

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Electric traction – Rotating electrical machines for rail and road vehicles –
Part 4: Permanent magnet synchronous electrical machines connected to an
electronic converter**

**Traction électrique – Machines électriques tournantes des véhicules ferroviaires
et routiers –
Partie 4: Machines électriques synchrones à aimants permanents connectées à
un convertisseur électronique**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**ELECTRIC TRACTION –
ROTATING ELECTRICAL MACHINES
FOR RAIL AND ROAD VEHICLES –**

**Part 4: Permanent magnet synchronous electrical
machines connected to an electronic converter**

FOREWORD

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This International Standard IEC 60349-4 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways.

This standard is derived from IEC 60349-2 changing the subject to permanent magnet synchronous machines.

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

FDIS	Report on voting
9/1734/FDIS	9/1759/RVD

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

A list of all parts of IEC 60349 series, under the general title *Electric traction – Rotating electrical machines for rail and road vehicles*, can be found on the IEC website.

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

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

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ELECTRIC TRACTION – ROTATING ELECTRICAL MACHINES FOR RAIL AND ROAD VEHICLES –

Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter

1 Scope and object

This part of IEC 60349 applies to converter-fed permanent magnet synchronous motors or generators (machines) forming part of the equipment of electrically propelled rail and road vehicles.

This standard is derived from IEC 60349-2 changing the subject to permanent magnet synchronous machines.

The object of this part is to enable the performance of a machine to be confirmed by tests and to provide a basis for assessment of its suitability for a specified duty and for comparison with other machines.

Where further testing is to be undertaken in accordance with a combined test, it may be preferable, that some type and investigation tests be carried out on the combined test bed, to avoid duplication.

Particular attention is drawn to the need for collaboration between the designers of the machine and its associated converter as detailed in 5.1.4.

NOTE 1 This part also applies to machines installed on trailers hauled by powered vehicles.

NOTE 2 The basic requirements of this part may be applied to machines for special purpose vehicles such as mine locomotives but this part does not cover flameproof or other special features that may be required.

NOTE 3 It is not intended that this part should apply to machines on small road vehicles, such as battery-fed delivery vehicles, factory trucks, etc. This part also does not apply to minor machines such as windscreen wiper motors, etc. that may be used on all types of vehicles.

NOTE 4 Industrial type machines complying with IEC 60034 may be suitable for some auxiliary drives, provided that it is demonstrated that operation on a converter supply will meet the requirements of the particular application.

The electrical input to motors covered by this part is be from an electronic converter. Generators may be connected to a rectifier or a converter.

The machines covered by this part are classified as follows:

- a) Traction motors
Motors for propelling rail or road vehicles.
- b) Main generators
Generators for supplying power to traction motors on the same vehicle or train.
- c) Auxiliary motors not covered by IEC 60034
Motors for driving compressors, fans, auxiliary generators or other auxiliary machines.
- d) Auxiliary generators not covered by IEC 60034
Generators for supplying power for auxiliary services such as air conditioning, heating, lighting and battery charging, etc.

2 Normative references

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

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

IEC 60034-8, *Rotating electrical machines – Part 8: Terminal markings and direction of rotation*

IEC 60034-9, *Rotating electrical machines – Part 9: Noise limits*

IEC 60034-14, *Rotating electrical machines – Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher – Measurement, evaluation and limits of vibration severity*

IEC 60050-131, *International Electrotechnical Vocabulary (IEV) – Chapter 131: Circuit theory*

IEC 60050-151, *International Electrotechnical Vocabulary (IEV) – Chapter 151: Electrical and magnetic devices*

IEC 60050-221, *International Electrotechnical Vocabulary (IEV) – Chapter 221: Magnetic materials and components*

IEC 60050-411, *International Electrotechnical Vocabulary (IEV) – Chapter 411: Rotating machines*

IEC 60050-811, *International Electrotechnical Vocabulary (IEV) – Chapter 811: Electric traction*

IEC 60085, *Thermal evaluation and classification of electrical insulation*

IEC 60850, *Railway applications – Supply voltages of traction systems*

IEC 62498-1, *Railway applications – Environmental conditions for equipment – Part 1: Equipment on board rolling stock*

3 Terms and definitions

For the purposes of this document the terms and definitions given in IEC 60050-131, IEC 60050-151, IEC 60050-221, IEC 60050-411, and IEC 60050-811 as well as the following, apply.

3.1

rating of a machine

combination of simultaneous values of electrical and mechanical quantities, with their duration and sequence, assigned to the machine by the manufacturer

3.1.1

rated value

numerical value of any quantity included in a rating

3.1.2

continuous rating

mechanical output that the motor (or electrical output that the generator) can deliver on the test bed for an unlimited time under the conditions specified in 8.1 without exceeding the limits of

temperature rise given in Table 2, all other appropriate requirements in this part also being satisfied

Note 1 to entry: Several continuous ratings may be specified.

3.1.3

short-time rating

(for example, 1 h)

mechanical output that the motor (or electrical output that the generator) can deliver on the test bed for the stated time without exceeding the limits of temperature rise given in Table 2. The test being carried out as specified in 8.1 starting with the machine cold, all other appropriate requirements in this part being also satisfied

3.1.4

short-time overload rating

mechanical output that the motor (or electrical output that the generator) can deliver on the test bed for the stated time without exceeding the agreed limits of temperature

Note 1 to entry: Short-time overload ratings are of value in determining the suitability of machines for duties which involve relatively long periods of operation below the continuous rating followed by a period above it. These are most likely to occur in locomotive applications. They are not relevant to the repeated short load cycles of rapid transit and similar duties, and should not be specified for such applications.

3.1.5

intermittent duty rating

duty cycle in which the machine may be operated without the temperature rises exceeding the limits given in Table 2 at any point

3.1.6

equivalent rating

continuous rating with constant values of voltage, current and speed that, as far as temperature rise is concerned, is equivalent to the intermittent duty cycle which the machine has to withstand in service

Note 1 to entry: This rating should be agreed between user and manufacturer.

3.1.7

guaranteed rating

rating assigned by the manufacturer for test purposes

3.1.8

guaranteed rating of a machine

normally the continuous rating but in special cases the user and manufacturer may agree that it be a short-time or intermittent rating

3.1.9

guaranteed rating of an auxiliary machine

continuous rating unless otherwise specified

3.1.10

rated voltage

root-mean-square value of the fundamental component of the line-to-line voltage of a machine when it is operating at a guaranteed rating

3.1.11

rated speed

speed at a guaranteed rating

3.2**maximum service voltage**

highest root-mean-square value of the fundamental component of the line-to-line voltage of the machine in service

3.3**maximum voltage**

highest root-mean-square value of the fundamental component of the line-to-line voltage of the machine in any possible condition

Note 1 to entry: motor **operated** at high speed with **open circuit** may have a higher **maximum** voltage than the maximum service voltage.

3.4**repetitive peak voltage**

peak value of the waveform of the converter output voltage, any random transient peaks arising from line voltage transients or other causes being disregarded

3.5**EMF**

electromotive force in the machine winding caused by the flux of the permanent magnets

3.6**induced voltage**

open circuit line-to-line root-mean-square value of the fundamental component of the EMF of the machine at a defined speed and a defined magnet temperature

3.7**maximum current**

maximum current shown on the specified characteristic as defined in 5.4

3.8**maximum working speed****3.8.1****maximum working speed of a traction motor**

highest rotational speed assigned to the motor by the manufacturer

Note 1 to entry: When the characteristics of the vehicle for which a motor is intended are specified, this speed is not less than that corresponding to the maximum service speed of the vehicle assuming fully worn metallic wheels or the minimum rolling diameter of rubber tyres.

3.8.2**maximum working speed of generator or auxiliary generator**

generator speed corresponding to the maximum governed speed of the engine for the particular application

Note 1 to entry: This will normally be the maximum governed speed on "no-load". Transient speed variations during load changes should be disregarded.

3.8.3**maximum working speed of an auxiliary machine**

highest rotational speed assigned to the machine by the manufacturer

Note 1 to entry: For specific applications, when assigning this speed, the most unfavourable conditions of voltage, frequency, loading, etc., that can occur in service should be taken in account.

3.9

user

normally the end customer, but can be delegated to an other organization

3.10

manufacturer

producer of machines

3.11

system manufacturer

organization which has the technical responsibility for the supply of the combined system

Note 1 to entry: The system manufacturer as defined above may also be the manufacturer of the motor, of the inverter, of the control, or of all of them, or of none of them.

3.12

cogging torque

torque at the disconnected motor, caused by variations of the reluctance in function of the rotor angle

4 Environmental conditions

Unless otherwise specified by the user, the following environmental conditions are assumed:

a) Altitude

Height above sea level not exceeding Class A3 according IEC 62498-1.

b) Temperature

Air temperature in the shade Class T1 according IEC 62498-1.

Whenever machines are intended to operate where one or both of these limits will be exceeded, special requirements may be agreed between user and manufacturer. For more information refer to IEC 60034-1.

Furthermore, the user shall inform the manufacturer of any particularly severe environmental condition such as dust, humidity, temperature, snow, dynamic effects, etc., to which the machines will be subjected.

5 Characteristics

5.1 Exchange of information

The machine and converter designers shall collaborate to produce all the technical information necessary to ensure that the combined unit will meet the requirements of this part of IEC 60349.

To fulfill this requirement, the machine designer shall provide the converter designer with all the information necessary to fully evaluate the interaction between the machine and the converter.

The converter designer shall also provide the machine designer with the characteristics showing, for example, the converter line-to-line output voltage (including the repetitive voltage peaks), current, fundamental frequency, harmonics and power over the whole range of the application, including operation at the maximum and minimum values of the contact-system voltage.

The machine designer shall provide the converter designer with the characteristics showing induced voltage due to the permanent magnets by 20 °C as a function of speed over the whole

range of application of the machine. To calculate the induced voltage for other temperatures the machine designer shall also provide the temperature coefficient of the induced voltage.

The documents recording this exchange of information shall form an integral part of the specification of the machine and of the converter.

NOTE 1 For more information refer to IEC 61287-1, 5.3.1.1, Interfaces between motor and convertor (inverter).

NOTE 2 The length of cable run between machine and converter and the effect on peak voltages seen at the machine terminals should be considered. Responsible for this issue is the system manufacturer.

NOTE 3 For information about wave fronts and the impact to the machine see IEC 60034-17.

5.2 Special characteristic of a driven permanent magnet machine

The EMF of a driven permanent magnet synchronous machine cannot be switched off. This effect shall be taken into account.

EXAMPLES (informative only):

- An internal winding short circuit induces a short circuit current as soon as the machine is rotating.
- There is a voltage present on the open terminals as soon as the machine is rotating.
- A permanent magnet machine may show a cogging torque.

5.3 Reference temperature

All characteristics, irrespective of the thermal class of insulation system used on the machine to which they apply, shall be drawn for a winding reference temperature of 150 °C and a permanent magnets temperature of 100 °C which shall be stated in the characteristics.

5.4 Specified characteristics

Machine specifications shall, as a general rule, include characteristic curves in accordance with the relevant clauses of this part. These curves, defined as the "specified characteristics", shall be plotted to the designed operating limits of each variable. Unless otherwise agreed between user and manufacturer, the characteristics shall show the performance at the nominal voltage of the intermediate circuit, and shall be submitted to the user before the order for the machines is placed.

5.5 Declared characteristics

Declared characteristics are derived from the results of type tests carried out in accordance with 8.2.1 and shall meet the requirements of 8.2.2.

Unless previously agreed, the declared characteristics of machines electromagnetically identical with any previously manufactured for the same user or application shall be those of the existing machines. In which case, compliance with the characteristics shall be demonstrated by reduced type tests.

5.6 Efficiency characteristics

Efficiency characteristics shall take into account losses arising from the harmonics in the supply from the converter.

5.7 Traction motor characteristics

The specified and declared characteristics of a traction motor shall be the converter-fed variable frequency characteristics, which shall show motor line-to-line voltage, current, induced voltage, mean torque and efficiency as a function of speed over the whole range of application of the motor. Voltage curves shall show the root-mean-square value of the fundamental

component. Current curves shall show the root-mean-square value of the fundamental component and the total root-mean-square value. For motor used in the braking mode, similar characteristics shall be produced showing the torque input and the electrical output as a function of motor speed.

NOTE Subclause 5.1 refers to the need for the exchange of information between the designers of the machine and of the converter.

As an alternative to motor torque and speed, the characteristics may show tractive effort at the rail and vehicle speed, in which case the gear ratio, wheel diameter and transmission losses shall be stated. If conventional values are used for the latter, they shall be in accordance with Figure B.1.

5.8 Main generator characteristics

The characteristic curves shall show voltage and efficiency as a function of load current at defined speeds.

Characteristic curves shall be drawn corresponding to the generator input power available for traction at (or between) maximum, average and minimum engine speeds, and if the engine has a number of predetermined intermediate speed notches, additional curves shall be drawn for a sufficient number of these speeds to adequately show the performance of the generator.

Alternatively, the characteristics may be plotted as a function of speed.

If the generator is used as starter for the main engine, use the same as in 5.7.

5.9 Auxiliary motor characteristics

The specified and declared characteristics of auxiliary motors shall be the converter-fed characteristics, which shall show the motor line-to-line voltage, current, speed and mean torque as a function of motor output for each operating frequency over the whole range of application of the machine. The characteristics of motors which operate at continuously variable frequency shall be plotted for the maximum and minimum frequencies only.

Voltage curves shall show the root-mean-square value of the fundamental component. Current curves shall show the root-mean-square value of the fundamental component and the total root-mean-square value. The characteristics shall take account of the additional losses arising from the supply harmonics and the efficiency at the guaranteed rating shall be stated.

Alternatively, the characteristics may be plotted as a function of speed.

NOTE Subclause 5.1 refers to the need for the exchange of information between the designers of the machine and of the converter.

5.10 Auxiliary generator characteristics

The characteristic curves of output voltage, power and efficiency shall be plotted as a function of output current at the rated speed and, for variable speed machines, at the minimum and maximum speeds for the application. The frequency of the a.c. outputs shall be stated.

If the generator is used as starter for an engine, use the same as in 5.9.

6 Marking

6.1 Nameplate

All machines covered by this part of IEC 60349 shall carry a nameplate including at least the following information:

- a) manufacturer's name;
- b) machine type designation;
- c) remark that indicates this is a permanent magnet machine;
- d) machine serial number;
- e) year of manufacture;
- f) indication of final assembly location.

Furthermore, a serial number shall be punched on both the stator and rotor of every machine, and machines designed for unidirectional rotation shall carry an arrow indicating the direction of rotation.

NOTE 1 f) may be integrated in a), d) or e).

NOTE 2 The machine name plate and, if applicable, the rotation arrow should be easily readable when the machine is installed in the vehicle.

6.2 Terminal and lead marking

Terminal and lead markings shall be in accordance with IEC 60034-8 unless otherwise agreed.

7 Test categories

7.1 General

There are four categories of tests:

- type tests;
- reduced type test;
- routine tests;
- investigation tests.

NOTE See Clause 1 on duplication of tests.

7.2 Type tests

7.2.1 General

Type tests are intended to prove the ratings, characteristics and performance of new types of machines. They shall be carried out on one machine of every new design. Unless otherwise agreed, the machine shall be one of the first ten manufactured. Where there is a change in place and/or method of manufacture, refer to 7.3.

The type test motor shall also be routine tested (see Clause 9).

Before testing commences, the manufacturer shall provide the user with a test specification outlining the tests to be undertaken to demonstrate compliance with this standard. Following completion of the type tests, the manufacturer shall supply the user with a full test report.