

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Rotating electrical machines –
Part 18-41: Partial discharge free electrical insulation systems (Type I) used in
rotating electrical machines fed from voltage converters – Qualification and
quality control tests**

**Machines électriques tournantes –
Partie 18-41: Systèmes d'isolation électrique sans décharge partielle (Type I)
utilisés dans des machines électriques tournantes alimentées par des
convertisseurs de tension – Essais de qualification et de contrôle qualité**



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IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

**Part 18-41: Partial discharge free electrical insulation systems (Type I)
used in rotating electrical machines fed from voltage converters –
Qualification and quality control tests**

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International Standard IEC 60034-18-41 has been prepared by IEC technical committee 2: Rotating machinery.

IEC 60034-18-41 cancels and replaces IEC/TS 60034-18-41 (2006).

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

FDIS	Report on voting
2/1728/FDIS	2/1738/RVD

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

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

NOTE A table of cross-references of all IEC TC 2 publications can be found in the IEC TC 2 dashboard on the IEC website.

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- withdrawn,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

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 μ s 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.

ROTATING ELECTRICAL MACHINES –

Part 18-41: Partial discharge free electrical insulation systems (Type I) used in rotating electrical machines fed from voltage converters – 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** U_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**

safe peak to peak voltage assigned by the manufacturer in relation to the rated voltage for a specified converter-driven machine and indicated in its documentation and 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** U_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** U_{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.

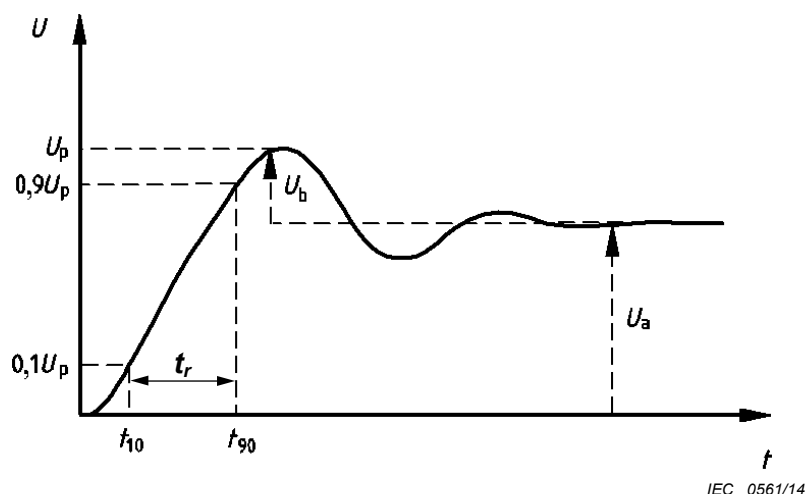
Note 2 to entry: For a multilevel converter, U_{dc} is equal to $\frac{1}{2} U_{pk/pk}$ minus the overshoot in Figure 2.

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

4 Machine terminal voltages arising from converter operation

Modern converter output voltage rise times may be in the $0,05 \mu\text{s} - 2,0 \mu\text{s}$ 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,

- operating line voltage of the converter;
- architecture and control regime of the converter;
- filters between the converter and machine;
- length and type of cable between them;
- design of the machine winding;
- 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 μ s – 2,0 μ s
Impulse voltage repetition rate	100 Hz – 20 000 Hz
Impulse duration	10 μ s – 10 000 μ s
Shape	Rectangular
Polarity	Unipolar or bipolar
Fundamental frequency	5 Hz – 1 000 Hz
Mean time between impulses	$\geq 0,6 \mu$ s

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
$U_{\text{max}} = \sqrt{2} U_{\text{phase}}$	Maximum phase/neutral voltage	V	Line
$U_{\text{pk/pk}}$	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 $2U_{\text{dc}}$ 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.

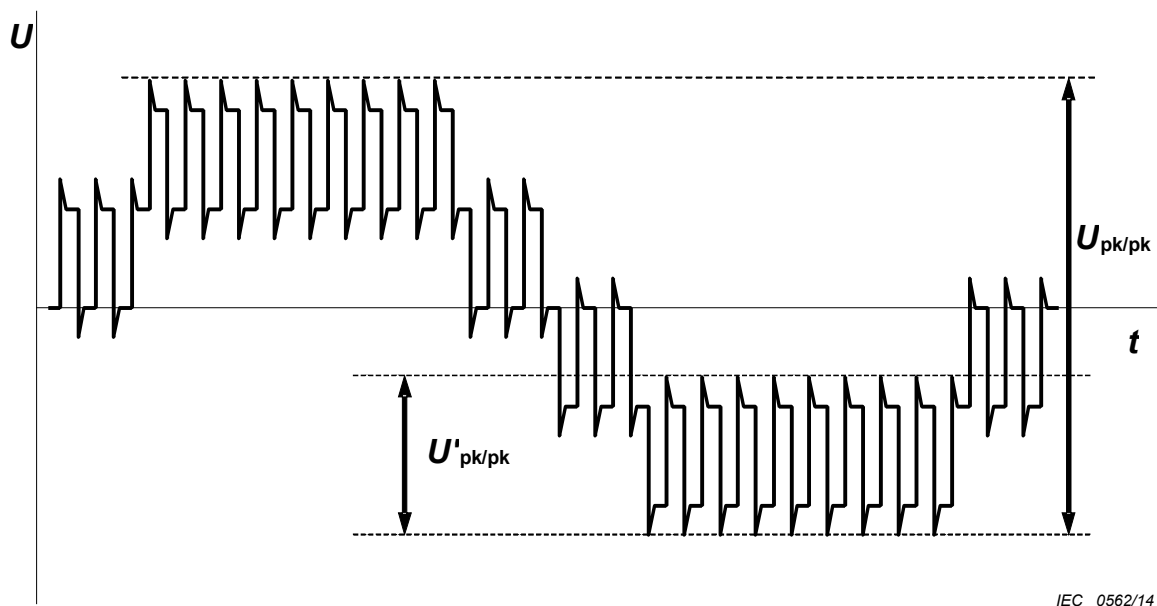


Figure 2 – Five step phase to phase voltage at the terminals of a machine fed by a 3-level converter

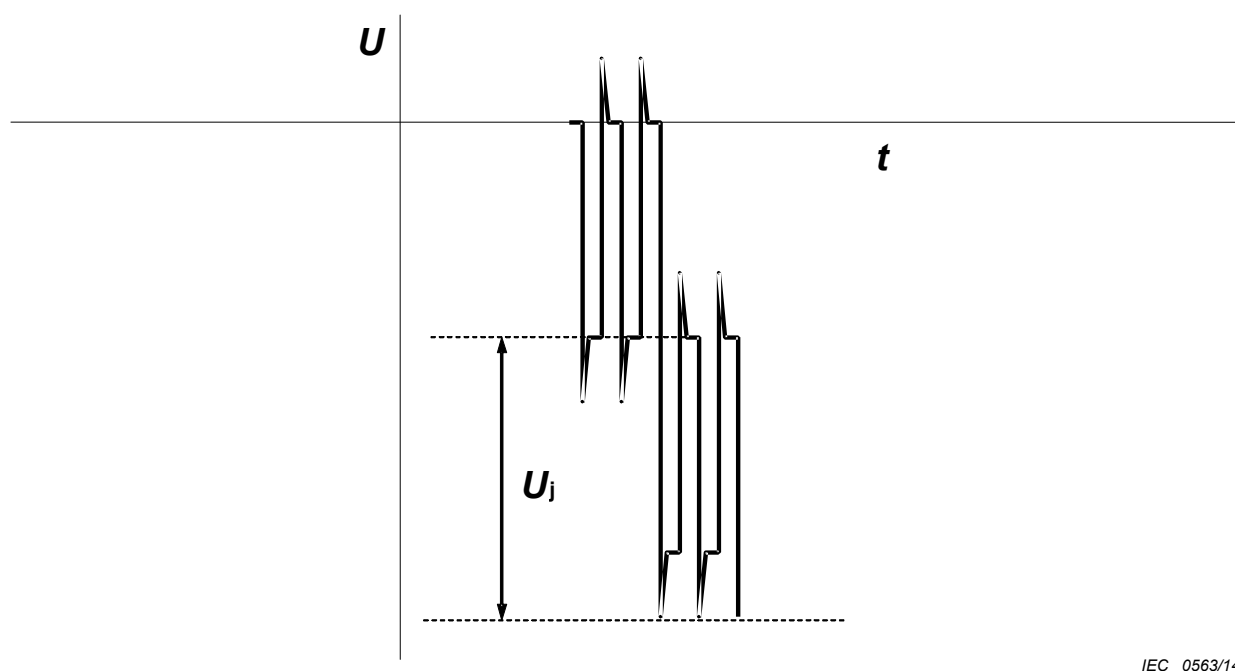


Figure 3 – Jump voltage (U_j) at the machine terminals associated with a converter drive

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:

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

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

The phase/ground values are estimated as follows:

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

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

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

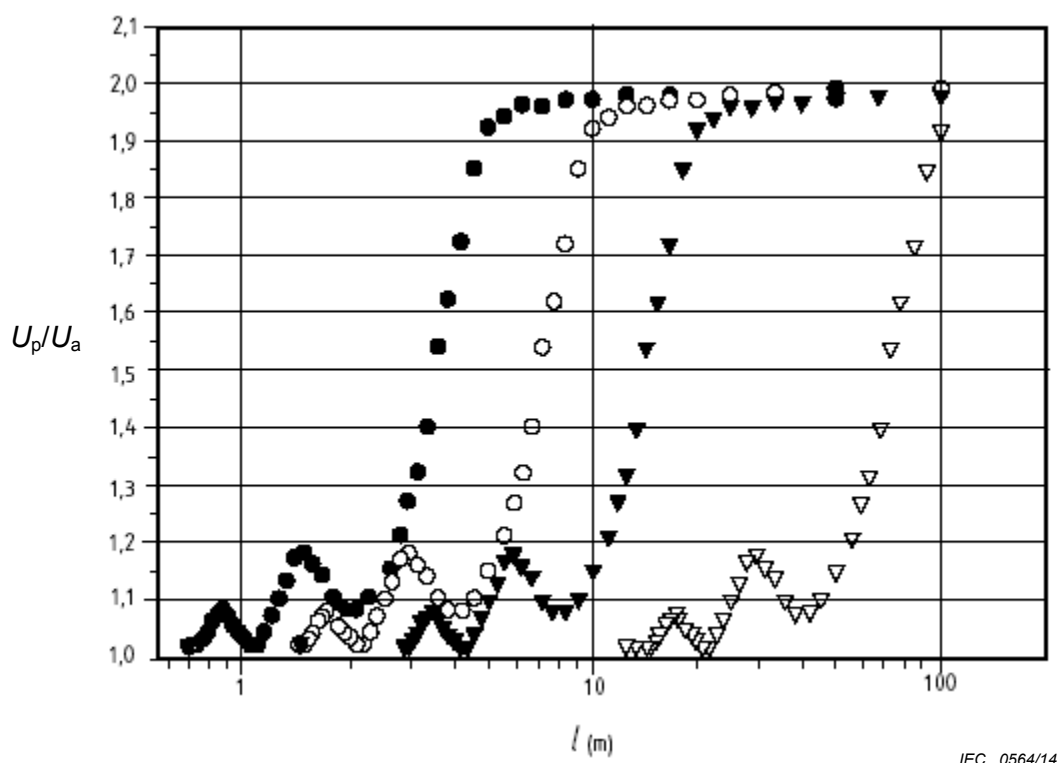
The proportion of jump voltage appearing across the first turn is obtained from Figure 7.

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 μ s 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.



IEC 0564/14

Key

● $t_r = 0,05 \mu s$ ○ $t_r = 0,1 \mu s$ ▼ $t_r = 0,2 \mu s$ ▽ $t_r = 1,0 \mu s$

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

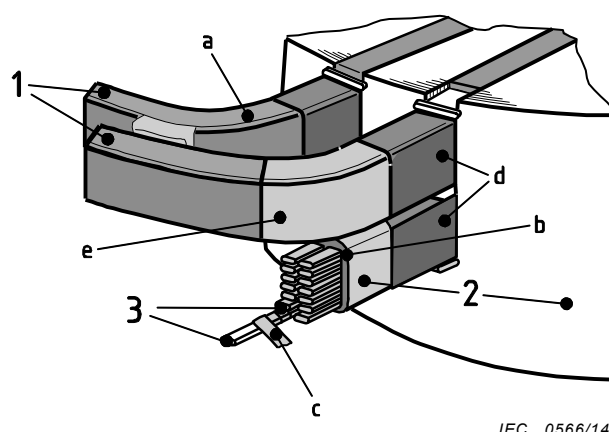
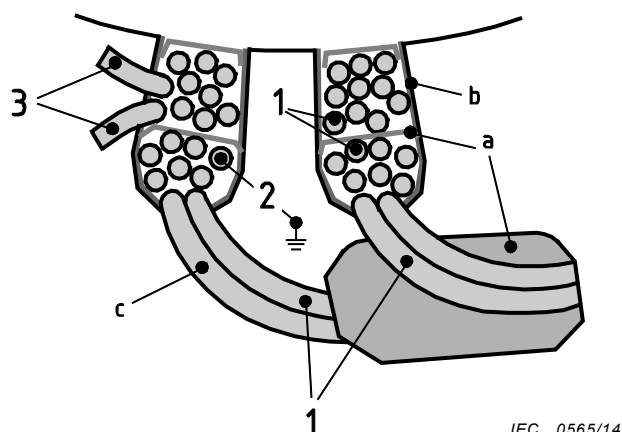
5.1 General

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

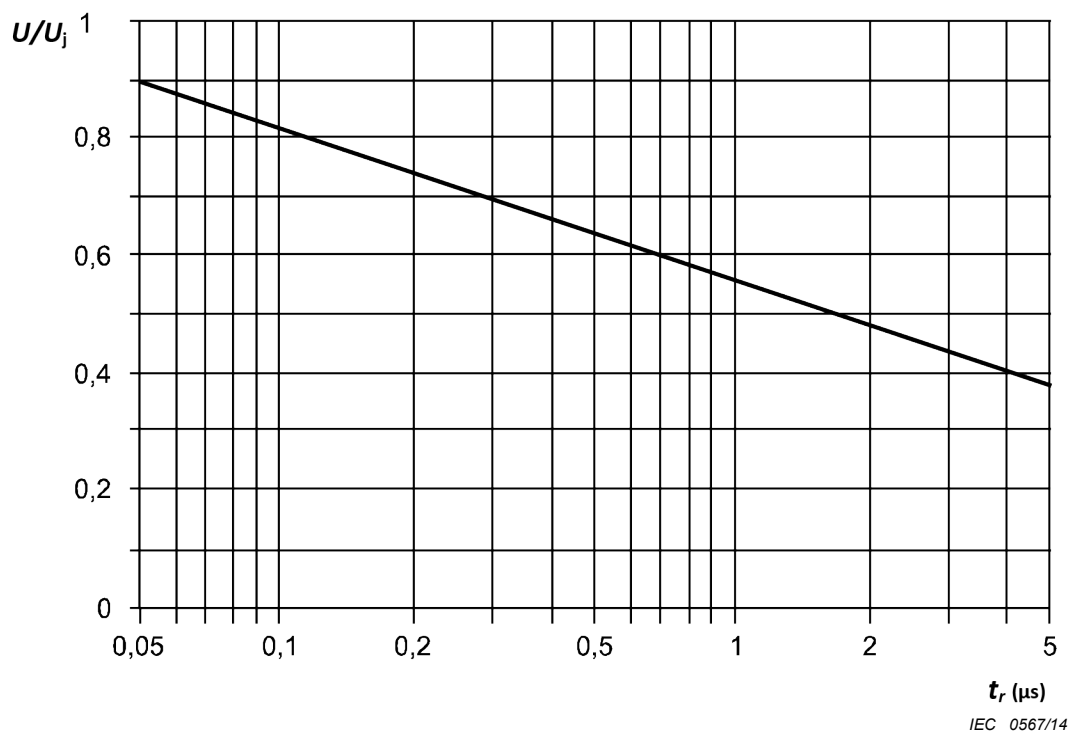
The maximum voltage stress on the phase/phase insulation is determined by the design of the winding and by the characteristics of the phase/phase voltage.

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 $\leq 1,1$	0,3
B – Moderate	$1,1 < \text{OF} \leq 1,5$	
C – Severe	$1,5 < \text{OF} \leq 2,0$	
D – Extreme	$2,0 < \text{OF} \leq 2,5$	

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 μ s (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 μ s 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 $0,3 \mu\text{s} \pm 0,2 \mu\text{s}$. 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 become

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.