IEC 60034-2-3

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INTERNATIONAL STANDARD

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colour inside

Rotating electrical machines –
Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC motors

Machines électriques tournantes –
Partie 2-3: Méthodes d'essai spécifiques pour la détermination des pertes et du rendement des moteurs à courant alternatif alimentés par convertisseur

IEC 60034-2-3:2020-03(en-fr)

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FOREWORD

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This first edition cancels and replaces IEC TS 60034-2-3, published in 2013.

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

FDIS	Report on voting
2/1974/FDIS	2/1982/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- withdrawn,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.

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INTRODUCTION

The objective of this document is to define test methods for determining total losses including additional high frequency motor losses and efficiency of converter-fed motors. Additional high frequency losses appear in addition to the losses on nominally sinusoidal power supply as determined by the methods of IEC 60034-2-1:2014. Results determined according to this document are intended to allow comparison of losses and efficiency of different motors when fed by converters.

Furthermore, the document gives seven standardized operating points to characterize the development of losses and efficiency across the whole torque/speed range. An interpolation procedure is provided to calculate losses and efficiency at any operating point (torque, speed).

In power-drive systems (PDS), the motor and the frequency converter are often manufactured by different suppliers. Motors of the same design are produced in large quantities. They may be operated from the grid or from frequency converters of many different types, supplied by many different manufacturers. The individual converter properties (switching frequency, DC link voltage level, etc.) will also influence the system efficiency. As it is impractical to determine motor losses for every combination of motor, frequency converter, connection cable, output filter and parameter settings, this document describes a limited number of approaches, depending on the voltage level and the rating of the machine under test.

The losses determined according to this document are not intended to represent the losses in the final application. They provide, however, an objective basis for comparing different motor designs with respect to suitability for converter operation.

In general, when fed from a converter, motor losses are higher than during operation on a nominally sinusoidal system. The additional high frequency losses depend on the harmonic spectrum of the impressed converter output quantity (either current or voltage) which is influenced by its circuitry and control method. For further information, see IEC TS 60034-25:2014.

It is not the purpose of this document to define test procedures either for power drive systems or for frequency converters alone.

Comparable converter

Latest experience and theoretical analysis have shown that the additional high frequency motor losses generally do not increase much with load. The methods in this document are mainly based on supplies from converters with pulse width modulation (PWM).

With respect to these types of converters and the growing need for verification of compliance with national energy efficiency regulations, this document defines a so-called comparable converter for testing of low voltage motors.

In principle, the comparable converter is a voltage source with a typical high frequency harmonic content supplying the machine under test. It is not applicable to medium voltage motors.

Limitations for the application of the comparable converter

It has to be noted that the test method with the comparable converter described herein is a standardized method intended to give comparable efficiency figures for standardized test conditions. A motor ranking with respect to suitability for converter operation may be derived, but it is not equivalent to determining of the actual motor losses for operation with a specific converter which requires a test of the whole power drive system (PDS) with the specific converter used in the final application.

Deviations are also expected for motors driven by multi-level voltage source or current source converters where the additional high frequency motor losses differ much more depending on speed and load than for two-level voltage source converters. Hence the determination of losses and efficiency should preferably use procedures where the motor is operated together with the same converter with which it is driven in service.

Another option is the determination of the additional high frequency motor losses by calculation. If this is requested by the customer, the pulse pattern of the converter is required. Such procedures are not part of this document.

The provided interpolation procedure for the determination of losses and efficiency at any operating point (torque, speed) is limited to the base speed range (constant torque range, constant flux range).

ROTATING ELECTRICAL MACHINES –

Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC motors

1 Scope

This part of IEC 60034 specifies test methods and an interpolation procedure for determining losses and efficiencies of converter-fed motors within the scope of IEC 60034-1:2017. The motor is then part of a variable frequency power drive system (PDS) as defined in IEC 61800-9-2:2017.

Applying the approach of the comparable converter, the motor efficiency determined by use of this document is applicable for comparison of different motor designs only.

The document also specifies procedures to determine motor losses at any load point (torque, speed) within the base speed range (constant torque range, constant flux range) based on determination of losses at seven standardized load points. This procedure is applicable to any variable speed AC motor (induction and synchronous) rated according to IEC 60034-1:2017 for operation on a variable frequency and variable voltage power supply.

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 60034-1:2017, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-2-1:2014, *Rotating electrical machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*

IEC 61000-2-4:2002, *Electromagnetic compatibility (EMC) – Part 2-4: Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances*

IEC 61800-9-2:2017, *Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60034-1:2017, IEC 60034-2-1:2014 as well as 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
motor losses with converter supply
when powered by a converter, motor losses are a combination of losses caused by fundamental frequency and losses caused by the converter high frequencies

3.2
fundamental losses
fundamental losses in the motor can be segregated into five different components: iron losses (varying with motor frequency and applied fundamental voltage), friction and windage losses (varying with motor speed), rotor winding losses, stator winding losses and additional load losses (all three varying with motor current). Fundamental losses are the losses of a motor running with application of rated voltage at fundamental frequency that does not contain any further high frequencies.

3.3
additional high frequency losses
additional high frequency losses are produced in the motor by the non-sinusoidal voltage and current waveforms generated by the converter and are in addition to the losses of iron, friction and windage, rotor winding, stator winding and additional load loss (fundamental losses)

3.4
base speed range
speed range from standstill up to the highest speed where the motor can be supplied with a voltage that changes in proportion to the speed so that the magnetic flux remains constant (constant ratio U/f) for induction machines and according to the MTPA (maximum torque per ampere) for synchronous machines. Within the base speed range, the maximum motor torque is constant (constant torque range), if constant flux control is used.

3.5
switching frequency
number of switching events of one semiconductor within one second. It determines, together with the selected pulse pattern and the converter topology, the lowest frequency of non-controllable high frequencies or inter-harmonics at the IPC (in-plant point of coupling) or the motor

Note 1 to entry: For a two level converter, the pulse frequency measured phase to phase is two times the switching frequency defined in 3.5 in case of continuous modulation and about 1,33 times the switching frequency defined in 3.5 in case of discontinuous modulation. A switching event is once on and once off of one semiconductor.

4 Symbols and abbreviated terms

f	Frequency, Hz
f_{Mot}	Fundamental motor frequency, Hz
f_N	Rated motor frequency, Hz
f_{sw}	Switching frequency, Hz
I_0	No-load current, A
I_N	Rated current, A
MTPA	Maximum torque per ampere control applied to synchronous motors
n	Speed, min^{-1}
n_N	Rated speed, min^{-1}
n_{ref}	Reference speed, min^{-1}
P	Power, W
P_{Ccon}	Constant losses at converter supply, W

P_{Csin}	Constant losses at sinusoidal supply according to IEC 60034-2-1:2014, W
PDS	Power drive system
P_{LHL}	Additional high frequency loss due to converter supply, W
P_{N}	Rated power, W
P_{ref}	Reference power, W
P_{1C}	Motor input power at converter supply, W
$P_{\mathrm{1\_60034\text{-}2\text{-}1}}$	Motor input power as tested according to IEC 60034-2-1:2014, W
P_{2C}	Motor output power at converter supply, W
$P_{\mathrm{2\_60034\text{-}2\text{-}1}}$	Motor output power as tested according to IEC 60034-2-1:2014, W
PWM	Pulse width modulation
T	Machine torque, Nm
T_{C}	Machine torque at converter supply, Nm
T_{N}	Rated torque, Nm
T_{ref}	Reference torque, Nm
U_{N}	Rated motor voltage, V
η	Efficiency

5 Basic requirements

5.1 Instrumentation

5.1.1 General

Unless otherwise stated in this document, the arithmetic average of the three line currents and voltages shall be used.

When testing electric machines under load, slow fluctuations in the output power and other measured quantities may be unavoidable. Therefore for each load point many readings shall be taken automatically by a suitable digital meter over a period of at least 15 s but not more than 60 s and this average shall be used for the determination of efficiency.

Considering the high frequencies involved in converters feeding AC motors and their contribution to the motor losses, the measuring equipment has to be selected according to the range of relevant frequencies with sufficient accuracy.

For temperature measurements, a thermosensor installed in the hot spot may be optionally used, as described in IEC 60034-2-1:2014.

5.1.2 Power analyser and transducers

The instrumentation for measuring power and current at the motor's input shall basically meet the requirements of IEC 60034-2-1:2014, but due to higher frequency components the following additional requirements shall also apply.

The specified uncertainty of the power meters shall be 0,2 % of the rated apparent power of the motor or better for the total active power at 50 Hz or 60 Hz. This is the total uncertainty of the power meter including possible sensors.

NOTE 1 For example, when a three-phase motor has a rated voltage of 400 V and a rated current of 10 A then the power meter's active power uncertainty is at least 0,2 % of √3 times 4 000 VA, which is 13,9 W or better.

The bandwidth of power meters and sensors shall be sufficiently wide that the error in the measurement of total active power for the entire frequency range (beyond 50 Hz and 60 Hz) is less than or equal to 0,3 % of the apparent power.

NOTE 2 In general, a bandwidth from 0 Hz up to 10 times of switching frequency is sufficient.

It is preferred to feed current and voltage directly into the power analyser. If an external current transducer is required, no conventional current transformers shall be used. Instead, wide bandwidth shunts or zero-flux transducers shall be used.

Fundamental voltage shall be measured at the motor terminals using a digital power analyser equipped with suitable software (FFT, Fast Fourier Transformation).

Internal line filters in digital power meters shall be turned off. Synchronization filters (also known as zero-cross filters) that are not in the signal path may be used.

For power measurement, the three-wattmeter method is preferred. All cables used to transmit measurement signals shall be shielded. It has to be noted, that the cable shield is not routed through the current transducers.

5.1.3 Mechanical output of the motor

The instrumentation used to measure supply frequency shall have an accuracy of ±0,1 % of full scale. The speed measurement should be accurate within 0,1 revolution per minute for speeds up to 3 000 min^{-1} and 0,03 % above.

The instrumentation used to measure the torque shall have a minimum class of 0,2 when the rated efficiency is expected to be below 92 %, 0,1 below 95 %and 0,05 or better for higher efficiencies. The minimum torque measured shall be at least 10 % of the torque measurement device’s rated torque. If a better class instrument is used, the allowed torque range can be extended accordingly.

5.2 Converter set-up

5.2.1 General

For all tests using the comparable converter, it should be parameterized according to the requirements of this document or, if a unique combination of converter and motor is to be tested, the converter should be parameterized according to the specific application requirements. The chosen parameter settings shall be recorded in the test report.

5.2.2 Comparable converter set-up for rated voltages up to 1 kV

The comparable converter has to be understood as a voltage source independent of load current.

It has to be noted, that the so-called comparable converter operating mode is not intended or requested for any commercial application, but it is a typical set-up. The purpose of the comparable converter set-up is to establish comparable test conditions for motors designed for operation with commercially available converters.

The reference conditions defined below shall only be used for verification of compliance with national energy efficiency regulations, in particular the 90 % speed and 100 % torque load point. For all other purposes including the interpolation procedure according to Annex A preferably the original system configuration should be used.

The following reference conditions are defined:

- Two level voltage source converter.

- No additional components influencing output voltage or output current shall be installed between the comparable converter and the motor, except those required for the measuring instruments.
- Operation at 90 % speed and rated torque with constant rated flux (approx. 90 % of rated voltage) for both induction machines and synchronous machines.

  NOTE The rated flux is defined by the rated voltage given on the name plate of the motor. Therefore, a measurement at the 90 % speed and 100 % torque point with rated flux will be fully replicable for regulation authorities.
- For motors with a rated speed up to 3 600 min^{-1}, the switching frequency shall not be higher than 5 kHz.
- For motors with a rated speed above 3 600 min^{-1}, the switching frequency shall not be higher than 10 kHz.

The conductor cross-sectional area of the motor cable should be selected such that the voltage drop is not significant at rated load. An example for a typical test setup can be found in IEC 61800-9-2:2017.

5.2.3 Testing with converters with rated voltages above 1 kV

For converters with voltage ratings above 1 kV a generally accepted comparable converter and cable length cannot be specified. Such motors, cables and specific converters can only be tested as a complete power drive system because the pulse patterns of frequency converters for higher output powers vary between manufacturers and differ greatly between no-load and rated load.

5.2.4 Testing with other converters

Motors that are operated with converters that produce a voltage with less harmonic content than in case of supply by the comparable converter, for example multi-level converters or converters with higher switching frequencies, will typically have lower losses compared with measurements made with the comparable converter at 4 kHz or 8 kHz switching frequency. Reference measurements on such motors shall still be performed under the reference conditions as given above. Motor efficiency values measured under non-reference conditions can be provided in the motor documentation.

6 Test method for the determination of the efficiency of converter-fed motors

6.1 Selection of determination method

For the verification of the rated losses and energy efficiency according to energy efficiency classification schemes, the preferred method 6.2 according to Table 1 shall be applied.

The preferred method 2-3-A is mandatory for verification of rated efficiency declared by the manufacturer. This verification may be required by end-users and regulators. For the declaration process and the seven load points according to Annex A the manufacturer is free to use other determination methods also.

Table 1 – Preferred test methods

Ref	Method	Description	Subclause	Required facility
2-3-A	**Direct-measurement Input-output**	Torque measurement	6.2	Torque meter or dynamometer for full-load; Comparable or specific converter supply

Alternate efficiency determining methods according to 6.3, 6.4 and 6.5 may be used for other requirements, Table 2.

Table 2 – Other test methods

Ref	Method	Description	Subclause	Required facility
2-3-B	**Summation of losses**	Additional high frequency loss determination with converter for final application	6.3	Sinusoidal supply and specific converter supply at no-load operation
2-3-C	**Alternate Efficiency Determination Method (AEDM)**	Calculation by qualified analytical model	6.4	Qualified base models and adequate calculation tool
2-3-D	**Determination of efficiency by calculation**	Calculation method for motors with rated output powers higher than 2 MW	6.5	Pulse patterns of the specific converter system and adequate calculation tool

6.2 Method 2-3-A – Direct measurement of input and output

6.2.1 Test set-up

This is a test method in which the mechanical power P_{2C} of a machine is determined by measurement of the shaft torque and speed. The electrical power P_{1C} of the stator is measured in the same test.

6.2.2 Test procedure

Tests shall be conducted with converter and an assembled motor with the essential components in place, to obtain test conditions equal or very similar to normal operating conditions.

Check the offset of the torque measuring device and set it to zero as described in IEC 60034-2-1:2014.

In case of permanent magnet machines, physically uncouple the motor under test, in order to avoid residual torque in unexcited condition induced by permanent magnets.

Couple the motor under test to a load machine with a torque measuring device.

Operate the machine under test at rated torque and speed until thermal equilibrium (rate of change of 1 K or less per half hour) has been reached.

At the end of the heat run, record:

T_C Output torque

n Speed

P_{1C} Motor input power

Check the offset of the torque measuring device after stopping the machine. When measuring several load points, the torque measuring device offset has to be checked only after the last load point has been measured.

Correct the output torque T_C by the determined offset.

6.2.3 Efficiency determination

Calculate the output power:

$$P_{2C} = 2\pi \cdot T_C \cdot n$$