

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Rotating electrical machines –
Part 23: Repair, overhaul and reclamation**

**Machines électriques tournantes –
Partie 23: Réparation, révision et remise en état**



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INTERNATIONAL STANDARD

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**Rotating electrical machines –
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Partie 23: Réparation, révision et remise en état**

INTERNATIONAL
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COMMISSION

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**ROTATING ELECTRICAL MACHINES –
Part 23: Repair, overhaul and reclamation****FOREWORD**

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International Standard IEC 60034-23 has been prepared by IEC technical committee 2: Rotating machinery.

This first edition cancels and replaces IEC TS 60034-23 published in 2003. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- the title of the standard has been changed to *Rotating electrical machines – Part 23: Repair, overhaul and reclamation*;
- Clause 1 Scope
 - Hydrogen cooled turbine generators added to special applications,
 - maintaining or improving the rated energy efficiency added
 - ensuring environmental considerations are taken into account added;

- Clause 4 General Principles added to cover: hazardous areas, traction motors, machine efficiency, environment, end of life recycling. and circular economy considerations;
- Clause 5 General: Scope of work, health and safety, standards, quality, information required and documentation now covered;
- Original Annexes B and C incorporated into the standard;
- Clause 9 Final tests updated;
- Clause 10 Additional requirements for the repair and testing of DC machines added;
- Clause 11 Additional requirements for the repair and testing of High Voltage AC machines added;
- Clause 12 Customer reports and handover added;
- New Annex B standard tolerances added.

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

FDIS	Report on voting
2/1923/FDIS	2/1924/RVD

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

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

A list of all parts in the IEC 60034 series, published under the general title *Rotating electrical machines*, can be found on the IEC website.

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

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

ROTATING ELECTRICAL MACHINES –

Part 23: Repair, overhaul and reclamation

1 Scope

This part of IEC 60034 covers the procedures necessary to ensure the satisfactory repair, overhaul, and reclamation of all types and sizes of rotating electrical machines covered by the IEC 60034 series. The standard creates a generic industry procedure covering common aspects of a complete repair. The scope of work depends on the machine type, rating, condition, and the importance of plant reliability and safety. It includes

- determining cause of failure, where necessary;
- determining the extent of repair, as applicable;
- defining revised performance, operating and ambient conditions, if required;
- reviewing the original design, and upgrading the specification of the design, if required;
- proving the quality and performance of the repaired machine, maintaining or improving the rated energy efficiency;
- ensuring environmental considerations are taken into account.

This document does not supersede the requirements prescribed in IEC 60079-19 or elsewhere concerning the repair and overhaul for machines used in explosive atmospheres.

Machines for special applications such as hermetic, submersible, nuclear, hydrogen cooled machines, military, aviation and traction motors might have additional requirements, which are the subject of agreement between the service facility and user.

This document is not intended to take the place of the original machine manufacturer's instructions and recommendations.

Re-designs and performance changes requiring machine designer input are beyond the scope of this document.

2 Normative references

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

IEC 60034 (all parts), *Rotating electrical machines*

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

IEC 60034-6, *Rotating electrical machines – Part 6: Methods of cooling (IC Code)*

IEC 60034-11, *Rotating electrical machines – Part 11: Thermal protection*

IEC 60034-30-1, *Rotating electrical machines – Part 30-1: Efficiency classes of line operated AC motors (IE code)*

IEC TS 60034-30-2, *Rotating electrical machines – Part 30-2: Efficiency classes of variable speed AC motors (IE-code)*

IEC 60050-411:1996, *International Electrotechnical Vocabulary – Chapter 411: Rotating machines*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60072-2, *Dimensions and output series for rotating electrical machines – Part 2: Frame numbers 355 to 1000 and flange numbers 1180 to 2360*

IEC 60079-19, *Explosive atmospheres – Part 19: Equipment repair, overhaul, and reclamation*

IEC 60136:1986, *Dimensions of brushes and brush-holders for electrical machinery*

ISO 21940-11, *Mechanical vibration – Rotor balancing – Part 11: Procedures and tolerances for rotors with rigid behaviour*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60034 (all parts) and the following apply.

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

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

3.1

customer

person or company, who places the order for a repair with the service facility and may or may not be the owner or user of the machine

3.2

dismantling

disassembly of a machine into component parts or sub-assemblies

3.3

maintenance

routine actions taken to preserve the installed equipment in a fully serviceable condition

3.4

manufacturer

party responsible for the manufacture of the machine as originally supplied

3.5

overhaul

action to restore to fully serviceable condition equipment which has been in use or in storage for a period of time but which is not faulty

3.6

reclamation

means of repair involving the removal or addition of material to reclaim component parts which have sustained damage, in order to restore such parts to a serviceable condition in accordance with the original standards and specifications

3.7

refurbisher

party responsible for the refurbishing work, its sub-contractors and suppliers

3.8

refurbishment

total process of preparing a machine, no longer adequate for duty with normal maintenance, to make it suitable for further service

3.9

relevant standard

standard to which the equipment was originally designed

3.10

repair

action to restore faulty equipment to its fully serviceable condition complying with the relevant standard

3.11

repairer

manufacturer, user, or a third party (repair agency) who carries out the repair of the equipment

3.12

rewinding

part of the refurbishment related to removing and replacing some or all of the machine winding their insulation, connection and support systems

3.13

service facility

manufacturer, user, or a third party (repair agency) providing a service that consists of the repair, overhaul, or reclamation of equipment

3.14

serviceable condition

condition which permits parts or equipment to be used without prejudice to performance

3.15

user

owner, or party arranging or requiring the repair

4 General principles

4.1 Use of referenced documents

Older machines being repaired were designed to conform to earlier versions of the relevant standards applicable when they were manufactured. It is possible that they would not be able to meet the requirements of the latest standards. If this is the case the earlier standard should be referred to for the specifications that the machine was manufactured to.

4.2 Hazardous areas

This document can be used in conjunction with IEC 60079-19, but does not supersede the requirements prescribed in the latest version of IEC 60079-19. Special restrictions apply including

- the scope of repair allowed by machine certification,
- individual personnel 'Ex' competency,
- the specific design limitations of different protection concepts.

4.3 Special applications

For rail and road traction motors, IEC 60349-1 is used by the manufacturers of these machines. The service centre should also use the information in IEC 60349-1 to ensure the quality of their repair, in conjunction with the IEC 60034-23 repair standard.

4.4 Efficiency

Where machines have been designed to meet Minimum Energy Performance Standards (MEPS), as in the IEC 60034-30-1 efficiency classes and IEC TS 60034-30-2, they might be subject to legal requirements to maintain efficiency levels. The designs might have been verified by third party testing with declared minimum efficiencies shown on the nameplate. It is important to follow when repairing or rewinding all machines to ensure no degradation of performance.

Current energy efficient motors have to be within a set tolerance of their rated efficiency label. Any repair workshop, manufacturer's or independent service centre, with a good quality control system, using modern materials and using this standard, can maintain or improve the efficiency of a machine within the original efficiency tolerances that the machine was designed to meet.

4.5 System efficiencies

If a motor has already been updated to an energy efficient machine, then a repair is often the most environmentally friendly solution to extend the life of the machine, and maintain its rated efficiency. During the course of a machine evaluation the decision to repair or replace should be considered.

This is often the best time to calculate whether replacement with a new, more efficient machine would be cost effective. This varies greatly with the number of hours the machine is used and requires careful specialist consideration. As an example, unregulated pumps, fans, and compressors might use more energy, depending on how much they are used, due to less slip and the higher speeds of energy efficient motors. The application might be suitable for use with a converter to overcome this problem, or the impeller could be re-profiled. Many machines are also special due to limitations of size, fit, duty, speed, torque, etc. Consideration should also be given to the possible lower downtime and lower carbon footprint of a repair and re-use.

Electric motors are generally very efficient and reliable converters of energy. The majority of wasted energy and energy losses are often caused in other areas of the driven system such as pumps, piping design, gearboxes, fans and fan ducting, compressors, wiring, transmission etc. All of these items should be looked at as a complete system when looking for energy savings.

4.6 Environment and End of life recycling

Environmentally there are many advantages in a service centre handling a machine at, or close to, the end of its life and environmentally disposing of replaced machines to remove them from the system. Where hazardous substances (such as asbestos, PCB, lead, etc.) are identified, suitable measures shall be adopted using best practice to meet legislative requirements on their removal and disposal.

- a) Root cause failure analysis of a failed machine can identify problems of overloading, contamination, misalignment, faulty power supply, incorrect application, design or contractual limitations, etc., and significantly increase the service life of the repaired machine, or any new replacement.
- b) The feasibility of whether a machine should be repaired or replaced can be calculated by a service facility taking into account its actual usage, power usage, cost of repair, cost of replacement, and payback period.
- c) If the equipment is not repaired and it is at the end of its life, the equipment can be scrapped in the most cost efficient way and to prevent it entering the second hand market. The old equipment should be split into its component materials for recycling, for example:
 - clean or burnt copper wire;

- copper wire mixed with insulation and varnish;
- cast aluminium housings;
- steel solids: bearings, shafts;
- light cast iron: housings etc.;
- remnants of mixed scrap.

Any replaced components during a repair, such as copper wire and bearings replaced, should also be similarly recycled. Apart from the varnish and insulation, the repair industry is able to sort and recycle around 98 % of an old machine, and any components used in a repair.

When recycled into the separate elements, these materials require minimal energy input and transportation before reuse. They are also correspondingly “greener” and more valuable.

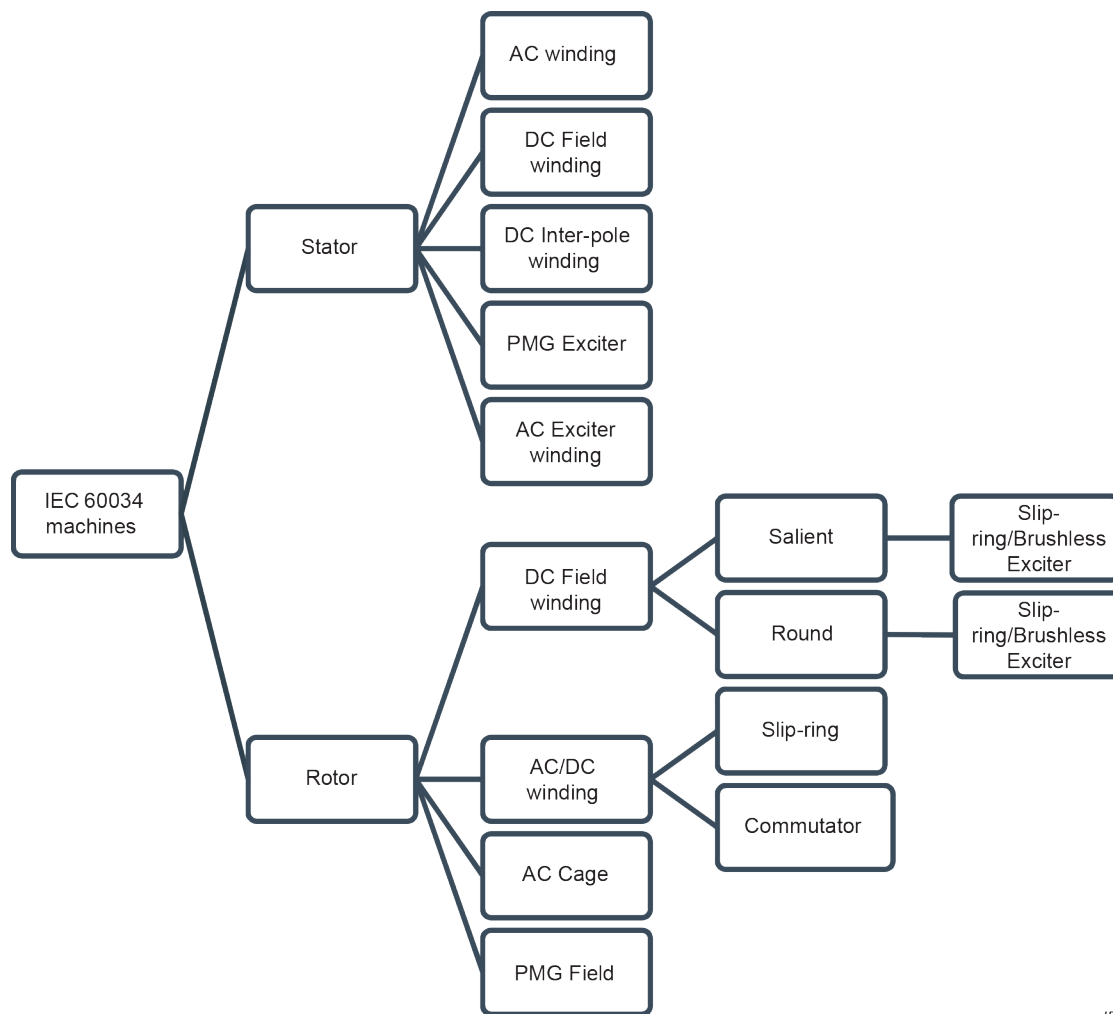
4.7 Circular economy

The repair process complies with all aspects of the circular economy, doubling or trebling the active life of rotating electrical machines and the use of materials in them. The rotating electrical equipment market has undergone a process of upgrading to more energy efficient machines to save on power usage, with the focus of standardisation on IE3 machines, or equivalent. The repair/refurbishment of energy efficient machines ensures the most efficient use of the world's dwindling resources. When repairing/maintaining a typical 110 kW machine with new bearings, the effective life is doubled and 99 % of the original machine is maintained. The old bearings, making up 1 % of the machine, are recycled as high quality “green” steel scrap. If the machine is rewound 90,5 % of the machine is reused during refurbishment. Weight for weight of the materials used during a rewind are returned as high quality green copper and steel scrap. The only items not reused or recycled during repair are the varnish, insulation, paint and grease, representing just 0,9 % by weight of the materials present in a typical 110 kW machine.

5 General requirements for repair

5.1 General

This clause covers those aspects of repair, overhaul, and refurbishment, which are common to all IEC 60034 series electrical machines. Subsequent subclauses deal with specific requirements for various machine types. In accordance with the needs of the user and local facilities, machines can be repaired on site, at the service facility works, or elsewhere. The key machine components are the stator and the rotor as shown below, see Figure 1.



IEC

Figure 1 – Electrical machine components

5.2 Service facility

The user should ascertain that the service facility can demonstrate the ability to undertake the repair being proposed. This includes adequate repair and overhaul facilities, the appropriate equipment necessary and trained operatives.

The service facility shall be competent in the techniques and technologies required for the repair of the original machine, and shall be able to predict the influence of the repair on the machine.

Clean conditions are extremely important during the storage and assembly of machines, and should be appropriate to the type of machine being repaired. These shall be provided and maintained by the responsible parties.

Precautions shall be taken to ensure protection from contamination and foreign material entry during the storage of components after strip down and during repair. Winding and final assembly should be undertaken in a clean and dry area protected from any ingress of foreign matter arising from disassembly, cleaning, machining, open doors, or poor housekeeping.

5.3 Scope of work

The service facility shall conduct an initial assessment of the state of the equipment and agree with the user the scope of work to be done.

The intent of the initial tests and visual inspections shall be to determine and record the condition of the received equipment, to document pre-work parameters, and to propose a scheme of work.

It is important to establish the 'root cause' if any failure has occurred. The problem might not have originated in the machine.

Machines shall be repaired to produce as good as, or better than, their original performance parameters, which shall be ascertained to the extent required by the user.

If any work could result in a permanent degradation of efficiency or other relevant performance parameters, the user's approval is required before proceeding.

5.4 Standards

The service facility should use the following key standards to check the dimensions and tolerances, or equivalent standards used in the manufacture of a machine. Standards are used by manufacturers in the design of their machines, and good repair practice should be to use the relevant standards wherever possible to check the quality of their repair:

Mechanical standards:

Dimensions and output (frames 56 to 400)	IEC 60072-1
Dimensions and output (frames 355 to 1 000)	IEC 60072-2
Enclosures (IP code)	IEC 60034-5
Methods of cooling (IC Code)	IEC 60034-6
Mounting arrangements (IM Code)	IEC 60034-7
Terminal markings	IEC 60034-8
Noise	IEC 60034-9
Vibration	IEC 60034 -14

Electrical testing:

Rating and performance	IEC 60034-1
Losses and efficiency	IEC 60034-2-1
Losses and efficiency of large machines	IEC 60034-2-2
Insulation resistance and polarisation index	IEC 60034-27-4

Where machines are manufactured and tested to other standards, for example NEMA, reference should be made to the relevant NEMA standard.

These attributes shall be maintained up to the original level after repair.

Built-in thermal protection and embedded temperature detectors, in accordance with IEC 60034-11, shall be of the same type and in the same locations as the originals unless otherwise agreed.

5.5 Quality program

A quality programme, which has been agreed with the user, shall be followed before starting the repair work to incorporate appropriate inspection, diagnostic, and test procedures. The programme shall ensure that the repair addresses the root cause of any failure, if this lies in the machine itself, and proves the machine is capable of the required performance after rectification. The user and service facility shall discuss problems originating from outside the machine which might have led to the failure.

Repair may be assisted by relevant items from the performance and test procedures, condition monitoring measurements, and criteria itemized below.

Applicability of these tests and diagnostic tools depends on the class of machine or component involved. User requirements should be agreed with the service facility where necessary.

The agreed procedures and tests for the applicable machine shall be included in the repair quality programme.

5.6 User supplied information

5.6.1 User transfer document

The user should provide information requested before a repair by the service facility in the form of a transfer document. The information required from the list will vary depending on the size and type of machine. Relevant information encompasses:

- a) operating environment, temperature, vibration, etc.;
- b) previous repairs, overhauls, modifications;
- c) efficiency requirements;
- d) supply quality, voltage unbalance, inverter harmonics, switching transients;
- e) type of driven equipment;
- f) hours of operation;
- g) active and reactive machine load;
- h) starting method, starting duty, number of starts, inertia, run-up time;
- i) auxiliaries fitted such as thermistors, thermocouples, resistance, temperature detectors;
- j) trending of key reliability parameters, e.g. insulation resistance;
- k) out of phase synchronisations;
- l) over speed and other abnormal operating conditions.

5.6.2 Operating environment

If the machine operates in severe environmental conditions, no repair methods or materials should be used which make the machine more vulnerable to these conditions than when it was originally built.

5.6.3 Converter/inverter operation

If the machine is powered by a converter/inverter, full details of the supply shall be obtained. Many applications designated as 'inverter duty' imply special design features such as magnet wire insulation, insulated bearings, and other precautions to ensure reliable operation.

5.6.4 Health and safety

The user should provide a 'safe to work on' statement advising that the machine contains no harmful chemicals, dust, bacteria, or other harmful substances (e.g. asbestos).

5.7 Documentation

5.7.1 Records

A new record of each machine received shall be established at the time of receipt. This should include (if relevant):

- a) nameplate data;
- b) electrical test data both before and after repair/refurbishment;

- c) mechanical inspection and measurement before and after repair/refurbishment;
- d) winding and connection data, before and after a rewind;
- e) list of replaced parts.

The service facility shall keep records of all work done including checks, measurements, problems found, mode of failure if applicable, repairs, and final tests carried out.

The relevant records should be made available to the user if required.

Records should be held for a minimum of three years, or as agreed with the user or specified in other national regulations or standards, for example 10 years for hazardous area equipment.

5.7.2 Labels and rating plates

The original rating plates shall be retained on the machine.

The repair facilities' name or logo and job number should be placed on a suitable label or indelibly embossed in the vicinity of the manufacturer's nameplate.

If any operational changes arise from the repair an additional rating plate conforming to IEC 60034-1 shall be provided.

6 Assembled machine: inspection, tests and evaluation

6.1 Visual inspection

The preliminary visual inspection forms an important part of the complete machine repair. It can provide information about the general condition of the machine and/or the reason for its failure. The inspection should be carried out before and after cleaning off any debris on the machine and consider whether it is relevant to the cause of failure. Records should be completed before any repair work on the machine is carried out and digital photographs of damaged or missing components, signs of distress, tracking, overheating, and poor lubrication.

Examples of areas to review include:

- a) machine nameplate data, efficiency standards, special rating plates e.g. converter, hazardous area, special service conditions, and transfer documents;
- b) frames, end shields, and bearing covers for signs of cracks or corrosion;
- c) insulation for signs of ageing, partial discharge activity (high voltage stator windings) abrasions, or cracking;
- d) stator core damage such as rotor rubs, loose laminations;
- e) shafts damage, distortion or discolouring;
- f) terminal boxes and glands including gaskets;
- g) cooling fans, ducts, fins, and covers, or blowers if fitted;
- h) heat exchanger systems (air-air, air-water, etc.);
- i) potential missing parts, such as gaskets.

For machines with access covers, or with open access to the stator or rotor, the detailed visual inspection shall include the condition of:

- the stator core;
- the stator winding and end-windings;
- the rotor.

Digital photographs provide an accurate record of how the machine was received. This also provides a visual record of any significant component defects found and provides evidence to the user of the remedial work required.

All findings should be recorded to ensure that a list of remedial action undertaken is available for the final report.

6.2 Tests before dismantling

6.2.1 Safety

In addition to those items covered in 5.6.4, machines should be lifted and handled using the eyebolts, integrally cast bosses, or lifting rings provided. If any doubt exists over the fitted lifting points alternative methods such as slinging should be used.

6.2.2 Application

Whilst still assembled before repair, initial electrical tests carried out can identify obvious winding faults. These tests can find short circuits, open circuits, incorrect connections, high resistance connections, and poor insulation quality. The following selection covers the major tests at this stage.

6.3 Stator winding or rotor winding tests

6.3.1 Winding resistance test

An ohmic resistance test between pairs of isolated line connections of each winding can identify shorted turns, bad connections, wrong connections, and open circuits. The resistance falls rapidly as machines increase in size and will require a suitably accurate measuring method using an ohmmeter or milli-ohmmeter. Any resistive imbalance should be within the defined tolerances. The windings should be at a stable temperature and readings corrected to a mentioned temperature.

6.3.2 Phase balance test

The resistances of each phase, or between any pair of terminals by applying a reduced voltage of around 15 % of rated voltage to the open stator, to give the approximate motor rated current. The results should be compared and any significant unbalance shall be investigated. Criteria should be in accordance with the manufacturer's specifications. Typically the windings resistance should be within 1 % of each other for form wound coils, or 3 % for random wound coils.

6.3.3 Insulation resistance test

The insulation resistance test is fully described in IEC 60034-27-4 (see Table 1). An insulation resistance measurement should be carried out using a megohmmeter recording the test values, and normalise according to the above standard. Measurements shall be for an entire winding: between all windings and ground, between windings if multi-wound, between windings and auxiliaries, and between auxiliaries and earth using a DC MΩ meter for 1 min.

Insulation resistance changes significantly with temperature, humidity and contamination. For trending purposes, insulation resistances should be normalised to a reference temperature (normally 40 °C). Minimum acceptable insulation resistance values corrected to 40 °C are a function of rated voltage, temperature, type of equipment and whether the winding is a repair or a rewind (partial or complete). The following are the lowest values recommended to carry out a voltage withstand test or surge test, or to run when testing complete impregnated windings (see Table 1).

- a) 5 MΩ for low voltage random, form-wound windings, and DC armatures.
- b) 100 MΩ for high voltage synthetic resin based insulation systems (form-wound windings).

- c) Rated voltage (kV) + 1 for high voltage shellac and asphalt based insulation systems and all field windings.

The minimum insulation resistance of one phase of a three-phase winding, tested with the other two phases earthed, should be at least twice that of the entire winding. Grounding time should be at least four times the charging time. If each phase is tested separately and guard circuits are used on the two phases not under test, the minimum resistance should be three times the entire winding.

With all phase windings connected together, to test the entire winding to ground, leakage and stress control coating currents on the end winding are reduced, because lower currents will pass to other phase windings. Therefore it can be expected that the PI will be higher, compared to individual phase winding testing. The same is valid for the IR, as the entire winding has a higher resistance when compared to the values obtained from the sum of single phase winding tests, when calculating the IR from single phase winding measurements.

If the reading is not acceptable then further tests, which can stress the winding to failure, should not be carried out i.e. withstand voltage (hipot) or surge testing. Corrective measures such as cleaning and drying in an oven should be carried out to increase the insulation resistance value to an acceptable level.

Care must be taken to ensure that any electrical or electronic components connected to the windings such as AVR's on generators and instrumentation are disconnected from the windings.

**Table 1 – Recommended minimum insulation resistance values
at a base temperature of 40 °C reference IEC 60034-27-4**

Test object windings	Minimum insulation Resistance R_{i1} MΩ
High voltage shellac and asphalt based insulation systems and all field windings	rated voltage (kV)+1
High voltage synthetic resin based insulation systems (form-wound windings)	100
Low voltage random and form-wound windings and DC armatures	5
R_{i1} is the recommended minimum insulation resistance value in MΩ of an entire winding of the machine corrected to the base temperature of 40 °C kV is the rated machine terminal to terminal voltage, in r.m.s. kV.	

6.3.4 Polarization index test

The polarization index (PI) test is fully described in IEC 60034-27-4, it should be carried out using a megohmmeter and the same voltages as in Table 2 for 10 min. The minimum polarization index for windings rated with Class 130 (B) insulation or higher should be 2,0.

If the reading for insulation resistance is above 5 000 MΩ after 1 min, the PI calculation can become unreliable and could be disregarded.

The determination of the polarization index may not apply to small random wound machine, field windings in generator rotors, non-insulated field and squirrel cage rotor windings, and DC machine armatures.

Table 2 – Guide to application of DC voltages for the insulation resistance and PI test

Rated winding AC voltage: Line to line voltage for three phase machines. Line to ground for single phase machines. Direct voltage for DC machines or field windings. V	DC voltage for insulation resistance tests V
Up to 1 000	500
1 000 to 2 500	500 to 1 000
2 501 to 5 000	1 000 to 2 500
5 001 to 12 000	2 500 to 5 000
Over 12 000	5 000 to 10 000

Tests can be performed at higher magnitude only by agreement between the test service provider and the customer.

6.3.5 No load test

If a no-load test is required before overhaul, refer to 9.4. For completely assembled machines a no-load run should only be performed once all static measurements and inspection have been carried out, to determine whether it is safe to run the machine.

Significant noise and vibration can indicate problems with balance, rubbing cores, resonances, soft foot, or loose components.

Noise level measurements and spectral vibration analyses can give an indication of the type of fault, such as bearing damage, broken rotor bars, etc.

6.4 Shaft and bearings

6.4.1 Shaft checks

The condition of shafts shall be checked for wear, straightness, scoring and damage to the keyway. See Table B.2.

6.4.2 Bearing checks

Turning the shaft by hand can reveal problems with the bearings. A stiff or lumpy action could point to bearing damage from, for example:

- a) inadequate lubrication;
- b) bearing fatigue;
- c) vibration;
- d) improper alignment or installation;
- e) shaft currents;
- f) insufficient load;
- g) overload;
- h) contamination by moisture or foreign material.

6.4.3 Bearing insulation resistance

If fitted and measurable, the resistance of insulated bearings, couplings, pedestals, and shaft seals should be measured and checked against manufacturer's data.

6.5 Rotor cage integrity

6.5.1 General

Where broken bars or a damaged cage are suspected in a machine, either harmonic analysis of the stator current, and the vibration signals under load, or single phase test, should be carried out.

6.5.2 Current signature analysis (harmonic analysis)

The presence in the stator current, and/or in the vibration signals of harmonic components, that differ by twice the slip frequency with respect to the main component, can be an indication of broken bars, or broken cage windings (see ISO 20958).

6.5.3 Single-phase test method

Disconnect the motor from the power supply. The test is carried out by connecting a low voltage single phase supply to any two of the stator winding leads. Keeping the test current close to the rating current, the rotor is rotated by hand. A supply voltage of between 1/8 and 1/4 of the rated voltage should provide a test current of 75 % to 125 % of the rated motor current. If the current varies by more than 3 % from the maximum to minimum, this should be investigated and could be an indication of an open circuit rotor.

6.5.4 Pole drop test – Salient pole rotor (motor or generator)

An AC voltage is applied to the field windings to identify shorted turns with the rotor stationary. The pole drop test is not suitable for finding shorted turns caused by centrifugal forces during operation. Balanced readings should be within a tolerance of 10 % of the average. A follow up DC drop test may be used if the AC test results are not satisfactory, using a recommended 5 % tolerance of the average for the DC test.

7 Dismantled machine: inspection, tests, and evaluation

7.1 General

If the assembled inspection indicates that further investigation is required to determine the extent of repairs or refurbishment, the machine should be dismantled.

End brackets and frames shall be clearly match-marked. During disassembly machine components shall be marked or identified. Bolts and small parts shall be stored in dedicated containers marked with an identification number. Disassembled components or assemblies, shall be suitably stored to prevent damage or deterioration in clean, dry conditions.

The following are additional inspections and tests for different types of machines as required, which should be agreed between all contract partners.

7.2 Cleaning

Record or photograph any debris that might have caused the machine failure. The debris should be examined for root cause analysis.

The machine's instruction manual typically recommends suitable cleaning methods. To keep insulation in good condition and all parts corrosion-free, windings and component parts should be cleaned. Dirt, grease, oil and other contaminants should be removed using appropriate methods, which will not damage the machine, such as pressure washing, steam cleaning, solvent, dry ice, etc.

Cleaning and dismantling should be carried out in a confined area to ensure no contamination by dust, dirt, or spray is transferred to the assembly area for the machine.

7.3 Visual inspection

There should not be any evidence of:

- a) flashovers, short circuits, electrical tracking, corona, or hot spots;
- b) surge damage;
- c) slot wedge deterioration, especially in the composite and magnetic wedges;
- d) loss of insulation integrity in the winding connectors, leads, and terminals;
- e) rotor core rubbing on the stator;
- f) looseness or deterioration of the winding overhangs;
- g) oxidation on metal surfaces.

7.4 Air gap

The air gap should be concentric. Any eccentricities may cause unbalanced magnetic-pull on the rotor, causing increased noise, vibration, and losses. The air gap should be uniform and within 10 % of the average air gap for smaller induction machines; 5 % for 2 pole machines and larger synchronous machines, or compared with manufacturer's data or an initial known value.

7.5 Ventilation

To ensure the correct and energy efficient ventilation, the following items should be checked to ensure that they can perform in accordance with their specification:

- a) covers, louvres, and their accessories;
- b) fans, internal and external;
- c) auxiliary blowers;
- d) duct-work (restrictions might lead to overheating);
- e) no erosion marks on heat exchanger cooler gaskets;
- f) non-standard fans might affect the cooling and efficiency of the machine.

7.6 Stator

The winding should be inspected for evidence of winding failure patterns, e.g. single phasing, surge damage, shorted phase, shorted turns, inverter failure induced modes, grounded, or overloaded. Any tests on the windings not carried out whilst assembled (see 6.2), should be completed. The stator core should be checked for:

- a) loosening of end winding supports and bracing system or presence of abrasion powder, using borescopic inspection where required;
- b) insulation burning, cracking, migration, brittleness or evidence of partial discharge activity;
- c) loose or damaged stator slot wedges or packing;
- d) oil, dust, or moisture surface contamination;
- e) clogging of hollow copper strands (for direct water cooled windings);
- f) damage to accessories such as thermistors, heaters, temperature detectors (RTDs and thermocouples), and associated wiring;
- g) loose or defective laminations, duct spacers or tooth support fingers;
- h) burning due to shorted inter-laminar insulation;
- i) stator core lamination damage in the bore due to rotor contact or loose component impacts;
- j) fretting of the core laminations, or between the laminations and the core, if the rotor core laminations can be dismantled;
- k) burning or fretting at the interfaces between core lamination dovetails and core support bars;

- l) insulated core bolts fitted through the core should have insulation resistance integrity checked;
- m) blockage of cooling gas ducts due to contamination;
- n) evidence of loose dust, watermarks, or rust, due to water ingress or condensation, which might have contributed to the failure;
- o) the stator pack being loose in the stator frame;
- p) lack of concentricity between the stator core bore, and spigot (rabbet) for bearing bracket mounting on the stator frame.

7.7 Rotor

7.7.1 General

The rotor should be removed using safe working practice as dictated by its weight and size. Care shall be taken to avoid damage to the air gap surfaces or the windings. The rotor shall not be allowed to scrape along the surface of the core during removal. A rotor removal tool should be used where necessary. The following items should be checked:

- a) The total indicated run-outs of the rotor shaft extension, bearing journals or mounting surfaces, and seal surfaces, see Tables B.1, B.3, B.4 et B.5.
- b) The rotor outer diameter should be concentric with the bearing journals or mounting surfaces.
- c) The exact position of any axial thrust washers should be noted when dismantling the rotor.
- d) Any previous repairs or machining of the rotor should be checked for accuracy and tolerances.
- e) Any contact between the stator and rotor should be checked. Laminations should be examined for potential hot spots.
- f) The tightness of slot wedges should be checked (if fitted).
- g) The shaft, cooling gas fans, and other attachments to the rotor shaft, should be checked for cracks and strength of connection to the shaft.
- h) The shaft should be checked for straightness, wear, cracks, and absence of damage to the shaft ends.
- i) Note the orientation of the shaft in relation to the main terminal box and leads.
- j) For DC machines refer to 10.5.

7.7.2 Rotor removal: vertical machines

Vertical machines should be handled and dismantled in accordance with the manufacturer's instructions or safe working practices. Lifting safety considerations such as centre of gravity, lifting points, etc. should be correctly assessed and procedures implemented.

The manufacturer normally provides lifting facilities for the machine only, but might provide special lifting facilities for large vertical rotors.

To ensure the correct rebuilding of the machine the following should be recorded:

- rotor lift (end play);
- bearing types;
- special bearing orientation, alignment, and method of securement if applicable.

7.7.3 Cage rotor

The rotor core should be the correct fit on the shaft, sleeve, or spider, onto which the core is assembled. The rotor core outside diameter should be checked for rubs, mechanical damage,

missing parts and burning due to shorted lamination insulation. Bars and end-rings should be inspected for integrity which may include the following optional tests:

- a) growler test to check the magnetic circuit around the rotor bars. The field patterns produced can reveal broken bars or defects in a die-cast rotor;
- b) tap test to check the tightness of fabricated rotor bars in their slots;
- c) rotor retaining ring checked for cracks, if fitted;
- d) rotor slot wedges checked for cracks, where fitted.

7.7.4 Cylindrical wound rotor windings

Recommended tests include the following:

- a) insulation resistance to ground, and between phases if possible;
- b) surge comparison test to confirm winding symmetry;
- c) inspect end-winding banding for cracks and looseness;
- d) the connections between the winding terminals and the slip-rings;
- e) By passing a high AC or DC current through the winding, any cold spots detected by a thermal imaging camera will indicate broken or cracked rotor bars.

7.7.5 Permanent magnet (PM) machines: rotor removal

Extreme care should be taken when removing and reinstalling the rotor from a Permanent Magnet (PM) machine. This should only be carried out by fully trained operatives using the correct equipment and procedures to ensure safe removal and replacement.

7.7.6 Salient pole rotor

The solid poles should be inspected for loose pole tip bolts, cracks, rubbing, overheating, and mechanical damage.

The rotor should be inspected for:

- a) loose pole pieces, and evidence of greasing from pole movement;
- b) cracked connectors;
- c) damaged pole piece laminations;
- d) signs of localized damage due to overheating or turn/turn faults;
- e) distortion of the field pole face or rotor rim face;
- f) the integrity of field coil insulation including washers;
- g) tightness and integrity of pole retaining screws, bolts, or alternative construction;
- h) the integrity of pole/inter-pole blocks, pole/inter-pole block insulation, bolts, or alternative constructions.

7.7.7 Cylindrical solid rotors

In addition for cylindrical solid rotors in turbo-generators and 2 pole high speed synchronous motors, the following checks can be carried out by agreement with the customer:

- a) The rotor teeth, slot wedges, and retaining rings should be checked for cracks using ultrasonic test or magnetic particle test equipment.
- b) The rotor shaft should be checked for cracks using borescopic inspection if required using ultrasonic test, magnetic particle, dye penetrant or eddy current test equipment.
- c) End windings and under the retaining rings should be checked for cracks and insulation damage and integral strength. The insulated winding resistance should be within acceptable limits.

- d) Checks for coil movement, blocking/bracing support for cracking or movement, and inspection of cross over joint and J strap connection, using borescopic inspection if required.

7.8 Slip rings

For correct mechanical and electrical functioning, the following characteristics should be confirmed:

- a) dimensions;
- b) ring surface appearance and patina;
- c) burning;
- d) flatting;
- e) ring run-out;
- f) roughness;
- g) contaminants;
- h) insulation resistance between phases and to earth.

7.9 Brushes and brush-holders

In addition for wound rotors with slip-rings, the following mechanical and electrical characteristics should be checked to ensure the correct current collection against recommended values:

- a) brush holders should be clean and free from any dirt or oil. All moveable parts should be free;
- b) the clearance of the brush holder from the slipring should be 1,5 mm to 3 mm depending on the size of the machine. Manufacturer's specifications should apply;
- c) spring pressure should be checked in accordance with the manufacturer's specifications for the application and brush type, and adjusted if required to provide the correct pressure;
- d) brush pressure should be determined by the spring tension, brush area, and brush weight;
- e) brush grades are the same and correct to the manufacturer's recommendation;
- f) brush wear, and the position of any short brushes;
- g) brushes and brush holders may be marked with a square for metric dimensions and a triangle for inch dimensions. Replacement brushes made to inch dimensions fitted into metric brush holders, or vice versa, might cause problems with an improper fit in the brush holder;
- h) the brush clearance in the brush holder should be checked against recommended values in accordance with IEC 60136, excessive play requires a brush or brush box change. (See 10.4.2, Table 5);
- i) the brush stud insulation should not be charred, cracked, or damaged;
- j) an insulation test should be applied to the brush holders and jumpers at the recommended test voltage.

7.10 Rolling element bearings

Replacement bearings should be equivalent to the original manufacturer's specifications, or be the exact size, type, clearances and precision class, with fit appropriate to the bearing. Bearing friction losses can be reduced if equivalent energy efficient bearings are available. Any bearing fit that is not within tolerance should be restored to the original bearing manufacturer or machine manufacturer's specification. The following checks should be carried out:

- a) The bearing fits on shafts and into housings should be checked and be to the recommended tolerances.
- b) The bearing housing fit into the frame should also be checked and be to recommended tolerances.

- c) The orientation of rolling element thrust bearings should be checked to confirm that it is the same as indicated by the manufacturer.
- d) Grease passages and pipes should be uncontaminated and unblocked. Open bearings should be filled during repair with the quantity and type specified from the bearing manufacturer. Over greasing will increase bearing losses and reduce efficiency. When excess grease enters the enclosure it can create insulation and commutation problems.
- e) Insulated bearings should have their insulation resistance checked to ensure it is at an acceptable level. The insulation resistance shall be greater than 1,0 MΩ if tested at 500 V.
- f) Bearings should be examined for evidence of bearing current damage, or fluting caused by either electrical discharge from a converter drive or inadequate earthing.
- g) Insulation resistance of couplings, pedestals, and shaft seals should be checked where insulated.

7.11 Sleeve bearings

- a) Clearances for the fit in the housing and bearing diameter should meet the manufacturer's original tolerances.
- b) They should be checked for babbitt damage and evidence of bearing-to-shaft journal misalignment.
- c) Oil rings should be round and, if made in two halves, the screw joint integrity should be checked. Retainers and sight glasses should be cleaned, inspected and replaced where necessary.
- d) The tilting pad, thrust bearing pads, and shaft runners, should be inspected for evidence of babbitt damage: wear, fluting, fretting, frosting, scoring and other defects, which might form part of a failure analysis.
- e) Insulated bearings should have their insulation resistance checked to ensure it is at an acceptable level. The insulation resistance must be greater than 1,0 MΩ if tested at 500 V.
- f) Bearings should be examined for evidence of bearing current damage, or fluting caused by, for example, electrical discharge from a converter drive or inadequate earthing.
- g) Insulation resistance of couplings, pedestals, and shaft seals, should be checked if insulated.

7.12 Seals and labyrinth seals

Clearance should be set to the equipment manufacturer's specifications.

8 Repair work

8.1 Winding inspection

- a) The pattern and colouration of any winding failure is an indication of the cause of failure of a machine and part of any root cause failure analysis. A record, or photographic evidence should be kept of any failure pattern.
- b) Before removing the windings the service facility shall produce a diagram of the existing winding showing coil groupings, parallels/phase, phase connections and temperature detector locations. Areas showing signs of stress or failure can be added to the diagram to assist root cause analysis.
- c) Coil/bar dimensions should be taken and recorded before removal. After winding removal record the slot, coil, bar, conductor, strand dimensions, coil pitch or pitches, insulation types, and turns/coil.
- d) The winding data taken above, should be checked for accuracy, and is the basis of copying the original winding. The completed winding should be as good as, or better than, the original winding. The cross section area of the wire should be at least equal to the manufacturer's original specification. An increase in the cross sectional area will increase the efficiency of the machine.

8.2 Core inspection

These are not in a procedural order.

- a) A core loss test or loop test should also be carried out if there has been any evidence of core rub due to bearing failure, excessive radial overloading, earth fault damage, corrosion, or potential age related core plate insulation deterioration. Full flux test 1,32 Tesla (50 Hz), or 85 000 lines per square inch (60 Hz). A value in excess of 12 W/Kg (50 Hz) or 10 W/Kg (60 Hz) will necessitate remedial action to reduce total core losses.
- b) The hot spot temperature limit for a full flux test on the core of a machine is a temperature increase of > 10 K (or higher by agreement). This is referred to as the rated induced axial voltage (or flux), hot spots > 10 K require repair. All areas of the core identified with hot spots shall be repaired, reinsulated, new laminations fitted, or a new core pack.
- c) It may be necessary to dismantle and restack cores either by reuse of the existing laminations or installation of new laminations. If the existing laminations are reused, damaged laminations have to be reinsulated. When using new laminations, it might be possible to reduce the iron losses using the lower loss electrical steels and optimising the machine design of the stator for additional efficiency. Lower loss steels can increase the excitation current.
- d) Core plate stack tightness and slot irregularity shall be within acceptable limits, and the core pack shall not be axially displaced from the stator, if the rotor is replaced.
- e) If the air gap surfaces of the laminations are uneven, or smeared together by mechanical damage, it may be possible to repair the damage by careful etching or grinding. The core should not be subjected to excessive grinding and filing. Care shall be taken that this does not increase the stray losses and affect the machine efficiency.
- f) If a pyrolysis or a burn out oven is used to carbonize the winding insulation before extraction, the temperature used should be carefully controlled to protect the electrical and insulation characteristics of the magnetic laminations. Machines should be placed in the oven horizontally, to avoid damage being caused by a chimney effect. The use of uncontrolled heat on a stator pack, or thermal lance is not recommended. A burn out oven temperature of 360 °C to 370 °C is suitable for most modern electrical steels and inter laminar insulation. On machines with high quality inorganic inter-laminar insulation, which is known to be ec5, ec6 coating, or better, as per IEC 60404-1-1, a temperature of up to 400 °C is acceptable. If there is any doubt the manufacturer's recommendation should be obtained as to any limitations in burn out procedures. Care should be taken with the temperature/time profile appropriate for organic or oxide insulation of core plate.
- g) A comparison of core loss readings before and after burn out should also be checked. An increase of more than 20 % in the core losses shall require remedial action to reduce the increase in core losses.
- h) There should be a controlled water, steam, or inert gas suppression system to damp down any overheating caused by the combustion of the insulation materials.
- i) A record should be kept of the core burn-out temperature limits, how the temperature is measured, and the location of the temperature sensing element relative to the equipment being burned-out.
- j) Windings should be removed in a manner that does not damage the laminations, care should be taken when cutting off the coil extension (normally the one opposite the connection end) or extracting the windings from the slots.
- k) The slots in the core should be clean and free from debris and sharp edges before replacing the windings.

8.3 Rewinding

8.3.1 General

The core, ventilation ducts, and frame shall be cleaned, inspected, and corrosion protected, if required, prior to a rewind and assembly, to avoid contamination.

8.3.2 Random wound coils

- a) A high quality winding wire should be used wherever possible, and consideration given to meet the demands of any converter drives fitted.
- b) Random wound coils should be neat, with a minimum of crossed conductors, and the forming process should not damage the conductor insulation.
- c) With modern insulation materials, winding wire, and copper, it can be possible to increase the copper section of conductors, which will reduce copper losses, and lead to an increase in efficiency. Care should be taken with reference to starting current.
- d) To maintain the efficient performance and minimize any mechanical clearance issues, the winding overhangs and mean length of turn (MLT) should be kept no greater than the original winding, whilst maintaining the end winding projection.
- e) End-windings should be finished to ensure adequate clearance by shaping and lacing, taking into account the mechanical forces and cooling during starting.
- f) Wedges should be inserted along the full length of the core with gaps permitted. They shall have the required material characteristics and thermal rating and be securely fitted into the slots. Particular care and additional devices can be required for vertical machines. It is not recommended to fit wedges longer 200 mm.
- g) Inter phase insulation should be used as barriers wherever possible.
- h) The winding may be altered to a two-layer lap winding, as opposed to the machine wound concentric winding, as long as the new winding has the same flux per pole as the original. The lap winding is generally easier and quicker to install and can help to minimize the winding overhangs and mean length of the turn (MLT) to maintain or improve efficiency. As all coils have equal exposure to the air flow, cooling can also be improved. Phase insulation and bracing of the coils for mechanical strength is also improved. Care should be taken not to reduce the MLT too much, which can make the machine difficult to wind and could affect the cooling of the windings.
- i) If required the number of poles, pole pitch and the rotating direction can be checked with a DC current and compass.

8.3.3 Form-wound coils

- a) Splicing or bypassing of high voltage coils are not acceptable repair procedures, however if time is of the essence, they can offer an expedient in-field repair to keep a customer operating at a reduced output. These repair methods can provide time for a planned repair, or a replacement machine/stator to be sourced, as long as they are carried out with the full agreement of the customer.
- b) Careful records and dimensions should be taken to ensure the correct fit of the preformed coils if manufacturing the coils in house, or as requested by an external coil manufacturer.
- c) To maintain the efficient performance and minimize any mechanical clearance issues, the winding overhangs and mean length of turn (MLT) should be kept no greater than the original winding whilst maintaining the end winding projection. The gap between coils in the end-winding and clearance to winding covers should be maintained.
- d) With modern insulation materials, winding wire, and copper, it can be possible to increase the copper section of conductors, which will reduce copper losses, and lead to an increase in efficiency. Care should be taken with reference to starting current.
- e) Form-wound coils should be shaped without damage to the conductor insulation. Each layer of insulation should be uniform and firmly applied to minimize air voids.
- f) Where high mechanical strength is required it might be necessary to apply varnish between each insulation layer, taking care that the material is compatible with the insulation system data.
- g) Where machines have surge rings (winding supports) fitted they shall be suitably insulated, if necessary.
- h) End-windings should be finished to ensure adequate clearance by shaping and bracing, taking into account the mechanical forces and cooling during starting.

8.3.4 Rewound stator tests

Before impregnation the new windings should be tested to ensure there are no wrong connections, or other faults. The winding resistance test, and surge comparison test (if required) should be carried out before the withstand voltage test.

8.3.5 Winding resistance test

A winding resistance test shall be carried out using an ohmmeter or milli-ohmmeter (see 6.3.1). Compare with previous readings or manufacturers data if available.

8.3.6 Surge comparison (or phase balance) test

A surge comparison test can be carried out, if required, using a surge comparison tester. A high voltage pulse is applied into two different sets of winding leads. The output is then monitored on an oscilloscope or screen. A satisfactory winding should give a single overlapping trace with a crest voltage of up to 1 000 V.

8.3.7 Withstand voltage test

This test is also known as a high potential, hipot, or flash test. New windings shall be able to withstand the appropriate Withstand voltage test in accordance with IEC 60034-1.

A test voltage, as specified in Table 3, shall be applied between the windings and the frame of the machine, with the core and the windings not under test connected to the frame. The withstand voltage test shall be carried out if previous tests have been passed.

The withstand voltage test at full voltage made on the windings shall not be repeated. If, however, a second test is required, the test voltage shall be 80 % of the voltage specified in Table 3.

To determine the test voltage from Table 3 for DC motors supplied by static power converters, the direct voltage of the motor or the r.m.s. phase-to-phase value of the rated alternating voltage at the input terminals of the static power converter shall be used, whichever is the greater.

Completely rewound windings shall be tested at the full test voltage for new machines.

When a user and a repair contractor have agreed to carry out withstand voltage tests in cases where windings have been partially rewound or in the case of an overhauled machine, the following procedure is recommended:

- a) partially rewound windings are tested at 75 % of the test voltage for a new machine. Before the test, the old part of the winding shall be carefully cleaned and dried;
- b) overhauled machines, after cleaning and drying, are subjected to a test at a voltage equal to 1,5 times the rated voltage, with a minimum of 1 000 V if the rated voltage is equal to or greater than 100 V and a minimum of 500 V if the rated voltage is less than 100 V.

Table 3 – Withstand voltage tests as per IEC 60034-1

Item	Machine or part	Test voltage (r.m.s.)
1	Insulated windings of rotating machines of rated output less than 1 kW (or kVA) and of rated voltage less than 100 V with the exception of those in items 4 to 8	500 V + twice the rated voltage
2	Insulated windings of rotating machines of rated output less than 10 000 kW (or kVA) with the exception of those in item 1 and items 4 to 8 ^b	1 000 V + twice the rated voltage with a minimum of 1 500 V ^a

Item	Machine or part	Test voltage (r.m.s.)
3	Insulated windings of rotating machines of rated output 10 000 kW (or kVA) or more with the exception of those in items 4 to 8 ^b Rated voltage ^a : – up to and including 24 000 V – above 24 000 V	1 000 V + twice the rated voltage Subject to agreement
4	Separately excited field windings of DC machines	1 000 V + twice the maximum rated circuit voltage with a minimum of 1 500 V
5	Field windings of synchronous generators, synchronous motors and synchronous condensers.	
5a)	Rated field voltage: – up to, and including 500 V, – above 500 V	Ten times the rated field voltage with a minimum of 1 500 V 4 000 V + twice the rated field voltage
5b)	When a machine is intended to be started with the field winding short-circuited or connected across a resistance of value less than ten times the resistance of the winding	Ten times the rated field voltage with a minimum of 1 500 V and a maximum of 3 500 V.
5c)	When the machine is intended to be started either with the field winding connected across a resistance of value equal to, or more than, ten times the resistance of the winding, or with the field windings on open circuit with or without a field-dividing switch	1 000 V + twice the maximum value of the r.m.s. voltage, which can occur under the specified starting conditions, between the terminals of the field winding, or in the case of a sectionalized field winding between the terminals of any section, with a minimum of 1 500 V ^c
6	Secondary (usually rotor) windings of induction machines or synchronous induction motors if not permanently short-circuited (e.g. if intended for rheostatic starting)	
6a)	For non-reversing motors or motors reversible from standstill only	1 000 V + twice the open-circuit standstill voltage as measured between slip-rings or secondary terminals with rated voltage applied to the primary windings
6b)	For motors to be reversed or braked by reversing the primary supply while the motor is running	1 000 V + four times the open-circuit standstill secondary voltage as defined in item 6a)
7	Exciters (except as below)	As for the windings to which they are connected
	<i>Exception 1:</i> exciters of synchronous motors (including synchronous induction motors) if connected to earth or disconnected from the field windings during starting	1 000 V + twice the rated exciter voltage, with a minimum of 1 500 V
	<i>Exception 2:</i> separately excited field windings of exciters (see item 4)	
8	Electrically interconnected machines and apparatus	A repetition of the tests in items 1 to 7 above should be avoided if possible, but if a test is performed on a group of machines and apparatus, each having previously passed its withstand voltage test, the test voltage to be applied to such an electrically connected arrangement shall be 80 % of the lowest test voltage appropriate for any individual piece of the arrangement ^d
9	Devices that are in physical contact with windings, for example, temperature detectors, shall be tested to the machine frame. During the withstand test on the machine, all devices in physical contact with the winding shall be connected to the machine frame.	1 500 V
^a For two-phase windings having one terminal in common, the voltage in the formula shall be the highest r.m.s. voltage arising between any two terminals during operation.		

Item	Machine or part	Test voltage (r.m.s.)
b	Withstand tests on machines having graded insulation should be the subject of agreement.	
c	The voltage occurring between the terminals of the field windings, or sections thereof, under the specified starting conditions, may be measured at any convenient reduced supply voltage, and the voltage so measured shall be increased in the ratio of the specified starting supply voltage to the test supply voltage.	
d	For windings of one or more machines connected together electrically, the voltage to be considered is the maximum voltage that occurs in relation to earth.	
e	The leakage current drawn by the machine during withstand voltage test will vary according to the size of the machine.	

8.3.8 Thermal protection

Thermocouples, thermistors, and resistance temperature detectors should be checked and replaced with identical or equivalent replacements. Built-in thermal protection and embedded temperature detectors shall be of the same type or equivalent replacements and in the same locations as the originals in accordance with IEC 60034-11, unless otherwise agreed.

8.3.9 Conductors and connections

- a) The current capability, temperature rating, insulation and mechanical qualities of new conductors should match or exceed the original specification and be appropriate to the temperature classification.
- b) Connections should not introduce high resistance joints into winding circuits.
 - 1) Brazing, crimping, welding, soldering shall be mechanically and electrically as good as the original.
 - 2) Pastes, fluxes, etc., should be neutralized after use, if necessary.
 - 3) Connections shall have a lower electrical resistance than the windings being joined.

8.3.10 Insulation system

- a) The complete insulation system and method of application should consist of compatible materials to meet the electrical, mechanical, and thermal rating of the machine. The insulation system should be suitable for the environment that the machine will be operating in.
- b) The insulation materials and application methods should be at least as good as, or better than, the original, e.g. a winding insulated with Class 130 (B) for 130 °C material would normally be upgraded to a minimum of Class 155 (F) for 155 °C material, where possible. This will give added protection to minimize future failures and overcome hot spots or unusual load conditions. Materials used should be compatible with one another both mechanically and electrically.
- c) The insulation system should be upgraded, if required, to meet the additional demands placed on the system by a converter drive.

8.3.11 Impregnation

This is an area where the service facility can work closely with the user to ensure the most suitable insulation system is used to match the actual application requirements.

The varnish and/or resin impregnation, if required, should be applied for mechanical and electrical strength, and cured at the manufacturer's recommended temperature over a suitable period of time for the size of machine.

Pre-heating the wound core improves the penetration of the insulation. Double dip might be required for some particularly demanding applications, if time permits, and the product allows it. Wound cores should be introduced to the varnish close to vertical from the bottom up, to force the air out of the wound core, and fill the air gaps with varnish.

Where cores have radial air ducts, with contra flow on each duct, cores will require rotary curing of the varnish.

Suitable application systems are:

For low voltage:

- a) dip and bake;
- b) trickle: The electrically heated winding is impregnated by capillary and gravity action;
- c) vacuum pressure (VPI).

For high voltage:

- d) vacuum pressure (VPI) or vacuum (VI);
- e) resin-rich tapes and foils. Alternative methods for form wound and high voltage machines.

A good penetration of impregnant and full cure helps transfer any heat generated in the windings to the coolant, helping to keep the winding temperature down and improving efficiency.

8.3.12 Wound rotor banding

Banding, where used, should be mechanically strong enough to withstand the centrifugal forces, starting currents and vibrations of the application.

The winding should be concentric to the bearing journals and consolidated prior to banding, if practical.

Resin filled glass banding shall be stored at the correct temperature before use.

Wire banding should be applied over an insulating barrier. The materials used and dimensions shall match the original. Note that allowance might have been made in the magnetic circuit for banding materials.

8.4 Components

8.4.1 General

The original components shall be evaluated to prove their fitness for the intended future service requirements.

Replacement components shall conform to the latest standards where practical, or to the original standards. Their performance should be identical to or greater than the original. A quality system should cover the requirements for material storage and testing before use.

Mechanical components shall be examined for defects. Any cracks, distortion, breaks, wear and tear, or weld integrity should be replaced or repaired to the manufacturer's specifications or the original standards, where they exist.

8.4.2 Housing and end brackets

The correct orientation of the end bracket and stator frame spigot (rabbet) shall be maintained. The original fits are not always perfectly circular. Rebuilt or sleeved bearing housings shall also be to the same dimensions and tolerances as originally manufactured. The end brackets and bearing caps should be refitted in exactly the same position as originally fitted.

Any reclamation is usually done by using welding, sleeving or metal spraying techniques. Material is built up and then machined to the manufacturer's dimensions. Any filling of components using epoxy compounds or similar should be agreed with the user prior to use.

Broken or missing cooling ribs should be replaced, and airways should be clear and unblocked, to maintain the integrity of the cooling characteristics.

A replaced or refitted stator frame should not be too tight a fit onto the stator, which would increase core losses, nor too loose which would obstruct normal heat transfer and increase the core losses. An interference fit should be to manufacturer's tolerances, or to good engineering practice.

8.4.3 Fans and fan cowls

Replacement fans or fan cowls should be dimensionally and structurally equivalent to the original. A replacement fan should be optimized in a way that ventilation losses are equivalent to or better than the original design.

Any proposed fan repairs should be agreed by the user. It is preferable to obtain replacement fans from the original machine manufacturer if available. The fan is an integral part of the ventilation system, which has been optimized for efficiency and performance. A larger fan will decrease the energy efficiency due to the extra power absorbed, but may make the machine run cooler, and a smaller fan will increase the efficiency of the machine, but may make the machine run hotter. Energy efficient machines tend to have smaller fans matched to the machines requirements.

Rises in operating temperature reduces the life of the insulation system, and alterations should only be carried out in consultation with the customer.

Fans shall be firmly fitted to the shaft by the original factory method. Welding to the shaft is not permitted.

8.5 Rotor

8.5.1 General

The axial position of the rotor relative to the stator should be centred axially within the stator core. If displaced, centring forces will exert undue pressure on the bearings. If displaced beyond the end of the stator core, there will be an increase in magnetising current. For machines with sleeve bearings, the relative axial position of the rotor with respect to the stator during operation shall be checked during the tests in order to avoid excessive axial force on the bearings endplay. The correct axial position should be indicated on the machine as per 9.5.

8.5.2 Air gap

The air gap should be measured and an acceptable minimum confirmed including an even radial distribution. Any increase in air gap will affect the efficiency of the machine.

8.5.3 Cage rotor

The resistivity and chemical composition of original rotor bar and end-ring materials should be measured to ensure that the replacement materials are the same.

Fabricated squirrel cage windings, including damper, should be a tight fit in the rotor slots.

Brazing or welding the end-rings to the rotor bars, as dictated by materials, should maintain the original design characteristics.

After fabrication the electrical joints should be examined to confirm integrity and full penetration of the joints.

Die cast cage rotors with damaged bars are beyond repair and should be replaced with rotors from the original manufacturer.