भारतीय मानक
Indian Standard

IS 15999 (Part 18/Sec 42) : 2018
IEC 60034-18-42 : 2008

घूर्णी विद्युतीय मशीन

भाग 18 बोल्टता कन्वर्टरों के पुष्ट घूर्णी विद्युतीय मशीनों में प्रयुक्त आंशिक तौर पर डिस्चार्जमुक्त विद्युतीय उष्मारोधी पद्धतियाँ (टाइप II)

अनुभाग 42 अहर्ता एवं स्वीकार्य परीक्षण

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

ICS 29.160.01

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Rotating Machinery Sectional Committee, ETD 15

NATIONAL FOREWORD

This Indian Standard (Part 18/Sec 42) which is identical with IEC 60034-18-42 : 2008 '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' 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.

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

a) Wherever the words 'International Standard' appear 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 certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC/TS 60034-18-41 Rotating electrical machines — Part 18-41: Qualification and type tests for Type I electrical insulation systems used in rotating electrical machines when fed from voltage converters	IS 15999 (Part 18/Sec 41) : 2017/ IEC 60034-18-41 : 2017 Rotating electrical machines : Part 18 — Qualification and type tests for Type I electrical insulation systems used in rotating electrical machines when fed from voltage converters, Section 41 Qualification and quality control tests	Identical with IEC 60034-18-41 : 2014
IEC 60216-3 Electrical insulating materials — Thermal endurance properties — Part 3: Instructions for calculating thermal endurance characteristics	IS 8504 (Part 4) : 2013 Electrical insulating materials — Thermal endurance properties: Part 4 Instructions for calculating thermal endurance characteristics	Identical with IEC 60216-3 : 2006

The technical 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	Rotating electrical machines — Functional evaluation of insulation systems — Part 18-1: General guidelines
IEC 60034-18-32	Rotating electrical machines — Functional evaluation of insulation systems – Part 18-32: Test procedures for form-wound windings — Electrical evaluation of insulation systems used in machines up to and including 50 MVA and 15 kV
IEC/TS 61251	Electrical insulating materials – A.C. voltage endurance evaluation — Introduction

(*Continued on third cover*)

Indian Standard

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

1 Scope

This Technical Specification defines criteria for assessing the insulation system of stator/rotor windings of single or polyphase AC machines which are subjected to repetitive impulse voltages, such as pulse width modulation (PWM) converters, and expected to withstand partial discharge activity during service. It specifies electrical qualification and acceptance tests on representative samples which verify fitness for operation with voltage-source converters.

This document does not apply to:

- Rotating machines which are fed by converters only for starting.
- Electrical equipment and systems for traction.

NOTE Although this Technical Specification deals with voltage-source converters, it is recognised that there are other types of converters that can create repetitive impulse voltages. For these converters, a similar approach to testing can be used if needed.

2 Normative references

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

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

IEC 60034-18-32, *Rotating electrical machines – Functional evaluation of insulation systems – Part 18-32: Test Procedures for form-wound windings – Electrical evaluation of insulation systems used in machines up to and including 50 MVA and 15 kV*

IEC/TS 60034-18-41, *Rotating electrical machines – Part 18-41: Qualification and type tests for Type I electrical insulation systems used in rotating electrical machines when fed from voltage converters*

IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC/TS 61251, *Electrical insulating materials – A.C. voltage endurance evaluation – Introduction*

IEC 61800-4, *Adjustable speed electrical power drive systems – Part 4: General requirements – Rating specifications for a.c. power drive systems above 1 000 V a.c. and not exceeding 35 kV*

IEC 62068-1, *Electrical insulating systems – Electrical stresses produced by repetitive impulses – Part 1: General method of evaluation of electrical endurance*

IEC 62539, *Guide for the statistical analysis of electrical insulation breakdown data*

3 Terms and definitions

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

3.1
voltage endurance coefficient
symbol: n
exponent of the inverse power model or exponential model on which the relationship between life and stressing voltage amplitude for a specific insulation system depends

3.2
life
time to failure

3.3
stress grading material
material generally having a non-linear resistivity characteristic, applied to the endwindings of stators to reduce the maximum surface electrical stress

3.4
corona protection material
material which is used to coat a stator bar within the slot portion of the stator core to avoid slot discharges

3.5
impulse rise time
symbol: t_r
time for the voltage impulse to go from 0 % to 100 % (See Figure 1)

NOTE Unless otherwise stated, it is estimated as 1,25 times the time for the voltage to rise from 10 % to 90 %.

3.6
electrical insulation system
insulating structure containing one or more electrical insulating materials together with associated conducting parts employed in an electrotechnical device

[IEC 62068-1]

3.7
(electric) stress
electric field in V/mm

3.8
rated voltage
symbol: U_N
voltage assigned, generally by the manufacturer, for a specified operating condition of a machine

3.9
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 For the purposes of this Technical Specification, the fundamental frequency of the machine terminal voltage is the one defining the speed of the converter-fed machine.

3.10
steady state voltage impulse magnitude

symbol: U_a
final magnitude of the voltage impulse (see Figure 1)

3.11
peak (impulse) voltage

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

NOTE 1 For bi-polar voltage impulses, it is half the peak to peak voltage (See Figure 2).

NOTE 2 The peak to peak voltage, $U_{pk/pk}$ is shown in Figure 2.

3.12
voltage overshoot

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

3.13
impulse repetition frequency

average number of voltage impulses per unit time generated by the converter (switching frequency)

3.14
jump voltage

symbol : $\boldsymbol{U}_j$
change in voltage at the terminals of the machine occurring at the start of each impulse when fed from a converter (see Figure 3)

3.15
peak to peak impulse voltage

symbol : $U'_{pk/pk}$
peak to peak voltage at the impulse frequency (See Figure 2)

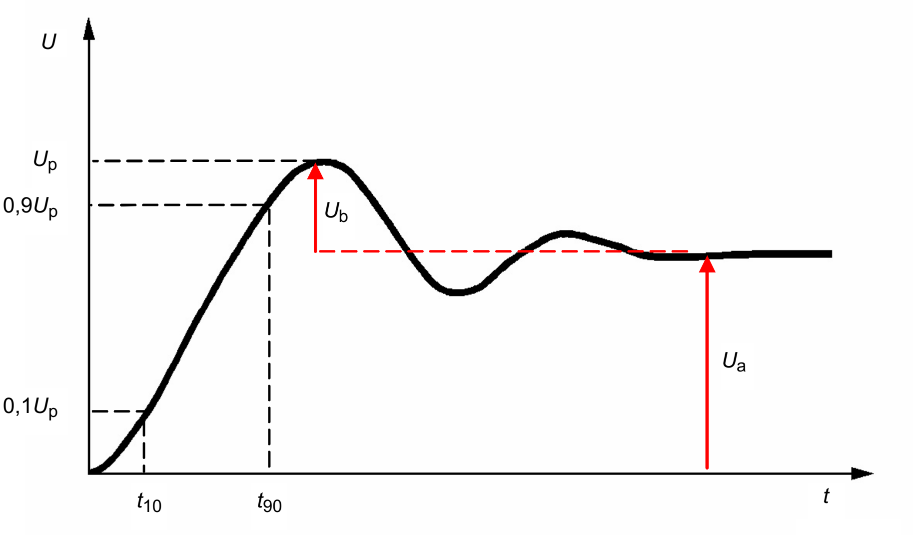
3.16
peak to peak voltage

symbol : $U_{pk/pk}$
peak to peak voltage at the fundamental frequency (See Figure 2)

3.17
partial discharge

electrical discharge that only partially bridges the insulation between conductors

NOTE It may occur inside the insulation or adjacent to a conductor.



Key

U voltage *t* time

Figure 1 – Voltage impulse waveshape parameters

4 Voltage effects from converter operation

4.1 Voltages at the terminals of the converter-fed machine

Modern converter output voltage rise times may be in the 50 ns to 2 000 ns range due to power semiconductor switching characteristics. The voltage appearing at the terminals of a converter-driven machine depends upon several characteristics of the power drive system (see IEC 61800-4), such as

- operating line voltage of the converter
- architecture and control regime of the converter
- filters between the converter and machine
- length and characteristics of the cable between them
- design of the machine winding
- grounding system

In order to apply this Technical Specification 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 6). 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. This voltage overshoot is created by reflected waves at the interface between cable and machine or converter terminals due to impedance mismatch. The voltage appearing at the machine terminals when fed from a 3-level converter is shown in Figure 2. The figure shows one cycle at the fundamental frequency.

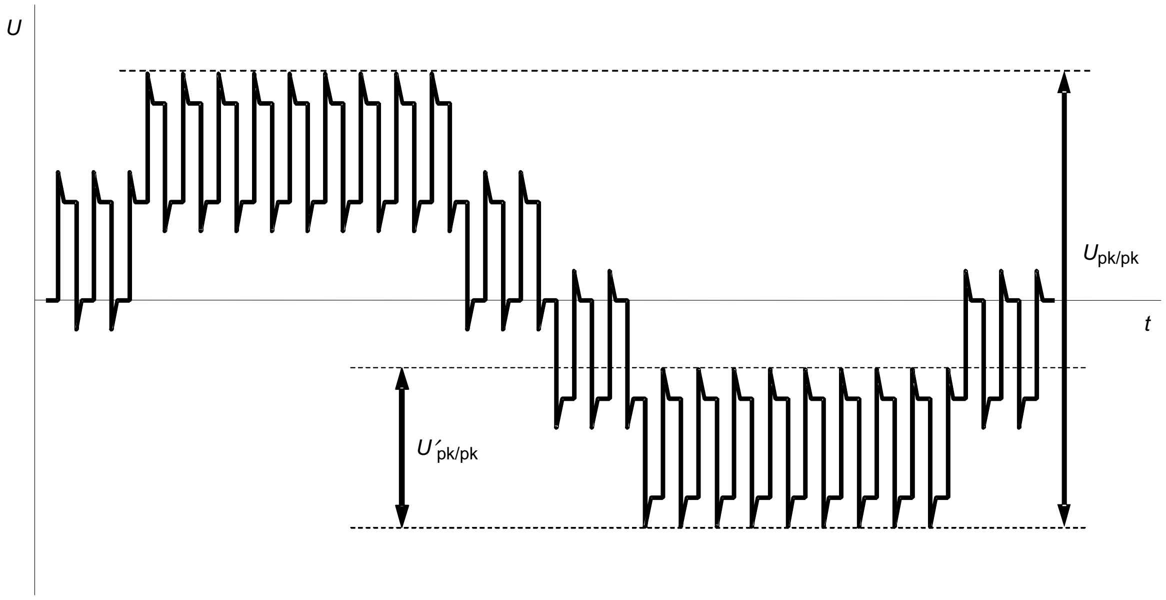


Figure 2 – Phase/phase voltage at the terminals of a machine fed by a 3-level converter

Two examples of the maximum change in voltage at the impulse frequency, U_j, are shown in Figure 3. This parameter is important in defining the voltage enhancement that can occur across the first or last coil in the stator. Although the smaller U_j in Figure 3 is the most common instantaneous voltage change occurring at the machine terminals, there is a possibility that on rare occasions this jump in voltage may occur at the moment of switching between stages, in which case the larger of the two voltages shown in Figure 3 can occur.

Examples of the enhancements that are produced for various rise times and cable lengths in the case of a 2-level converter are given in Figure 4, where the worst case is shown, arising from an infinite impedance load. In this case, the enhancement to the voltage for an impulse rise time of 1 000 ns is insignificant below about 15 m and only exceeds a factor of 1,2 when the cable length is greater than 50 m.

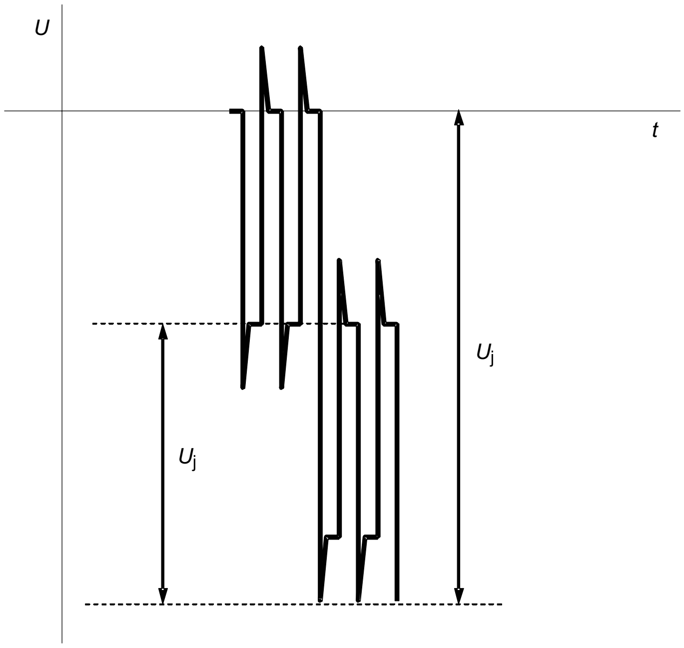
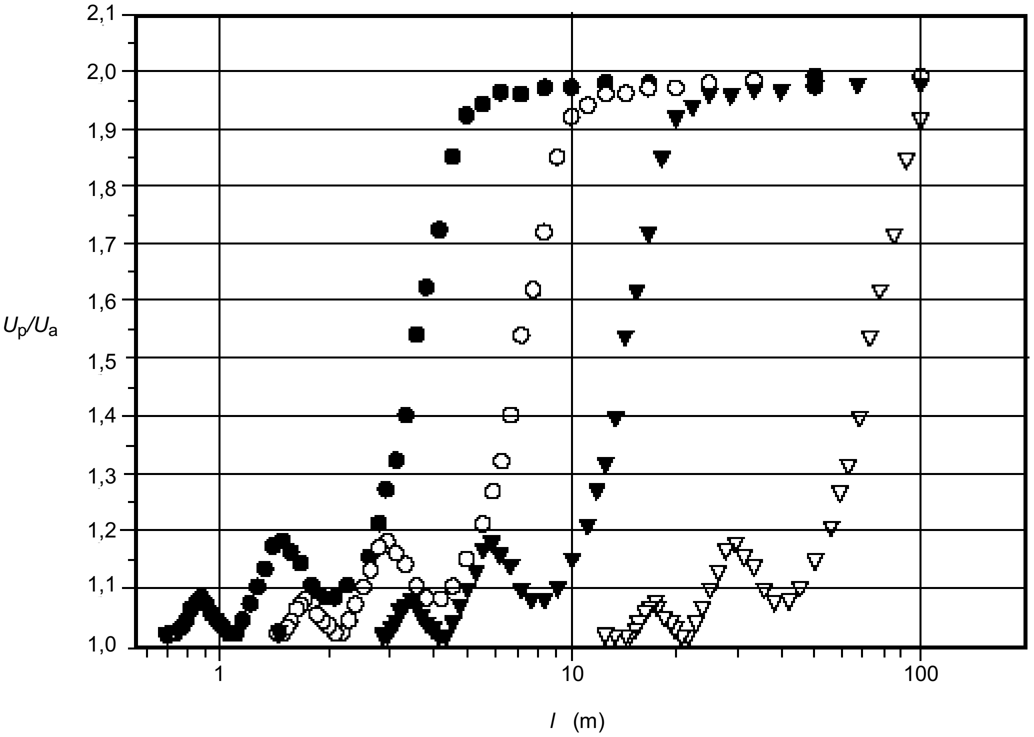


Figure 3 – Possible jump voltages (U_j) at the machine terminals associated with a converter drive



Key

● t_r = 50 ns

○ t_r = 100 ns

▼ t_r = 200 ns

∇ t_r = 1 000 ns

l cable length

Figure 4 – Maximum voltage enhancement at the machine terminals as a function of cable length for various impulse rise times for a 2-level converter

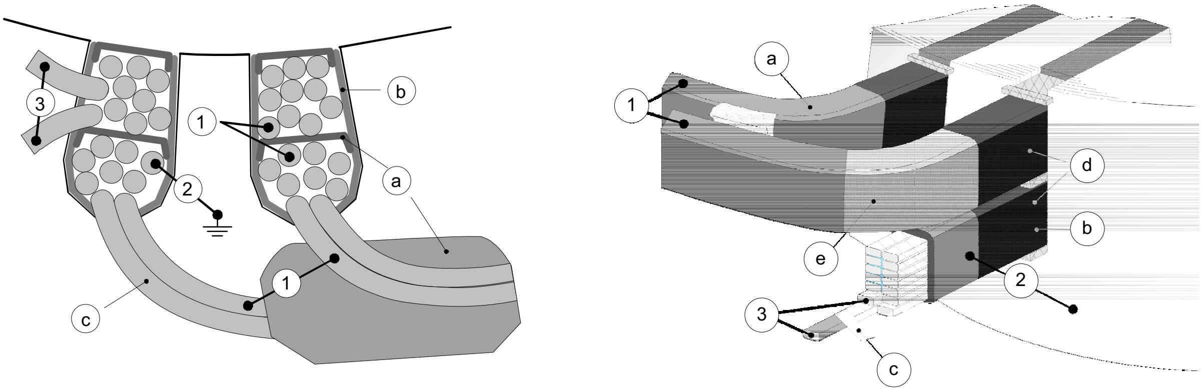
4.2 Electrical stresses in the insulation system of machine windings

4.2.1 General

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

- between conductors in different phases,
- between a conductor and ground,
- between adjacent turns, generally 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.



Key

a phase insulation /endwinding insulation

b ground insulation

c turn insulation

d slot corona protection

e stress grading

1 phase to phase

2 phase to ground

3 turn to turn

Figure 5a – Example of a random wound design

Figure 5b – Example of a form-wound design

Figure 5 – Design examples

4.2.2 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.

4.2.3 Voltages stressing the phase/ground insulation

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

4.2.4 Voltages stressing the turn insulation

The voltage stressing the turn insulation is determined by the jump values of the phase to ground voltage (amplitude and rise time) and by the design of winding (number of coils, number and length of the turns). If this voltage is not known, it may be estimated to be the phase to ground jump voltage divided by the number of turns (for a normal coil) or layers of the coil (for transverse coils). There is a further enhancement which occurs due to the travelling wave along the conductor.

5 Type II insulation systems

If any part of an insulation system is likely to have to withstand PD during its life, it is defined to be Type II and should therefore contain materials that resist PD. Typically, machines with a rated voltage ≥ 700 V use Type II insulation systems. Manufacturers usually 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, although the manufacturer may still assign a rated voltage for 50 Hz or 60 Hz operation and put it on the rating plate on the machine. The rating of the insulation system for converter operation should be defined using the stress factors under which its qualification was achieved. The power frequency rated voltage assigned by the manufacturer to the machine may not be appropriate to the insulation system when powered from a converter.

6 Stress factors for converter-fed Type II insulation systems

The converter drive integrator should specify to the machine designer the voltage that will appear at the machine terminals. This information should be included in the purchase specification, in addition to the traditional parameters such as rated voltage, thermal class, humidity, etc. Specifically, the limiting values are to be defined for the following parameters of the voltage that appear at the machine terminals.

a) Fundamental and impulse voltage repetition frequencies at the machine terminals.

b) Peak to peak voltages of the fundamental and repetition frequencies as well as the jump voltages that are expected to occur at the machine terminals.

c) The impulse rise time, $t_{r.}$

Table 1 gives an indication of the significance of the features of the machine terminal voltage to the ageing of components of a Type II insulation system. In machines having Type II insulation systems, the main wall, phase to phase and turn to turn insulation materials are generally based on combinations of organic and inorganic materials. For stators operating above 700 V, there may be slot corona protection present, which is designed to provide a grounded screen to the insulated stator winding in contact with the slot wall. The surface of the insulation on the conductor is subject to a stress concentration as it emerges from the slot and, for higher voltage machines, it may be treated with stress grading material to avoid the occurrence of surface arcing. These five components (turn to turn, mainwall, phase to phase, slot corona and stress grading) constitute a typical Type II insulation system. Phase to phase voltages are present where two coils are in contact in the same slot. However, in this case there exist two layers of mainwall insulation, usually separated by an insulating spacer, and so the voltage stress is not considered to be of significant magnitude to merit testing of phase to phase insulation systems. No specific testing is therefore recommended for phase/phase insulation. The insulation components assessed in qualification and acceptance tests are shown in Table 1.

Table 1 – Influence of features of the converter drive voltage on acceleration of ageing of components of Type II insulation systems

Insulation component	**Fundamental frequency**	**Impulse repetition frequency**	**Fundamental frequency pk/pk voltage**	**Jump voltage**	**Impulse repetition frequency pk/pk voltage ($U'_{pk/pk}$)**	**Impulse rise time**
Turn to turn insulation	○	●	○	●	○	●
Main wall insulation	●	○	●	○	○	○
Corona protection layer and stress grading	○	●	●	●	●	●

NOTE ○ Less significant ● More significant

For insulation systems designed for use under power frequency supply, the long and short-term effects of rated line-to-ground voltage across the mainwall insulation and along the length of the stress grading are of principal concern. The turn insulation is generally specified by the maximum short rise-time surge requirement of the design; such surge events are generally of very short duration and are relatively infrequent compared with the impulse repetition rate. For this reason, the acceptance requirements are generally satisfied by the ability of the mainwall winding to withstand a power frequency withstand test and the turn insulation to withstand a surge test. The ability of the system to meet the design life requirements is usually satisfied by longer-term voltage endurance testing at 50 Hz or 60 Hz. This endurance test allows the designer to establish the long-term capability of the mainwall insulation system.

In the case of converter-fed systems, the more complex voltage waveform produced by the drive will provide a different stress distribution in the winding. The mainwall, stress grading and corona protection systems are affected by the magnitude of the voltage overshoot, U_b, the rate of rise of voltage and the impulse voltage repetition rate. The last of these may increase dielectric heating in the mainwall insulation, the corona protection layer and the stress grading material. As the rise time of the impulses decreases, the voltage stress usually increases on the insulation between adjacent turns on the line end coil of multi-turn coils. The combination of these factors and their effect on the insulation system as a whole are extremely difficult to quantify.

7 Qualification and acceptance tests

7.1 General

There are two stages to the testing of Type II electrical insulation systems for machines fed from converter drives. The first stage is qualification of the mainwall insulation and turn insulation systems. Each system will be defined by each manufacturer’s unique design rules governing parameters, such as, insulation materials, acceptable stresses, stress control materials and application techniques, processing routes and dimensional guides. It is these design rules that are being qualified. For qualification of Type II mainwall insulation systems, coils or bars are subjected to accelerated electrical ageing to determine an electrical life curve. A method of calculating life for converter-fed systems using data from power frequency voltage endurance tests is also possible in some cases. Separate testing is carried out for the stress control system and the turn insulation. If it can be shown that the turn insulation or the mainwall insulation is not expected to experience PD activity during service, the voltage endurance testing of that part of the insulation system may be omitted.

The second stage is an acceptance test. In this test, complete coils made to production standard are subjected to a 50 Hz or 60 Hz voltage endurance test. It is performed by agreement between the purchaser and manufacturer.

7.2 Qualification tests

For the purposes of this Technical Specification, qualification testing is performed to qualify the materials, design rules and processing of an insulation system to resist PD in a winding under a given set of stresses. These tests are based on the general procedures for functional evaluation of insulation systems described in IEC 60034-18-1, according to which the insulation system intended to be used under converter conditions (candidate system) is compared to an insulation system having service experience under line-fed conditions or in converter operation (reference system).

For Type II insulation systems, the qualification of the mainwall and turn insulation systems is through voltage endurance testing at room temperature or at elevated temperature (see for example IEC 60034-18-32). By using different over-voltages or frequencies, a life curve may be established (Clause 9). Note that interactive ageing mechanisms between turn and mainwall insulation are ignored in this document. On the basis of the following assumptions, the life of the insulation system under impulse conditions may be estimated from a life curve, even though it has been derived from sinusoidal voltage testing.

a) The ageing rate due to impulse and power frequency voltages is the same, provided the peak/peak values and the number of fundamental voltage cycles are the same.

b) The lifetime exponent, n, is not frequency dependent below 1 kHz.

Qualification of the stress grading and corona protection systems is undertaken through a separate ageing test in which a representative sample of insulated winding in a simulated slot is exposed to impulse voltage stresses similar to those expected in service for a period of time to determine if any visible damage occurs, such as discolouration or burning.

The use of service experience as an alternative to qualification testing is subject to agreement between purchaser and manufacturer.

7.3 Acceptance test

In the case of Type II insulation systems, production coils in simulated slots are subjected to a 50 Hz or 60 Hz sinewave voltage, applied across the mainwall insulation for 250 h with a peak/peak value equal to the 4,3 times the maximum peak to peak voltage appearing across the mainwall insulation under converter operation (Annex C). This is a quality test of the mainwall insulation and a withstand does not imply an acceptable service life with a converter drive. However, it is feasible to undertake it within the contract period and thereby establish the absence of major flaws in the production system.

8 Qualification of turn insulation

8.1 General

The turn insulation in the coils of a machine winding operating from a sinusoidal power supply is generally specified according to the requirement to withstand discrete voltages of high magnitude and short duration. The concerns governing turn insulation design are distinct from those for the main wall insulation. The materials, dimensions and processes used in the construction of turn insulation may be different from those of the main wall.

Depending on the expected phase/ground voltage in the machine, qualification of the turn insulation may be required. The principal features of this voltage in regard to ageing of the insulation between turns are the impulse rise time and magnitude of the jump voltage. When regarded as part of the overall coil design for the winding, the turn insulation also forms part of the mainwall insulation and contributes to the ageing curve described in Clauses 7 and 9.

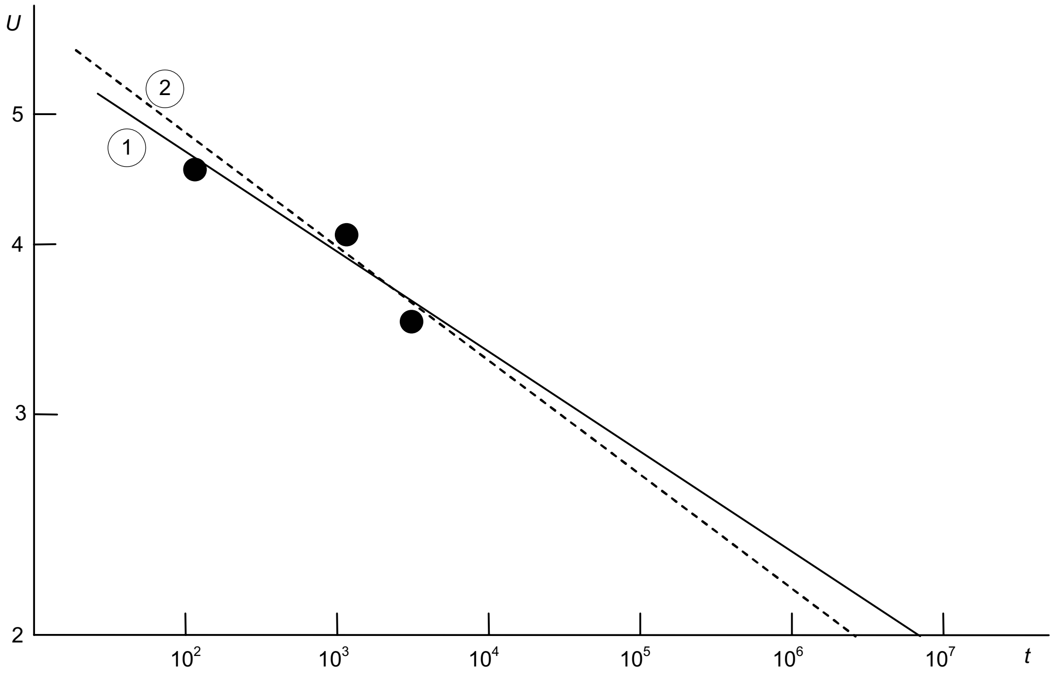
In the majority of sinusoidal voltage applications, the insulation between turns will not be stressed significantly during service. Its principal role is to withstand occasional voltage surges or similar events. However, as the rise time of the impulses decreases, the electrical stress associated with the jump voltage begins to shift to the regions between turns, particularly at the turn corners. This can cause thermal and electrical ageing of the turn insulation in service. The stress between turns intensifies with decreasing rise time, increasing the probability of partial discharges between turns. The effect of the expected phase/ground voltage on the turn insulation will also be dependent on the number of turns in the coil. In line-fed operation, stochastic high impulse voltages occur which are absent under converter operation. Therefore, the turn insulation will not get aged electrically in line-fed operations but it may in converter operations, due to the high impulse repetition frequency.

In general, experience indicates that the stress intensification is greatest between the first and second turns in line-end coils but it may be possible for waveform reflection to initiate ageing at sites further into the winding.

8.2 Test methods

The purpose of testing is to show that the electrical life of the turn insulation in service is acceptable. That is to say, it is expected to last as long as, if not longer than, the mainwall insulation. Samples will consist of two single turns that are formed as described in 11.2. It is expected that the manufacturer will know what is the maximum peak/peak voltage to appear between turns in a particular service application. This value should be increased by a safety factor, in accordance with the manufacturer’s design rules, to give the basic peak/peak test voltage, U_{turn}. If the maximum peak/peak voltage in service is unknown, it should be assumed that the complete jump voltage may fall across the first coil and so the test voltage is the jump voltage divided by the number of turns, multiplied by a safety factor. In a transverse design of coil, U_{turn} is taken to be the jump voltage divided by the number of layers and multiplied by a safety factor. An additional enhancement may be included to allow for the voltage developed along a conductor arising from the travelling wave that is propagated along it. This enhancement varies with rise time of the impulse.

The testing is in two stages. In the first stage, U_{turn} is applied between the two conductors of the test sample as a 50 Hz or 60 Hz sinusoidal voltage for 60 s. If partial discharge is absent, it may not be necessary to perform qualification testing. If partial discharge activity is detected, a voltage endurance test is to be performed. This will consist of applying repetitive impulses as described in IEC 62068-1 or a sinusoidal voltage at (or above) the repetition frequency of the converter between the two conductors in the test sample until electrical breakdown occurs. Suggested examples of voltage are 4,5 U_{turn}, 4,0 U_{turn} and 3,5 U_{turn}. The number of test voltages should be at least three. Five samples should be tested at each voltage. The time to failure may be calculated using any commonly used statistical methods (see IEC 62539). A graph may then be plotted showing the time to failure of the turn to turn insulation as a function of test voltage, as shown in Figure 6, where the scales are logarithmic.



Key

Line 1 life line for turn insulation

Line 2 life line for mainwall insulation

t time to breakdown

U test voltage/U_{turn} for line 1 or test voltage/U_{N} for line 2

Figure 6 – Life lines of turn and mainwall insulation

This life line may then be compared with the life line for the mainwall insulation and should show a longer projected lifetime at service voltage. Since it is not practicable to extrapolate over such a large distance, it is enough that the turn insulation life curve should be equivalent to, or better than, that for the mainwall. Equivalence is supported by any partial overlap of the 90 % confidence intervals of life values and voltage endurance coefficients of the life lines for turn and mainwall insulation for ageing times longer than 1 000 h. It is recognised that a satisfactory life curve may not be available for comparison purposes. In this case, the manufacturer is responsible for providing a satisfactory design.

9 Qualification of ground wall insulation systems

9.1 General

Acceleration of the ageing process that leads to electrical failure will be a desirable feature of the test method used. Care should be taken to avoid introducing a failure mechanism that would not be present in service. Where acceleration is produced by an increase in voltage excursion (peak to peak), the technique may change the level of partial discharge activity occurring within each impulse. Alternatively, the repetition frequency of the test voltage may be increased to a level above the fundamental frequency of the power drive system in service. This is intended to retain the partial discharge activity level and achieve acceleration through an increased repetition rate. In this approach, there may be an increase in heating of the insulation due to frequency dependent losses in the material and the stress grading system but this can be reduced by forced air cooling. Localised hot spot temperature measurements are required in the region where stress control systems are used to ensure that the insulation material does not exceed the assigned temperature for its thermal class.

Temperature monitoring may be performed using any convenient technique. Temperature sensitive paints or films are simple but not very accurate while thermocouples may have electromagnetic pick-up and HV isolation difficulties. A non-invasive measurement technique, such as infrared thermography, enables surface hot spots to be identified and quantified simply. These limit the operating conditions for the machine. Monitoring of the ageing process may be performed at appropriate intervals by measuring electrical parameters, such as partial discharge activity, loss tangent and permittivity. These tests may be performed at 50 Hz or 60 Hz for diagnostic purposes.

9.2 Test methods

Techniques for accelerated voltage ageing are described in IEC 61251, IEC 62068-1 and IEC 60034-18-32. They are based on a comparison of life tests performed on the candidate system and on a reference system, already assessed for service life. A commonly used electrical life model is

$$L = k \times U^{-\mathrm{n}}$$

where:

n is the voltage endurance coefficient;

L is the life of the test object;

U is the applied periodical peak voltage;

k is a constant.

The technique requires testing at three or more over-voltages to enable a graph of log(applied voltage) to be plotted against log(time to failure). The test voltages should be chosen to produce mean times to failure ranging from 100 h to 3 000 h. The candidate and reference systems should be tested under the same conditions, which may involve any prescribed voltage waveform. Statistical analysis should be performed according to the procedures given in IEC 62539 in order to establish the mean life under each test condition. The voltage endurance coefficient is the slope of the regression line (see IEC 60216-3). The life line of the candidate insulation system should be at least equivalent to that of a reference system tested at 50 Hz or 60 Hz which has been shown to give an acceptable service life. Equivalence is supported by any partial overlap of the 90 % confidence intervals of life values and voltage endurance coefficients of the life lines for candidate and reference systems for ageing longer than 1 000 h. Failure to fit a linear regression in a log/log co-ordinate system usually indicates that the ageing mechanism has changed within the test stress range.

For mainwall and turn insulation, many publications show no essential influence of the voltage frequency on the number of impulses to failure or the number of voltage cycles to failure. In many cases, therefore, the following formula can be used to calculate the expected life for a given peak voltage.

$$L_2 = L_1 \times f_1 / f_2$$

where

L_2 is the life at frequency f_2;

L_1 is the life at frequency f_1.

Combining the frequency and voltage dependent ageing formulae leads to the general expression

$$L_{\mathrm{f2,u2}} = L_{\mathrm{f1,u1}} \times (U_1/U_2)^{\mathrm{n}} \times (f_1/f_2)$$

where

$L_{\mathrm{f2,u2}}$ is the life at frequency f_2 and voltage U_2,

$L_{\mathrm{f1,u1}}$ is the life at frequency f_1 and voltage U_1.

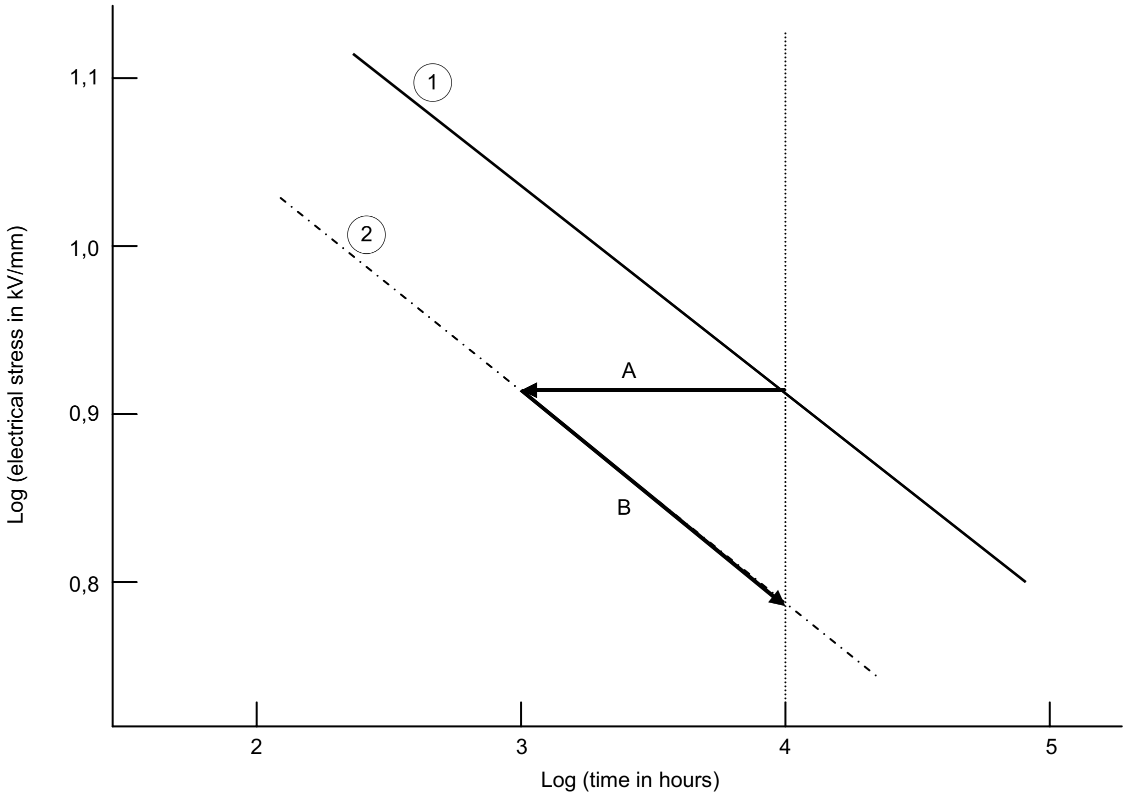
Using this formula, testing at different frequencies and voltages is possible for mainwall and turn insulation. Experimental evidence exists to support the validity of this approach in calculating life under sinusoidal and impulse voltages at least up to 1 kHz. However, the frequency range over which it is maintained for any particular system may be unknown and for a rigorous application of the formulae (see Annex B), the variation of the life exponent “n” with frequency should be known. In the event that the exponent “n” is unknown, a rough calculation may be performed on the basis of a range for “n” in epoxy/mica systems of $10<n<12$. The dominant factor in voltage ageing is the peak to peak voltage at the fundamental frequency. This does not coincide with the peak to peak of the fundamental voltage obtained from the Fourier transform of the supply waveform. For insulation systems fed from converters, there is a contribution to ageing from the impulse frequency jump voltages. However, most converter drives for Type II insulation system machines are at least 3-level and this results in less ageing than from a 2-level system because the impulse frequency peak to peak voltages are smaller. Nonetheless, it may be necessary to take account of the smaller ageing effect produced from impulse frequency peak to peak voltage transitions and this may be calculated using the procedure described in Annex B, based on the general life expression above.

A calculation of the contribution to ageing from the impulses at the repetition frequency for values of “n” in the range 8 to 12 and for various overshoot factors is shown in Table B.1 for the case of a 3-level converter. A repetition frequency of 1 kHz is representative of present day practice. For values of “n” equal to 10 or more, the contribution to ageing from the impulse frequency voltage is insignificant at 1 kHz.

9.3 Use of 50 Hz or 60 Hz life data to predict the service life with a converter drive

A typical life curve for a Type II insulation system derived from 50/60 Hz voltage endurance testing is shown in Figure 7. The log (mainwall electrical stress in kV/mm) is plotted as a function of log (time to failure) of the mainwall insulation on a stator bar. The life curve is usually a straight line and the manufacturer should know from service experience that the curve represents a design that will provide an acceptable service life. For converter-fed machines, the electrical stress is calculated on the basis of the peak to peak voltage occurring in service across the mainwall insulation.

If it is expected that the same insulation system may be subjected to a fundamental frequency which is, for example, 10 times greater than that used to derive the curve, it is assumed that the appropriate life curve for this operating condition will be translated to the left (arrow A) by one decade in time, as shown. The manufacturer can then compensate by reducing the mainwall insulation stress to move down this curve and thereby restore the life to the original value (arrow B). Alternatively, if the operating frequency is one tenth of that used to derive the life curve, the line will be translated to the right by a decade in time and the stress may be increased to restore the life to the original value.



Key

1 Life curve derived from power frequency endurance testing

2 Life curve predicted for the same insulation under converter drive at ×10 frequency

Figure 7 – Example of a life curve for a Type II mainwall insulation system

10 Qualification of the stress control and corona protection system

10.1 General

If a stress control system is to be applied to the endwindings, it will be necessary to qualify it. For this purpose, similar voltages and repetition frequencies to those appearing in service are required. The materials, if based on semi-conductive components such as silicon carbide, have a non-linear resistivity. Others have a linear resistivity. Their field controlling ability is influenced by frequency, electric stress, temperature and time. In other cases, the stress grading may be achieved by capacitive means. For test purposes, the peak/peak voltage, the repetition rate and the impulse rise time are chosen by the manufacturer to ensure that the expected conditions in service are matched or exceeded in severity.

The effect of increasing frequency is to shorten the distance over which the surface electric stress on the endwinding is stress graded and thereby result in elevated stresses. When these exceed a level of about 500 V/mm, arcing activity can occur which erodes the surface or produces tracking (conductive carbonaceous paths).

The effect of increased electric stress is to reduce the resistivity of stress grading material, thereby fulfilling its primary purpose. Unfortunately, the effect is also to increase the heat dissipation. For converter-fed machines, there is a conflict between providing a low enough resistivity to grade the voltage and a high enough resistivity to keep the heat dissipation within acceptable limits. A surface temperature rise in the endwinding region may be as little as 10 K or as high as 40 K for a converter-fed machine where there is no forced cooling. The dominant influence on the temperature of the insulation is expected to be the heating from the copper losses but the self-heating of the stress grading material can make a significant contribution. When assessing the limiting temperature at which the machine can operate, it is necessary to take account of this factor as it effectively reduces the maximum rated temperature of the machine.

It has been found that, for non-linear stress grading materials for example, there are two principal effects of temperature. The first is an immediate increase in the conductivity of the material at a particular voltage stress. Of similar significance is the reduction in slope of the conductivity/electric stress curve on which successful performance of silicon carbide-based stress grading material depends. In some cases the non-linearity of the conductivity may be lost altogether.

The second effect may be a permanent reduction in conductivity from this temperature excursion. After a single short-term period at 155 °C for as little as a few hours, a return to 20 °C can show a significant reduction in conductivity. After a longer period at 155 °C, say 500 hours, the stress grading performance may be partially restored. This is attributed to post-curing of the resin in the stress grading material that shrinks and binds the silicon carbide particles closer together.

The corona protection layer is used to prevent slot discharges and may be based on carbon loaded tapes or paints. At the beginning of the endwinding region, there may be problems with the electrical contact to the stress grading material. Where a good electrical contact is required in the design, a high contact resistance can result in overheating and discharge activity, which can degrade the materials and also the performance of the stress control system on the endwindings. Where capacitive coupling is used, no direct connection is required between the corona protection layer and the stress grading material.

Design of the stress control system is a crucial element in achieving successful performance. The factors governing this are the choice of materials and the application technique.

10.2 Test methods

The aim of qualification testing of the stress control system is to provide assurance that it will operate satisfactorily for the required service life. A satisfactory performance is one in which surface arcing is avoided and the temperature rise on the surface of the endwinding does not raise the mainwall insulation above its assigned temperature.

The two major influences on the life of the stress grading system are the applied voltage and the temperature. Ideally, a test is required in which sample bars, prepared with a corona protection layer and stress grading material as appropriate, are arranged in simulated slots and subjected to voltage impulses that are at least 1,3 times the magnitude of the voltages to be withstood in service. The bars may be shorter than in the service machine in order to reduce the capacitive load on the impulse generator. However, they should replicate all other design features. The test should continue for 100 h.

The cost of laboratory equipment to provide the required HV impulses may be significant. Furthermore, it would not generally be practicable to use the converter intended for service application to apply the impulses. A proposal is made for a simple screening test which experience has shown can quickly reveal deficiencies in a stress grading system. It avoids the need for a commercial converter drive and is based on an impulse repetition circuit using a spark gap. An example of a circuit that has been used for testing bar samples is given in Annex A.

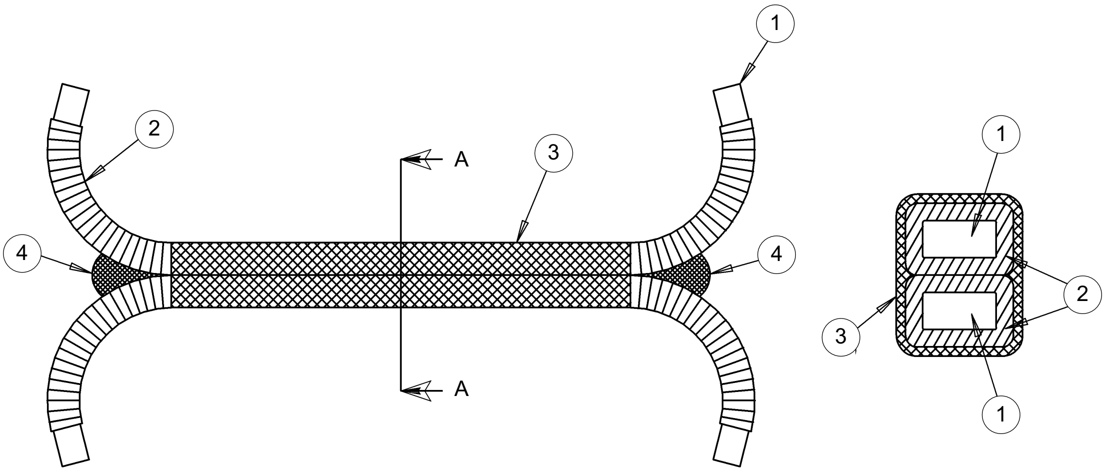
11 Preparation of test objects

11.1 General

The test objects in this clause are for qualifying the performance of the insulation components described in Table 1. The samples are made from the same materials and processes that are used to make service coils.

11.2 Turn/turn samples

The turn/turn samples should represent the insulation system used in the machine in terms of materials and dimensions. Pairs of insulated conductors are held together (Figure 8) with the terminals splayed apart and processed according to production standards. The insulated conductors should be in contact along the length of the straight portion to simulate the contact between turns in a coil. To maintain this contact it may be necessary to process the samples using pressing operations and/or VPI, as required by the design and materials. Round wires may require a different construction, such as twisted pairs impregnated to production standards. The test samples for turn insulation in random wound machines are described in IEC/TS 60034-18-41.



Key

1 Copper conductor

2 Turn insulation

3 Binding tape

4 Non-conductive, one-part silicone filler (or equivalent)

Figure 8 – Example of the construction of a turn/turn test sample for rectangular conductors

The bend formed in the conductors should be no more severe than the smallest radius to be encountered in the production coils. A flexible barrier such as a polyimide film should be used between the splayed conductors if there is a likelihood of an electrical failure being introduced at this point which would not occur in service.

11.3 Coils

To qualify the mainwall insulation and stress control system to be used in the stator, testing of coils built to production standards and fitted into representative slots is undertaken. In this case, the test objects should be made to the full manufacturing specification for a production machine but may be of reduced slot length so that the capacitive load is minimised.

12 Qualification test procedures

12.1 General

It is not practicable to design a single test method that simulates all the interactions between the various insulation components shown in Table 1. For example, to obtain a life curve for the mainwall insulation system by applying over-voltages would subject the stress grading system to excessive stress. Qualification has therefore been divided into separate test procedures. In all cases, the power supplies should be chosen to provide the required voltage, repetition rate and rise time at the sample terminals.

The aim is, firstly, to establish the life curves of the mainwall and turn insulation from which the expected lives may be calculated when the machine is driven from a converter supply in service. It is recognised that PD activity may take place between the turn and mainwall insulation. Since the phase to ground insulation includes the turn insulation, the qualification procedure includes this interactive effect. Ageing is performed by the application of electrical stress at an elevated voltage or frequency or both. The voltage waveform used for ageing may be sinusoidal or impulsive in the case of turn/turn or coil samples. The end-point is to be electrical breakdown. There should be a sufficient number of samples to achieve a statistically valid outcome to the test. The second aim is to establish that the stress control and corona protection systems are suitable for service. Testing is undertaken using an impulse waveform.

12.2 Turn/turn samples

The test samples for the candidate turn insulation system should conform to the manufacturer's design, materials and construction used for production coils. It is recommended that at least 5 turn pairs be tested at each test voltage under ambient conditions. Test samples should be separated to prevent electrical flashover between the leads.

Partial discharge testing is undertaken initially on five samples at the maximum expected turn/turn peak/peak service voltage, multiplied by a safety factor (U_{turn}). The test voltage may be sinusoidal and applied between conductors at a frequency of 50/60 Hz under ambient conditions. If PD activity is detected within 60 s, a life line should be determined by voltage endurance testing. The voltage endurance testing should be performed as described in 8.2 using no fewer than three applied voltages in order to construct a life curve for the turn insulation. If it can be established that no partial discharge activity will occur in service between neighbouring turns in a coil, it may not be necessary to test turn/turn samples.

12.3 Coils

The purpose of the test is to establish the life curve for the mainwall insulation using elevated voltage and/or frequency. At least three voltages or frequencies should be selected and the end-point is when breakdown of the insulation takes place. A calculation is performed according to 9.2 to estimate the life under converter drive and this is compared with the values derived from an accepted life curve, i.e. one that has been derived from an insulation system that has been shown to provide an acceptable service life under power frequency or other frequency operation. A minimum of 5 samples should be tested at each test condition. In order to reduce the capacitive load on the test supply, the samples may be of reduced length but otherwise similar to the coils or bars used in service. If it can be established that no partial discharge activity will occur in service across the mainwall insulation in a coil during converter operation, it may not be necessary to qualify the mainwall insulation system.

It is recognised that, where stress grading systems are in use on endwinding insulation, they may be subjected to an unacceptable severity during life testing of complete coil systems at elevated voltages. For this reason, the coils may be tested with any stress relieving measure, such as stress cones or additional layers of insulation, in order to ensure that failure occurs only in the mainwall insulation. The stress grading system may be repaired during the test period.

12.4 Stress control samples

Where a stress control system is to be used in the region of the endwindings, samples should be made to the requirements of 9.2 and mounted in representative or simulated grounded slots. They are then subjected to a 100 h impulse voltage test which satisfies the requirements given in 9.1. Testing should be performed at room temperature and also at the maximum temperature at which the machine is expected to operate in service. The voltage impulses should be at least 1,3 times the magnitude of the voltages to be withstood in service. In addition, the rise time should be at least as small and the repetition rate at least as large as expected in service. A sufficient number of samples should be tested to provide a statistically valid outcome. As a guide, it is recommended that at least five samples of stress graded region be tested at each temperature.

The region of insulation outside the simulated grounded slot should be scanned for temperature hot spots using infrared thermography. Testing should also be performed under the same conditions inside a dark room to establish that no arcing takes place on the surface of the endwinding. Experience has shown that if surface discharges are present, they may be identified visually after a period of about 20 min.

13 Qualification test pass criteria

13.1 Turn/turn samples

If the application of U_{turn} between conductors does not give rise to partial discharge activity in any of the five samples tested, the insulation may not need to be qualified. If PD activity is detected in this test in one or more samples, the turn insulation life line should be compared with that of the mainwall insulation. If the value of the voltage endurance coefficient and the lifetime at a selected percentile (normally 50 % or mean values) are equivalent to those of the mainwall insulation tested at 50 Hz or 60 Hz that has been qualified for converter duty, the turn insulation is qualified. Equivalence is supported by any partial overlap of the 90 % confidence intervals of life values and voltage endurance coefficients of the life lines for turn and mainwall insulation materials for values above 1 000 h. It is recognised that a satisfactory life curve may not be available for comparison purposes. In this case, the manufacturer is responsible for providing a satisfactory design.

13.2 Coil samples

The life line obtained from voltage endurance testing should be corrected according to 9.3. The value of the voltage endurance coefficient and the lifetime at a selected percentile (normally 50 % or mean values) should be equivalent to those of conventional insulation tested at 50/60 Hz that has been shown to give an acceptable service life. Equivalence is supported by any partial overlap of the 90 % confidence intervals of life values and voltage endurance coefficients of the life lines for candidate and reference materials for values above 1 000 h.

13.3 Stress control samples

No partial discharge activity should be visible to the unaided eye in a dark room after 20 min of testing with impulse voltages. The maximum hot spot temperature measured on the surface of the endwinding region of the test objects should not raise the temperature of the insulation above its assigned temperature limit at the maximum expected operating temperature of the machine. No deterioration of the stress control system should be visible on the outer surface of the endwinding by the unaided eye (i.e. without the aid of a microscope or magnifying glass) after 100 h of testing with impulse voltages.

14 Acceptance test for Type II insulation systems (Type test)

14.1 General

Type II insulation systems are subjected to an accelerated ageing test using a 50 Hz or 60 Hz waveform and failure should not occur before a specified time. The decision as to whether acceptance tests are undertaken or not is to be agreed between the manufacturer and purchaser.

14.2 Acceptance test methods

Coils made to production standards are mounted in simulated slots and subjected to a 50 Hz or 60 Hz sinusoidal voltage with a peak to peak value of 4,3 times the maximum peak to peak phase to ground voltage appearing on the coils during converter operation. The voltage ratio of 4,3 is related to a lifetime exponent of approximately 10. The slot simulators should be earthed. Any stress control and corona protection measures to be used should be applied to the coils beforehand. This is primarily a test of the mainwall insulation and the test conditions may be too severe for the stress grading materials to last the complete test period. Remedial work on the stress grading materials is permitted. The test is conducted at room temperature and humidity on at least two complete coil samples by agreement between the manufacturer and the purchaser.

14.3 Acceptance test pass criteria

After 250 h, no samples should have failed by electrical breakdown. If any coil sample fails, an investigation of the cause should be carried out. The test is to be repeated with new improved samples.

NOTE Experience has shown that a lifetime of 400 h with a multiplying factor of 3,4 is an equivalent criterion and may be used instead.

15 Analysis, reporting and classification

The approach given in 5.6 of IEC 60034-18-1 to analysis, reporting and classification should be adopted so that all relevant data is analysed correctly and reported in a traceable manner.

Annex A
(informative)

A.1 Impulse test circuit based on a spark gap oscillator

A circuit diagram is shown in Figure A.1 for a laboratory test kit to produce impulses similar in magnitude, repetition rate and rise time to those used in commercial converter/machine assemblies at present. It has been found suitable for turn/turn and stress control system testing but not for complete coils.

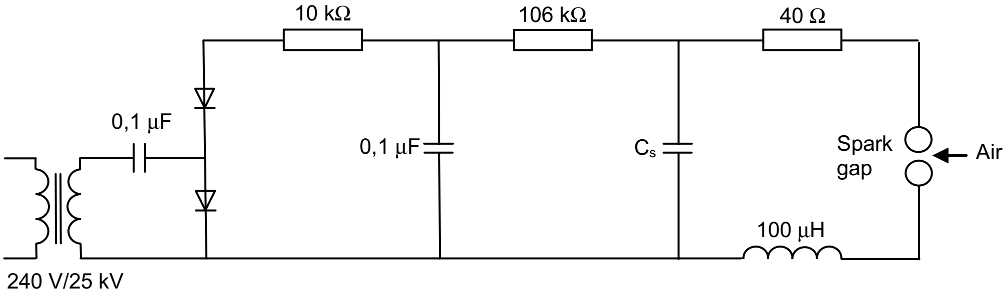


Figure A.1 – Example of a simple converter voltage simulation circuit

In this circuit, the sample bar is C_s and typically has value of 2 nF. If its capacitance is less, additional parallel capacitance should be added to reach this value. The spark gap is made using two tungsten rods, each 10 mm diameter with a hemispherical tip, and requires a jet of air at 2 bar across it. It should be set with a spacing of about 2 mm to give a breakdown voltage of 7 kV, at 2,5 mm for a breakdown voltage of 10 kV and 3 mm for a breakdown value of 12 kV. Under these circumstances, a stream of impulses with a maximum repetition rate of 3,5 kHz and an average of 1,5 kHz is generated. The variation arises from the simple half-wave rectification process. The impulse waveform is a falling voltage until breakdown occurs after which the voltage rises in 1,5 µs with a peak/peak value of 16 kV (Figure A.2). The maximum dV/dt in the wavefront is 15 kV/µs. There is a small oscillation after this impulse but it has a relatively slow rise time and small peak/peak voltage. The repetition rate, rise time and peak/peak voltage can be changed through the circuit parameters. Some of the resistors and the diodes need cooling. Experience has shown that, under these conditions, the tungsten tips may need re-grinding after about 24 h.

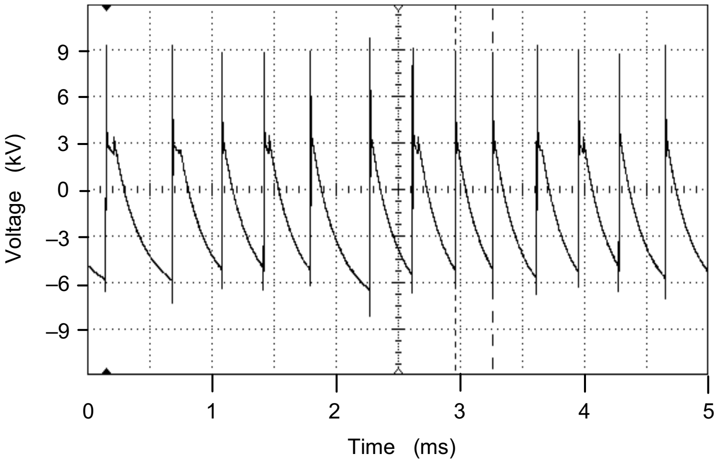


Figure A.2 – Typical waveform generated from the spark gap oscillator

Annex B
(informative)

B.1 Calculation of the contributions to ageing from a 3-level converter

This Annex gives examples of the factors for accelerated ageing of stator mainwall insulation in 3-level converter-fed machines. It shows the effects of electrical ageing and ignores thermal ageing. The following assumptions have been made.

a) The general life expression in 9.2 applies.

b) The value of "n" does not change with voltage or frequency in the range considered.

The converter characteristics chosen for this example are a 3-level system with a repetition frequency of 1 kHz, which is a commonly found value. The contribution to the ageing from the converter impulses is given as a percentage of the total ageing for different values of overshoot factor U_b/U_a (see Figure 1).

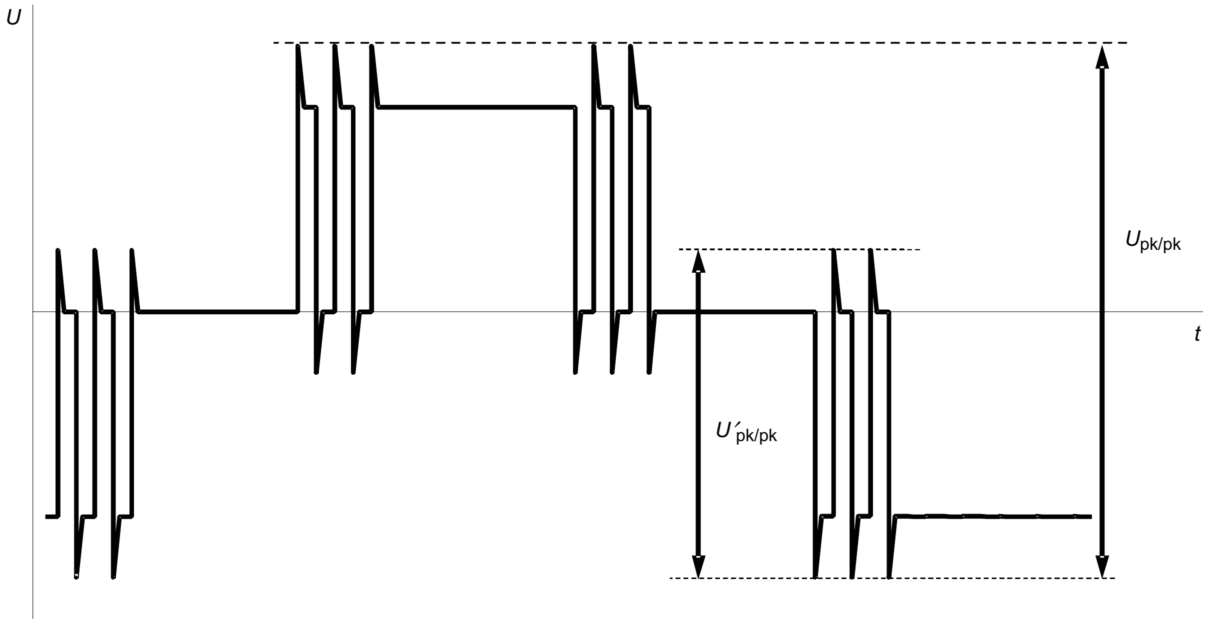


Figure B.1 – Representation of the phase to ground voltage at the terminals of a machine fed from a 3-level converter

The calculation used for each contribution to ageing is based on the formulae given in 9.2. The ageing rate per impulse is proportional to 1/L so, as an example, for a fundamental impulse at 50 Hz and a peak to peak fundamental voltage of $U_{pk/pk}$ the contribution to ageing over a period of 20 ms is given by

Ageing rate (50 Hz) = $(U_{pk/pk})^n/k$ where k is a constant.

For a 3-level converter with no voltage overshoot, the contribution to ageing from 1 kHz impulses over 20 ms is given by

Ageing rate (1 kHz) = $\frac{(U'_{\mathrm{nk/nk}})^{n} \times 20}{k}$ (See Figure B.1)

According to the cumulative ageing rate theory and in the absence of synergism, the total ageing rate is therefore the sum of these two contributions.

Table B.1 has been generated by substituting appropriate values in the two equations above. As an example, a 20 % overshoot factor (Figure B.1) would give

$$U'_{\mathrm{pk/pk}} = 1{,}4U_{\mathrm{a}} \text{ and } U_{\mathrm{pk/pk}} = 2{,}4U_{\mathrm{a}}$$

and the percentage contribution to ageing from the converter impulses for n = 10 is given by

$$\frac{(1{,}4)^{10} \times 20 \times 100}{(2{,}4)^{10}}$$

Table B.1 – Contribution to electrical ageing by 1 kHz impulses from a 3-level converter as a percentage of the ageing from the 50 Hz fundamental voltage for various values of voltage endurance coefficient (n)

Overshoot factor (U_b/U_a)	**Frequency of impulses**	**n = 8**	**n = 9**	**n = 10**	**n = 11**	**n = 12**
0 %	1 kHz	7 %	4 %	2 %	< 1 %	< 1 %
10 %	1 kHz	14 %	8 %	4 %	2 %	1 %
20 %	1 kHz	27 %	16 %	9 %	5 %	3 %
50 %	1 kHz	78 %	52 %	35 %	23 %	15 %

Annex C
(informative)

C.1 Derivation of the acceptance test voltage

Industrial experience has shown that the mainwall insulation in a line fed (sinewave) rotating machine should be able to withstand 2,5 U_N for at least 250 h in an electrical endurance test. This is equivalent to a voltage of 4,3 times the phase to ground voltage. In the case of converter-fed machines, the meaning of rated voltage is not clear and the relationship between the phase to phase and phase to ground voltage is more complicated. Nonetheless, the ageing mechanism of the ground wall insulation is still considered to be dependent on the peak to peak voltage excursion and the number of impulses in the same way as for line fed machines. This enables the equivalent acceptance test for converter-fed machines to be calculated as follows.

Acceptance test voltage for line fed coils

= 2,5 U_N (r.m.s.) for at least 250 h

= $2{,}5 \times \sqrt{3} \times U_0$ (where U_0 is the phase to ground r.m.s. voltage)

= $\frac{2{,}5 \times \sqrt{3}}{2\sqrt{2}}$ × (phase to ground peak to peak voltage)

Therefore

Acceptance test voltage for converter-fed coils = $\frac{2{,}5 \times \sqrt{3}}{2\sqrt{2}}$ × (maximum phase to ground peak to peak voltage).

For example, if the maximum peak to peak phase to ground voltage on a coil in a converter-fed machine is 8 kV,

The r.m.s. value of the acceptance test voltage = $\frac{2{,}5 \times \sqrt{3} \times 8}{2\sqrt{2}}$ kV = 12,25 kV.

(*Continued from second cover*)

International Standard	*Title*
IEC 61800-4	Adjustable speed electrical power drive systems — Part 4: General requirements — Rating specifications for a.c. power drive systems above 1 000 V a.c. and not exceeding 35 kV
IEC 62068-1	Electrical insulating systems — Electrical stresses produced by repetitive impulses — Part 1: General method of evaluation of electrical endurance
IEC 62539	Guide for the statistical analysis of electrical insulation breakdown data

Only the English text language of the IEC Standard has been retained while adopting it as an Indian Standard, and as such the page numbers given here are not the same as in IEC 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 : 1960 ‘Rules for rounding of numerical values (*revised*)’. 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

Amendment No.	Date of Issue	Text Affected

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