10.4.2 Pre-diagnostic tests

A pre-diagnostic electrical ageing test shall be undertaken for 24 h at ambient temperature in which an elevated frequency is applied, with the voltage appropriate for the chosen stress category enhanced by a factor according to Table B.2. The purpose of this test is to detect at an early stage the presence of any dielectric materials which have high loss tangent and, although performing satisfactorily at power frequencies, may result in overheating at the higher frequencies encountered during converter operation. The choice of frequency is determined by the maximum impulse voltage repetition rate expected in service.

10.4.3 Diagnostic tests

Diagnostic tests shall be performed on samples prior to the first ageing cycle and after each ageing sub-cycle as follows. Each electrical diagnostic test shall be performed on each coil of each motorette/formette or winding component. In addition to the diagnostic tests specified in IEC 60034-18-21 or IEC 60034-18-31, a PD test shall be undertaken to check whether PD inception has occurred at the specified test level (Table 4 and Clause B.1).

10.4.4 Ageing cycle

The appropriate thermal ageing sub-cycles specified in IEC 60034-18-21 or IEC 60034-18-31 should be applied to the test samples in order to qualify the systems for the required thermal class. If the thermal class for the insulation system under test has already been determined through testing according to IEC 60034-18-21 and IEC 60034-18-31, it is only necessary to perform ageing at one of the appropriate temperatures. The specified diagnostic sub-cycles in IEC 60034-18-21 and IEC 60034-18-31 shall also be applied. These shall include the mechanical, moisture and voltage tests. It should be noted that moisture may affect the PD test results. For this reason, the moisture test shall be performed at a different stage of the procedure so that the PD test at the end does not follow it immediately.

10.4.5 PD tests

With regard to the PD tests, they should be undertaken:

a) Phase/phase.

b) Phase/ground.

c) Turn/turn.

It is only necessary for the voltage in the PD test to be raised to the test value and to ensure that PD inception has not taken place. It is not necessary for the inception voltage to be measured. During these tests, all sensors embedded within the winding shall be connected electrically to the stator core.

For the phase/ground insulation, the test shall be performed at each phase terminal to ground consecutively, with the other phase terminals and the core grounded. For phase/phase insulation, the test voltage should be applied in turn between each terminal and the other two with the core floating. In the case of sinewave AC voltage application, it will be necessary to disconnect each phase winding before this test. Each of the three possible combinations shall be tested in turn. The turn/turn test may be undertaken with sinewave AC voltage when parallel conductors are used. Otherwise, the voltage stress between turns is generated by means of impulse voltage test equipment. It will be necessary to detect the partial discharge activity during these tests with measuring equipment capable of operating under impulse conditions (see IEC/TS 61934).

A visual inspection of the test samples to observe the condition of the insulation materials should be performed and reported but this is not an end-point criterion for evaluation.

10.5 Pass criterion for the design qualification test

The pass criterion for qualification of a Type I test sample is that partial discharge inception is above the operating voltage for the selected stress category voltage (Tables B.3 and B.4), multiplied by an enhancement factor (Table B.2), with testing performed on samples which have had thermal ageing. The candidate system shall endure the same or more ageing cycles than the reference system without the PD inception occurring below the specified value. An example of how to calculate the test voltage is described in Clause B.6.

Where partial discharge tests are performed under impulse conditions, the impulse voltage shall conform to the requirements described in Clause B.2.

11 Type test procedure for Type I insulation systems

11.1 General

The type tests are performed on a complete winding or machine. Acceptance is achieved through a series of tests in which the PD inception voltage shall exceed specified values. Tests are performed under impulse conditions or at power frequency, according to Table 5. If the design qualification testing has been performed successfully on a complete winding, the insulation system has effectively passed its type test and no additional type test is required.

The testing with sinusoidal voltage at power frequency when all phases can be separated is more easily performed and leads to conservative test results. The impulse testing is a more realistic representation of the expected stress under converter. In addition, an impulsive voltage waveform as close as possible to the real one provided by the converter shall be available for the test. It shall in any case conform to Figures B.1 and B.2a. The results may differ due to the different test voltage distributions within the winding under test [2].

For sinewave testing, PD inception is recognised when there is at least 1 pulse detected per cycle. For impulse testing, the equivalent test is for there to be at least one pulse detected during all the impulses which occur in one fundamental operating cycle.

Partial discharge testing is performed at the maximum peak/peak operating voltage multiplied by an enhancement factor. An example of how to calculate the test voltage is described in Clause B.6. The temperature of the winding shall be 20 °C ± 10 °C. This test is performed by agreement between the purchaser and manufacturer.

11.2 Power frequency PD tests

The complete winding is first of all subjected to partial discharge tests at 50 Hz/60 Hz as follows. The operating voltage levels given in Table B.3 are increased by the relevant enhancement factor in Table B.2. If the partial discharge inception voltage is below the test voltage, the winding has failed.

a) A phase/ground PD test is performed between all the phase terminals and the core. It is not necessary to disconnect any windings.

b) A phase/phase PD test is performed with the core floating and the star point disconnected. For delta windings, all the phases should be disconnected and the core floating. If the star/delta point cannot be disconnected to isolate the phases, impulse testing shall be used.

11.3 Impulse PD tests

Impulse testing is more representative of service [4][5][6]. The impulse shape may influence the test result and therefore an impulsive voltage waveform as close as possible to the one provided by the converter in service shall be used for the test. If the repetitive partial discharge inception voltage is below the specified test voltage, the winding has failed.

a) Perform a phase/ground PD test with impulse voltage having the expected rise time from the converter and with the specified waveform according to Figure B.2. The rise time can be longer than the specified one as it is less significant according to Table 3. With a longer rise time, overstressing of the turn/turn insulation is reduced. The test should be performed at each phase terminal to ground consecutively, with the other phase terminals and the core grounded. Note that the impulse test voltage is applied not only to the phase/ground insulation but also to the phase/phase insulation. Therefore, if the specified phase/ground test voltage is higher than the phase/phase one, the phase/ground insulation shall be tested using power frequency voltage so that no stress occurs on the phase/phase insulation.
b) Perform a phase/phase PD test with impulse voltage of the specified waveform according to Figure B.2. The impulse test may only be performed if no PD inception has been detected during the phase/ground insulation test. The rise time may be longer than the specified one as it is less significant according to Table 3. In this way, overstressing the turn/turn insulation can be reduced. The test voltage should be applied in turn between each terminal and the other two with the core floating. In this way, overstressing the phase/ground insulation is reduced.
c) Perform a turn/turn insulation test by applying impulse voltages between each phase terminal and ground consecutively, with the other phase terminals and the core grounded. The impulse voltage rise time shall be in accordance with the values given in Table B.1 and Figures B.1 and B.2 and the amplitude in accordance with Clause B.6. If the RPDIV is below the pass criterion, the winding has failed. If the RPDIV is above the pass criterion, the winding has passed the test. If the machine is to be assigned a special impulse voltage insulation class for the turn/turn insulation (see Clause C.2), this test is performed using parallel conductors in the winding if no other way is possible.

12 Routine tests

12.1 Optional PD test

It is good practice to perform a routine test on each winding. For this purpose, it is recommended that the PD tests described in 11.2 and 11.3 are performed in agreement between the manufacturer and customer on each machine produced. The passing of this PD routine test, that has been performed according to this document and to the IVIC specified, shall be entered into the documentation for the machine, if required, or stored in the relevant database of the manufacturer.

12.2 Routine withstand voltage test

A mandatory minimum withstand voltage test for all machines with or without IVIC is described in IEC 60034-1. This withstand voltage test may be required at an increased voltage level for converter-fed machines, according to the specified IVIC, as described in Annex D. The derivation of test voltage factors (TVF) for the routine withstand voltage test of Type I converter-fed rotating electrical machines and an example of routine withstand test voltages for a 500 V rated rotating machine fed from a converter are given in Annex D.

The passing of this test with the withstand voltage level according to this document and to the specified IVIC, shall be entered into the documentation for the machine, if required, or stored in the relevant database of the manufacturer.

During the routine testing of quantity produced machines up to 200 kW (or kVA) and rated for U_N 1 kV, the 1 min test may be replaced by a test of 1 s (see IEC 60034-1) at 120 % of the test voltage specified in Table D.1, for example S – (manufacturer specified): (TVF $2U_N$ + 1 kV)   1,2.

For very small sized machines or windings, produced in large quantity, for example with a rated power of < 1 kW, a test level of 120 % for the 1s-withstand-test may be excessive in case of IVIC C or D specified machines. In this case an IVIC-specified test level of 100 % can be used instead, but at least to the test level defined in IEC 60034-1.

13 Analysis, reporting and classification

The approach given in 6.2 of IEC 60034-18-1:2010 to analysis, reporting and classification should be adopted so that all relevant data is analysed correctly and reported in a traceable manner. In particular, a photographic record of the impulse voltage waveform at the machine terminals during tests shall be provided.

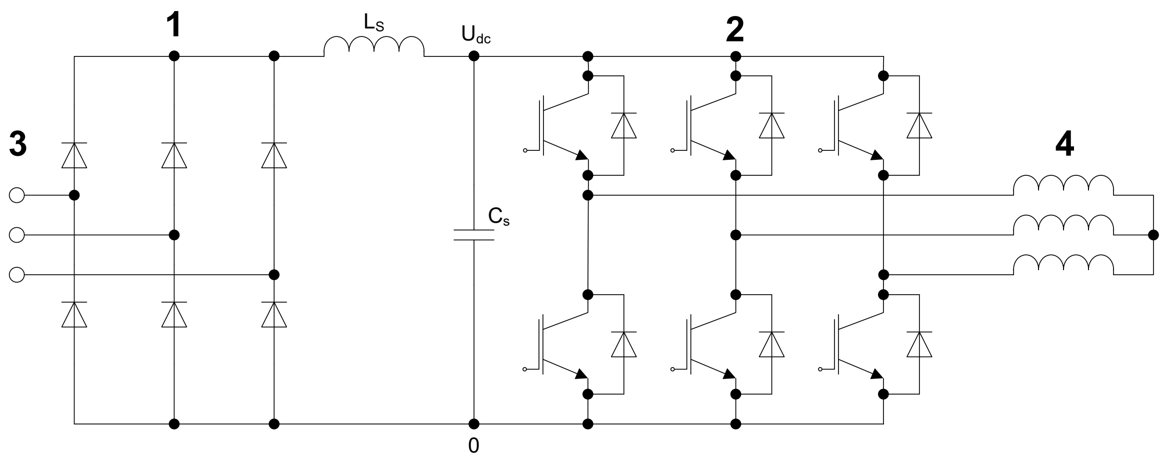
Annex A
(informative)

Derivation of possible terminal voltages in service for a converter-fed machine

A.1 Calculation of d.c. bus voltage

A U-converter, pulse width modulation (PWM) or vector machine power control generates rectangular waves of fixed amplitude voltage that have varying width and repetition rate. The voltage of the impulses at the output of the converter is not more than the d.c. bus voltage (U_{dc}). This voltage depends on the rectified mains voltage or braking voltage level or power factor correction regulation voltage.

A simplified circuit diagram for a converter/machine system is shown in Figure A.1.



Key

1 Rectifier

2 PWM converter

3 AC input

4 Machine winding

L_s and C_s are system inductance and capacitance

Figure A.1 – Circuit diagram for a converter/machine system

As a first step, it is necessary to define a neutral point from which all voltages may be referenced. For example, in a 3-phase system:

$$u_1(t) = \sqrt{2}U_{\text{phase}} \sin(\omega t)$$

$$u_2(t) = \sqrt{2}U_{\text{phase}} \sin\left(\omega t - \frac{2\pi}{3}\right)$$

$$u_3(t) = \sqrt{2}U_{\text{phase}} \sin\left(\omega t - \frac{4\pi}{3}\right)$$

This may be extended to a multiphase system. The general law for defining the magnitude of the voltage of a multiphase a.c. voltage after rectification is given by:

$$U_{\text{dc}} = a\left(\frac{\varphi}{\pi}\right)\sin\left(\frac{\pi}{\varphi}\right)U_{\text{max}} = k \cdot U_{\text{max}}$$

Where:

k is a constant;

a is the rectifying type (a = 1 for half wave rectification or a = 2 for full wave rectification);

φ is the number of phases (minimum of 2).

The formula only applies to balanced systems and so φ has a minimum value of 2. In the special case of a single-phase drive, it is necessary to consider the voltage to be a combination of two voltages, each $\sqrt{2}U/2$, with φ =2.

The voltage at the output of the d.c. bus (U_{dc}) and therefore the peak value of the output voltage of the converter may be calculated using the above formula. For example, in the general case of a three-phase sinusoidal voltage fully rectified it leads to

$$U_{\text{dc}} = 2 \cdot \frac{3}{\pi} \cdot \sin\left(\frac{\pi}{3}\right) \cdot \sqrt{2}U_{\text{phase}} = 2 \cdot \frac{3}{\pi} \cdot \frac{\sqrt{3}}{2} \cdot \sqrt{2}U_{\text{phase}} = \frac{3}{\pi} \cdot \sqrt{3}\sqrt{2}U_{\text{phase}} \text{ and}$$

$\sqrt{3}U_{\text{phase}} = U_{\text{line}}$ (that is, the r.m.s. phase to phase voltage).

Therefore, $U_{\text{dc}} = \frac{3}{\pi} \cdot \sqrt{2}U_{\text{line}}$

For example, if U_{line} = 500 V r.m.s. then

$$U_{\text{dc}} = 500\frac{3}{\pi}\sqrt{2} = 675\,V = 1{,}35U_{\text{line}} = 1{,}65U_{\text{max}}$$

The factor of 1,35 has been derived from theoretical considerations but in practice may be larger. For example, in cases of regeneration, the DC bus voltage maximum limit is the cut-off voltage in the drive, which will be much higher than the mains derived DC bus voltage.

A.2 Calculation of maximum peak voltages for a 2-level converter

The peak voltages are a consequence of the cable and machine arrangements, which result in overshoot voltages of 0 U_{dc}, 0,5 U_{dc}, U_{dc} or 1,5 U_{dc} superimposed on the converter output voltage. In order to allow for practical considerations, the value of overshoot factor for the lowest stress category is raised to 1,1. The values shown in Table A.1 arise from the following calculation.

U_{dc} = DC link voltage = $\frac{3}{\pi}\sqrt{2}U_{\text{line}} = \frac{3}{\pi}\sqrt{3}U_{\text{max}}$

Phase/phase voltage on the machine = DC link voltage × overshoot factor (1,1, 1,5, 2 or 2,5).

To convert to units of U_{max}, the voltage is divided by the maximum phase/neutral voltage for the system as calculated in Clause A.1.

Table A.1 – Examples of maximum peak voltages

Rated voltage Vr.m.s.	U_{dc} V	Overshoot factor U_p/U_a	U_p V	U_{max} V	$U_{p/p}/ U_{max}$
500	675	1,1	743	409	1,82
500	675	1,5	1 013	409	2,48
500	675	2	1 350	409	3,30
500	675	2,5	1 688	409	4,13

Annex B
(normative)

Derivation of test voltages for Type I insulation systems

B.1 Stress categories

The test voltages to be used in this standard for qualification and type testing of an insulation system are derived from the stress category that has been selected. The stress categories given in Clause 7 provide operating ranges for the peak voltage appearing at the terminals of a rotating machine driven from a 2-level converter and the default rise time of the impulses. A careful selection shall therefore be made of the specified tests so that appropriate testing is performed on the insulation system. The stress categories are shown again for convenience in Table B.1.

Table B.1 – Summary of stress categories

Stress category	Overshoot factor (OF) U_p/U_a	Impulse rise time t_r µs
A – Benign	OF ≤ 1,1	0,3
B – Moderate	1,1 < OF ≤ 1,5	
C – Severe	1,5 < OF ≤ 2,0	
D – Extreme	2,0 < OF ≤ 2,5	

B.2 Requirements for the applied impulse voltage

The overall width of the impulse to be used in performing the RPDIV tests shall be long enough to allow initiation of a PD pulse [5]. The impulse waveshape to be used consists of a rising front with rise time 0,3 µs. The average peak voltage shall gradually decrease to be equal to, or exceed the slope from U_1 to U_2 until a time of 5 µs has elapsed. This is explained in terms of a forbidden zone which the applied impulse should not enter, as shown in Figure B.1. In recognition of the difficulty which may occur in achieving the required rise time using commercially available impulse generators, the tolerance on the rise time of the waveform is relaxed to ± 0,2 µs.

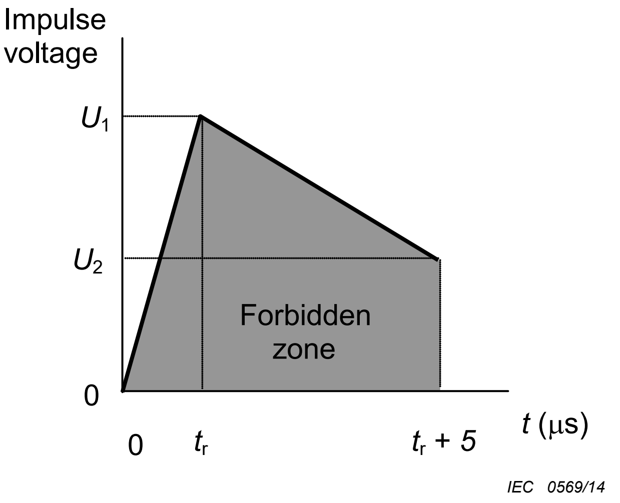
It is accepted that, in practice, it may not be possible to achieve precise values for the impulse waveshape and the following deviations are permitted.

a) The start and end of the rising front are permitted to deviate from linearity by 10 %.

b) Voltage oscillation is permitted at the peak of the impulse voltage, provided the average voltage does not enter the forbidden zone.

c) The peak of the impulse voltage shall not be less than 97 % of the value appropriate for the chosen stress category.

Examples of acceptable and unacceptable impulse voltage waveforms are shown in Figure B.2.



Key

U_1 Test voltage

$U_2 = U_1 \times U_a/U_p$

Figure B.1 – Forbidden zone (shaded) for impulse tests

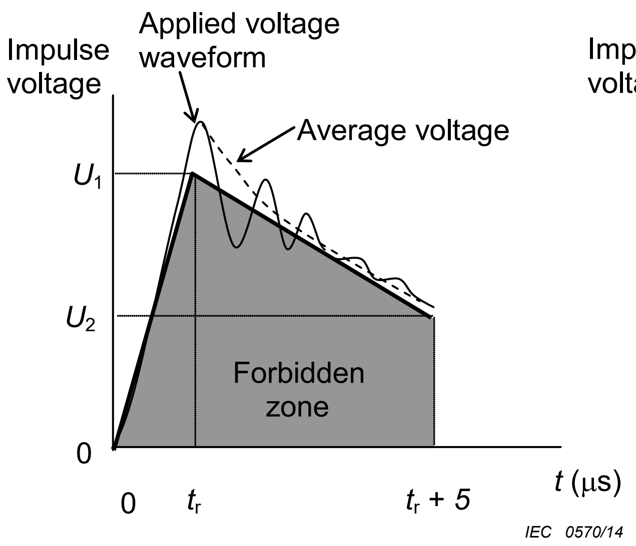


Figure B.2a – Acceptable waveform for the voltage used in the impulse PD test (key as in Figure B.1)

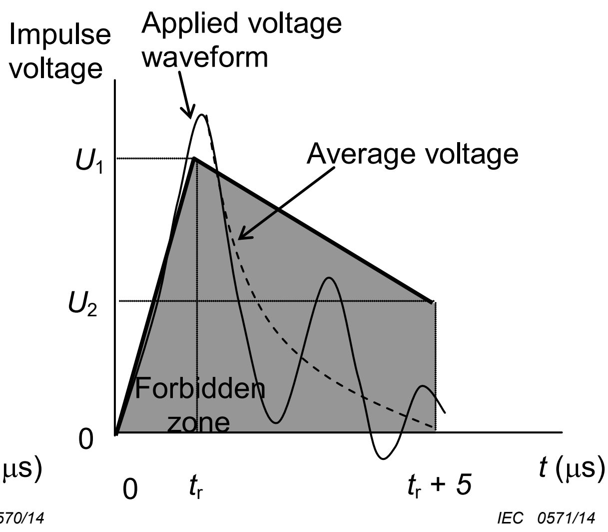


Figure B.2b – Unacceptable waveform for the voltage used in the impulse PD test

Figure B.2 – Examples of test waveforms

B.3 Enhancement factors for PD tests

There are various factors that should be considered for enhancement of the maximum peak/peak operating voltages specified in the qualification and type tests for Type I insulation systems. The first arises from the requirements of IEC 60664-1, which lists safety factors by which the PD test voltages should be increased. A safety factor of 1,25 relates to the hysteresis effect by which PDEV is said from practical experience to be 25 % below the PDIV. This is relevant if PD activity is initiated by a transient overvoltage exceeding the normal peak voltage.

A second enhancement factor to be considered arises from the claim in 7.6 of IEC/TS 60034-25:2007 that an increase in winding temperature from 25 ºC to 155 ºC typically results in a fall in the PDIV by 30 %. For phase to ground testing, this factor is reduced due to the cooling effect of the slot on the neighbouring turns and only adds a further 5 % – 10 %.

Finally, the effect of thermal ageing should be considered. If the machine is being operated near to the class temperature of the insulation, it is reasonable to expect PD inception voltages to fall as a result of thermal ageing in service. It is a requirement for Type I machines that they remain PD free for their lifetime. An empirical factor should therefore be introduced to raise the test voltages on new machines to take account of the effect of ageing. A change in service application may also change the ageing rate. A value of up to 1,2 is proposed but a smaller value may be used, based on service experience or laboratory testing. The precise value of the ageing factor depends upon the service temperature and if this were significantly below the temperature class of the insulation, it may be unnecessary to apply it. The ageing factor has a minimum value of 1,0. For a service temperature near to the class temperature, the following formula may be used.

$$\text{Ageing factor} = 1{,}2\left(1 - \frac{\text{Class temperature} - \text{Service temperature}}{\text{Class temperature}}\right)$$

A summary of the enhancement factors to be applied to the operating voltages is given in Table B.2.

Table B.2 – Summary of enhancement factors to be applied to the operating voltages

		Enhancement factors (EF)			
		PD Safety factor	Temperature	Ageing	Total EF
Qualification test	Phase/phase	1,25	1,0 – 1,3	1,0	1,25 – 1,63
	Phase/ground		1,0 – 1,1		1,25 – 1,38
	Turn/turn		1,0 – 1,3		1,25 – 1,63
Type test	Phase/phase	1,25	1,0 – 1,3	1,0 – 1,2	1,25 – 1,95
	Phase/ground		1,0 – 1,1		1,25 – 1,65
	Turn/turn		1,0 – 1,3		1,25 – 1,95
NOTE The total enhancement factor (Column 6) is the product of the individual factors in columns 3-5.					

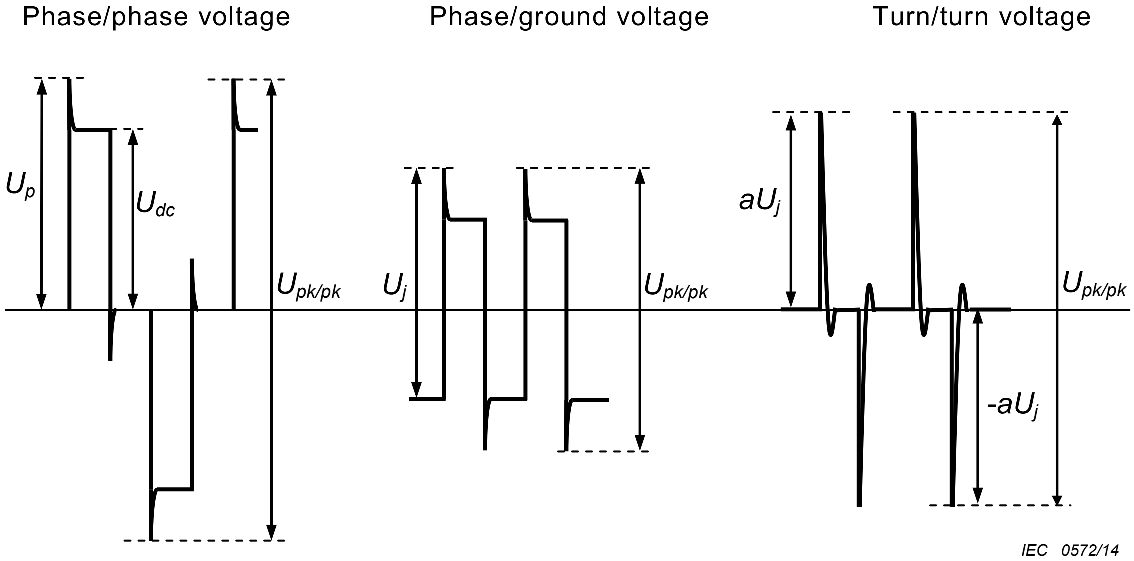
It is known and well documented in the relevant literature, that relative humidity (environmental on-site conditions) and density of air (altitude) may affect the PD inception voltage during testing and in service to a similar extent as the temperature. Results reported in literature suggest, that the relative and absolute humidity during test and in service will influence the actual PDIV/RPDIV in both directions. For this reason, a further enhancement factor could be applied to correct PDIV/RPDIV results.

The influence of the altitude on the RPDIV can become quite high, according to the strongly reduced air-pressure resulting in reduced PDIV/RPDIV. Depending on the design of the insulation system and the expected maximum altitude in service, this should be reflected by an additional enhancement factor.

B.4 Voltage for design qualification and type tests

For the design qualification and type testing of Type I insulation systems, the voltage to be used for PD tests is calculated using the maximum operating voltage for the chosen stress category as shown in Tables B.3 and B.4 for a 2-level converter. Note that the values for U_p and U_b relate to phase/phase voltages on the machine terminals.

The important phase/phase and phase/ground voltages appearing at the terminals of a rotating machine fed from a 2-level converter and the turn/turn voltages of coils of the rotating machine fed from the converter are shown schematically in Figure B.3. Note that $U_{pk/pk}$ is the main stressing voltage of the phase/phase, phase/ground, and turn/turn insulation because the effects of switching impulses are smaller and may be ignored. The jump voltage U_j of the phase/ground voltage is important for turn/turn insulation because it generates additional turn/turn voltage. Since the jump voltage occurs at both the rising and falling edges of the phase/ground voltage, the turn/turn voltage has positive and negative peaks. The positive and negative peak voltages are proportional to the jump voltage. The fraction, a, of jump voltage stressing the turn/turn insulation in the worst case is shown in Figure 7.



NOTE This is a schematic representation and not scaled for phase/phase, phase/ground and turn/turn voltages. The letter "a" represents the fraction of voltage stressing the turn/turn insulation.

Figure B.3 – Comparison of phase/phase, phase/ground, and turn/turn voltages for a 2-level converter

In the qualification and type tests, the voltage applied to each insulation component by the test voltage source should comply with the specified rise time and amplitude. The most important parameter of the voltage is the peak/peak value, as described in 5.1. In the case of the phase/phase and phase/ground tests, the voltage amplitude on each insulation component is equal to the applied test voltage level. On the other hand, in the case of turn/turn insulation test for a winding, the voltage amplitude on the turn/turn insulation depends on the test voltage waveform as well.

Figure B.4 shows impulse test voltage waveforms and the levels for applying the same voltage on the turn/turn insulation at the time when the rotating machine is fed by converter. In the case of the unipolar rectangular impulse test voltage (a), the impulse rise time is 0,3 μs at both the leading and falling edges. The time between rising and falling edges is relatively short. The stressing of the turn/turn insulation is dependent on the derivative of the voltage waveshape and so both the rising and falling edges contribute to the turn/turn voltage. If the conventional impulse test voltage (b and c) is used in which the fall time is much longer than the rise time, say 10 μs, only the leading edge contributes to the turn/turn voltage. Therefore, the peak/peak test voltage from a conventional impulse voltage is required to be double that of a rectangular impulse voltage.

	a	b	c	d
Impulse type	Unipolar rectangular impulse with a 0,3 μs rise time at both the leading and falling edges	Unipolar impulse with falling time that is much longer than the rise time	Bipolar impulse with falling time that is much longer than the rise time	Phase/ground voltage of a rotating machine fed by converter

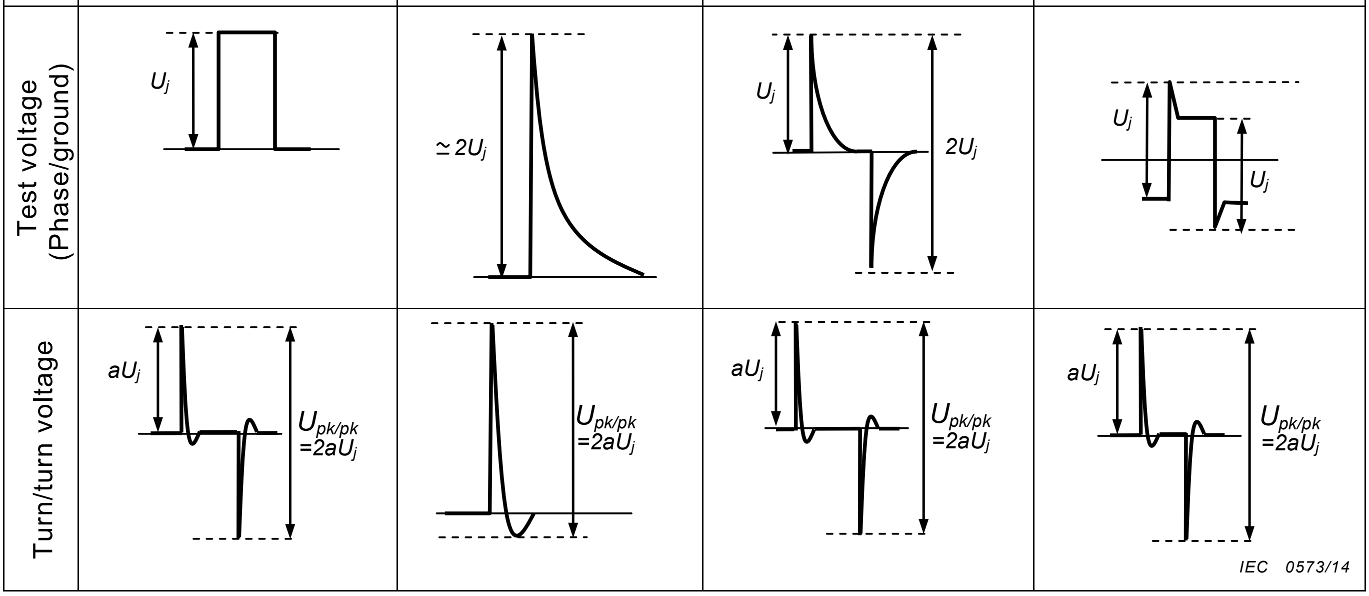


Figure B.4 – Impulse test voltage waveforms and the levels for applying the same peak/peak voltage of $2aU_j$ on the turn/turn insulation (schematic representation)

Examples of maximum peak/peak operating voltages are shown in Tables B.3 and B.4. The test voltages to be used are obtained by multiplying these values by the relevant enhancement factor obtained from Table B.2. Columns 3 and 4 are for the phase/phase and phase/ground insulation.

Table B.3 – Maximum peak/peak operating voltages related to U_{dc} for a 2-level converter according to the stress categories of Table 4

Overshoot factor	Overshoot	Maximum peak/peak operating voltages in units of U_{dc}	
U_p/U_{dc}	U_b/U_{dc}	Phase to phase (Formula 1)	Phase to ground (Formula 2)
1,1	0,1	2,2	1,5
1,5	0,5	3,0	2,1
2,0	1,0	4,0	2,8
2,5	1,5	5,0	3,5

Examples of how to calculate the test levels for the turn/turn insulation are given in Clause B.6. They are related, as described above, to two different forms of impulse generator.

B.5 Examples of maximum peak/peak operating voltages

The phase/phase and phase/ground operating voltages may be calculated from the formulae given in Clause 4 and these lead to the values in Table B.3. Examples are given in Table B.4 for a 500 V r.m.s. rated winding fed from a 2-level converter. The maximum operating voltages are calculated on the basis that U_{dc} for such a system is 675 V (see Annex A).

As an example, for a moderate stress category, the maximum peak/peak operating voltages in Table B.4 are calculated using the following two formulae.

Phase/phase maximum operating voltage = $\frac{3\sqrt{2}}{\pi} \times U_{\text{line}} \times 3{,}0 = 675 \times 3{,}0 = 2\ 025\ \text{V}\ (\text{pk}/\text{pk})$

Phase/ground maximum operating voltage = 0,7 × 2 025 = 1 418 V (pk/pk)

An additional factor to be considered is that the line voltage in service may vary by ±10 %. To allow for this, the operating voltages (from which the test voltages are derived) are increased by a further 10 % so that in the above example the final operating voltages become 2 228 V and 1 560 V. This factor is incorporated into the values shown in Table B.4.

Table B.4 – Examples of maximum peak/peak operating voltage for a 500 V r.m.s. rated winding fed from a 2-level converter, according to the stress categories of Table 4.

Stress category	Examples of maximum peak/peak operating voltage	
	Phase/phase V	Phase/ground V
A (Benign)	1 634	1 144
B (Moderate)	2 228	1 560
C (Severe)	2 970	2 080
D (Extreme)	3 713	2 600

B.6 Calculation of test voltages

As an example, the peak/peak PD-test voltages for phase/phase and phase/ground insulation in a 500 V rated rotating machine fed from a 2-level converter are calculated as in Clause B.5 but without the additional factor of 1,1 (arising from line voltage variations) and multiplied by the relevant total enhancement factor shown in Table B.2. This applies whether the test voltage is sinewave or impulse. It is generally expected that the total enhancement factor will be 1,25. The resulting test voltages for the example shown in Table B.4 are given in Table B.5.

Table B.5 – Examples of maximum peak/peak PD-test voltage for a 500 V rated winding fed, e.g. from a 2-level converter, according to the stress categories of Table 4 and with EF 1,25

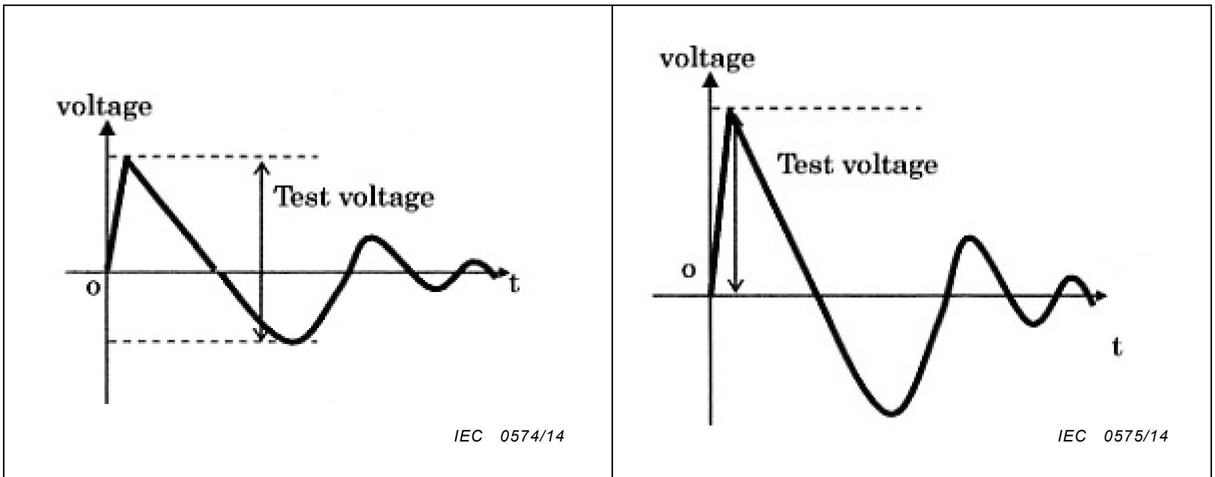
Stress category or impulse voltage insulation class (IVIC)	Examples of maximum peak to peak PD-test voltage	
	Phase to phase V	Phase to ground V
A (Benign)	1 857	1 300
B (Moderate)	2 532	1 773
C (Severe)	3 375	2 364
D (Extreme)	4 219	2 955
S (manufacturer specified)	To be decided	To be decided

According to Clause C.2, an IVIC S may be assigned by the manufacturer which defines the maximum allowable peak to peak voltages and the resulting PD test voltages.

The qualification and type test voltage levels for turn/turn insulation depend upon the waveform of the test generator and the type of winding. In the case of a complete winding, an impulse voltage is used for the turn/turn insulation test and it is applied between the phase and ground. Only the steep-fronted part of the impulse voltage is effective as the turn/turn insulation test voltage. There are two possible tests.

a) For a unipolar impulse voltage having a risetime of 0,3 μs at both the leading and trailing edges, a level of 0,5 × phase/ground test voltage shall be used.

b) For a unipolar impulse voltage, having a risetime of 0,3 μs at the leading edge but with a long fall time (> 10 μs), a level equal to the phase/ground test voltage shall be used.



a. Phase/ground test voltage	b. Turn/turn test voltage

Figure B.5 – Test voltages for phase/ground and turn/turn impulse tests using a unipolar impulse

Guidance for testing the turn/turn insulation in the case of special windings or twisted pairs (see Table 5) is given in Table B.6. Three situations are specified. Where there is no information available, it shall be assumed that the full jump voltage for that coil may form across the insulation. If the impulse rise time of the voltage at the terminals of the machine is known, the worst case voltage distribution shown in Figure 7 should be assumed. In the case of a known voltage distribution, the actual values may be used. For twisted pairs and special windings, the test voltages to be used may be sinusoidal with the same peak/peak values. For other tests, an impulse voltage with a rise time of 0,3 ± 0,2 μs shall be used.

Table B.6 – Turn/turn PD test levels for special windings and twisted pairs

Available information	Test voltage
None	Jump voltage (see Formula 3) × EF
Impulse rise time	Jump voltage × ratio in Figure 7 for the appropriate impulse rise time × EF
Voltage distribution in windings and impulse rise time	Actual values × EF

Annex C
(normative)

Derivation of allowable voltages in service

C.1 Impulse voltage insulation class (IVIC) of the machine

It is recognised that, where a rotating machine is to be fed from a converter, manufacturers and customers need to have an additional rating assigned to the machine insulation system in its documentation and on its rating plate which defines its limits of reliable performance under converter fed conditions (impulse voltage insulation class). The procedure is to use the letters IVIC X, where X is the impulse class letter in Table C.1 and represents the stress category for which the insulation system has been qualified according to Clause 10.

For example, if the machine has been rated for 500 V power frequency (rated voltage) and its insulation system is qualified for moderate impulse stress category, the rating plate will show U_N = 500 V and IVIC B. This permits users of a converter fed machine to check on site, by a simple measurement of the voltages in service, if the machine is being operated reliably within its qualified limits. The turn/turn-insulation voltage stress cannot be measured in service.

The maximum allowable voltages assigned to the impulse insulation classes in Table C.1 have been derived using Formulae (1) and (2) together with the arbitrarily chosen stress category overshoot factors in Table 4. They are given in units of U_N (i.e. the voltages in Table B.4 divided by 500) in order to have them independent from various rated machine voltages. While these voltage limit steps have been derived from operating voltages experienced in service, they pose arbitrary classes in nature. In many cases, intermediate steps for these voltage limits and independency of the limits for phase-phase and phase-ground voltages may be required (see Clause C.2).

Table C.1 – Maximum allowable operating voltage at the machine terminals in units of U_N

Impulse insulation class (A-D)	Maximum allowable peak/peak operating voltages in units of U_N	
	Phase/phase	Phase/ground
A (Benign)	3,3	2,3
B (Moderate)	4,5	3,1
C (Severe)	5,9	4,2
D (Extreme)	7,4	5,2

C.2 Impulse voltage insulation class assigned in special designs

A manufacturer may wish to design and qualify the phase/phase and phase-ground insulation systems of a rotating machine to a combination of impulse voltage insulation classes not given in Table C.1. In this case, the test voltages are determined according to the procedures described in this standard and the documentation and rating plate are marked as follows. The phase/phase and phase/ground insulation systems can each be assigned a separate impulse voltage insulation class. A different impulse voltage insulation class may be assigned to the turn/turn insulation but only when qualified using parallel conductors (see 10.4.5). Here the maximum allowable turn/turn voltages for the classes A-D are defined according to Figure 7 to be 70 % of the related phase/ground voltage of the same class. For example, if the phase/phase, phase/ground and turn/turn insulation systems have been qualified to stress categories C, D and C respectively, the rating plate is marked IVIC C/D/C.

If these class values for the maximum allowable voltage are not appropriate for a special purpose machine design or if the manufacturer wishes to design and qualify the insulation systems using a different rise time to 0,3 μs, the machine may be labelled IVIC S. The rise time used and the voltage values in terms of U_N shall be given as additional information within the product documentation.

Annex D
(informative)

Derivation of routine withstand test voltages and an example for a 500 V rated machine

Table D.1 shows the test voltage factors (TVF) for Type I converter-fed rotating machines, which have been qualified with an IVIC classification, and the resulting routine withstand test voltages for a 500 V rated machine as an example. The test voltage factor (TVF) shown in Table D.1 is defined as the maximum allowable operating peak to peak phase to ground voltage in units of U_N divided by $2\sqrt{2}$. Here, this divisor reflects, that U_N and accordingly related test voltages defined in IEC 60034-1 are given as r.m.s-value. The values are shown for each of the appropriate impulse voltage insulation classes. The routine withstand test voltage for a converter-fed machine is not permitted to be below the value for a line-fed machine having the same rated voltage.

Table D.1 – Withstand test voltages according to IVIC for Type I insulation systems

IVIC	Maximum allowable peak to peak operating voltages in units of U_N [a] – Phase to phase	Maximum allowable peak to peak operating voltages in units of U_N [a] – Phase to ground U_{IVIC} / U_N	Maximum allowable enhancement ratio for the phase to ground peak to peak voltage	TVF	Examples of routine phase to ground test voltages for a machine with U_N = 500 V tested at 50/60 Hz according to IEC 60034-1 (kV r.m.s.) – Converter-fed (IVIC specified)	Examples of routine phase to ground test voltages for a machine with U_N = 500 V tested at 50/60 Hz according to IEC 60034-1 (kV r.m.s.) – Line fed[b]
None (line)	2,8	1,6				2
A – Benign	3,0	2,1	1,3	0,7	2,0	2
B – Moderate	4,1	2,8	1,7	1,0	2,0	2
C – Severe	5,4	3,8	2,3	1,3	2,3	2
D – Extreme	6,7	4,7	2,9	1,7	2,7	2
S (manufacturer specified)	X	Y	$\frac{Y\sqrt{3}}{2\sqrt{2}}$	$\frac{Y}{2\sqrt{2}}$	TVF $2U_N$ + 1 kV	2

- [a] These voltages are calculated using the formulae described in Clause B.5. The factor of 1,1 for the variation of the line voltage is not included.
- [b] The voltage in this column is the test voltage specified in IEC 60034-1 for U_N = 500 V.

NOTE 1 Enhancement ratio is the maximum allowable phase to ground peak to peak voltage under converter-fed operation U_{IVIC} divided by the phase to ground peak to peak voltage under line operation $U_N/\sqrt{3} \cdot 2/\sqrt{2}$.

NOTE 2 The values X and $Y = U_{IVIC} / U_N$ are independent and are chosen by the manufacturer.

NOTE 3 S is defined in Clause C.2.

NOTE 4 The test voltage is defined only by the maximum allowable peak to peak voltage at the motor terminals in operation. Other differences in the voltage waveform in operation are not taken into consideration.

NOTE 5 The equations in the line of IVIC “S” apply to the other IVICs A, B, C, D as well.

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[6] Stone,G.C. & Culbert, I., "Partial discharge testing of random wound stators during short rise time voltage surges", *IEEE Electrical Insulation Conference*, Montreal 2009

[7] IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

(*Cointued from second cover*)

The Committee has reviewed the provisions of the following international standards referred in this adopted standard and has decided that they are acceptable for use in conjunction with this standard.

International Standard	*Title*
IEC 60034-18-1 : 2010	Rotating electrical machines — Part 18-1: Functional evaluation of insulation systems — General guidelines
IEC 60034-18-21	Rotating electrical machines — Part 18-21: Functional evaluation of insulation systems — Test procedures for wire-wound windings — Thermal evaluation and classification
IEC 60034-18-31	Rotating electrical machines — Part 18-31: Functional evaluation of insulation systems — Test procedures for form-wound windings — Thermal evaluation and classification of insulation systems used in rotating machines
IEC/TS 60034-25 : 2007	Rotating electrical machines — Part 25: Guidance for the design and performance of a.c. motors specifically designed for converter supply
IEC TS 60034-27	Rotating electrical machines — Part 27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines
IEC 60664-1	Insulation co-ordination for equipment within low voltage systems — Part 1: Principles, requirements and tests
IEC/TS 61800-8	Adjustable speed electrical power drive systems — Part 8: Specification of voltage on the power interface
IEC/TS 61934	Electrical insulating materials and systems — Electrical measurement of partial discharges (PD) under short rise time and repetitive voltage impulses

Only English language text has been retained while adopting it in this Indian Standard, and as such the page numbers given here are not the same as in the International Standard.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test, shall be rounded off in accordance with IS 2: 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Amendments Issued Since Publication

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