IEC 60034-2-3

Edition 2.0 2024-03

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 60034-2-3:2024-03(en-fr)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

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

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ROTATING ELECTRICAL MACHINES –

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

FOREWORD

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IEC 60034-2-3 has been prepared by IEC technical committee 2: Rotating machinery. It is an International Standard.

This second edition cancels and replaces the first edition of IEC 60034-2-3 published in 2020. This edition constitutes a technical revision.

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

a) Harmonization of requirements and procedures with IEC 60034-2-1.
b) Extension of the interpolation procedure to the field weakening range.

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

Draft	Report on voting
2/2164/FDIS	2/2179/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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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. Results determined according to this document are intended to allow comparison of losses and efficiency of different motors if 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 motor under test.

The losses determined with the comparable converter as defined in 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, if fed from a converter, motor losses are higher than during operation on a nominally sinusoidal system, even though the converter normally enables vast energy savings overall on system level, when the motor and the load application can be operated with variable speed. 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.

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 torque for a specific speed. 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 motor under test. It is not applicable to medium voltage motors.

Limitations for the application of the comparable converter

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 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, then the pulse pattern of the converter is required. Such procedures are not part of this document.

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. The motor is then part of a variable frequency power drive system (PDS) as defined in IEC 61800-9-2.

Applying the approach of the comparable converter, the motor efficiency determined by use of this document is applicable for comparison of different low voltage motor designs only. The comparable converter approach is not applicable to medium voltage motors.

This document also specifies procedures to determine motor losses at any load point (torque, speed) within the constant flux range (constant torque range, base speed range), the field weakening range and the overload 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 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*, Rotating electrical machines – Part 1: Rating and performance*

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

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

IEC 61800-9-2, *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, IEC 60034-2-1 as well as the following apply.

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

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

3.1
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)

3.2
constant flux 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). Within the constant flux range, the maximum motor torque is constant (constant torque range), if constant flux control is used. Constant flux range can also be called base speed range.

3.3
field weakening range
speed range above the speed where the motor can be supplied with a voltage that changes in proportion to the speed. Therefore, the magnetic flux in this speed range is reduced in relation to constant flux range.

3.4
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 higher frequencies.

3.5
motor losses with converter supply
if powered by a converter, motor losses are a combination of losses caused by fundamental frequency and losses caused by the converter high frequencies

3.6
multi-level voltage source converter
frequency converter topology, where the output voltage (phase-to-ground) is switched in three or more steps or levels up to the maximum possible output value of both positive and negative voltage

3.7
switching event
operation sequence of one semiconductor with switching once on and switching once off

3.8
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) of the motor

3.9
thermal equilibrium
steady state temperature level of a motor which is reached, if the rate of change of temperature is 1 K or less per half hour

3.10
two-level voltage source converter
frequency converter topology, where the output voltage (phase-to-ground) is switched between two levels

Note 1 to entry: For a two-level converter, the pulse frequency measured phase to phase is two times the switching frequency defined in 3.8 in case of continuous modulation and about 1,33 times the switching frequency defined in 3.8 in case of discontinuous modulation.

4 Symbols and abbreviated terms

c_{BH}	Loss separation coefficient for friction and windage losses and hysteresis losses
c_{Con}	Winding connection coefficient
c_{fe}	Loss separation coefficient for hysteresis losses and eddy current losses
c_{LL}	Loss separation coefficient for additional load losses
c_{Volt}	Voltage coefficient
c_{WHf}	Loss separation coefficient for winding losses and high frequency losses
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
n	Speed, s^{-1}
n_{N}	Rated speed, s^{-1}
n_{ref}	Reference speed, s^{-1}
n_{FW}	Relative speed at which field weakening range starts,
P	Power, W
P_{Ccon}	Constant losses if supplied by a converter, W
P_{Csin}	Constant losses at sinusoidal supply according to IEC 60034-2-1, 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 if supplied by a converter, W
$P_{1\_60034\text{-}2\text{-}1}$	Motor input power at sinusoidal supply according to IEC 60034-2-1, W
P_{2C}	Motor output power if supplied by a converter, W
$P_{2\_60034\text{-}2\text{-}1}$	Motor output power at sinusoidal supply according to IEC 60034-2-1, W
PWM	Pulse width modulation
T	Motor torque, Nm
T_C	Motor torque if supplied by a converter, 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.

If testing electric motors 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 5 s but not more than 60 s and this average shall be used for the determination of efficiency.

For winding temperature measurements, the methods described in IEC 60034-2-1 shall be used. The resistance method is preferred.

5.1.2 Power analyser and transducers

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

The instrumentation for measuring power and current at the motor input shall meet the requirements of IEC 60034-2-1. 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 apparent power at rated operation of the motor or better for the rated power at 50 Hz or 60 Hz. This is the total uncertainty of the power meter including possible sensors.

NOTE 1 For example, if 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 must be 0,2 % or less of √3 times 4 000 VA, which is 13,9 W or better.

The bandwidth of power meters and sensors shall be sufficiently wide so that the error in the measurement of total calculated 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.

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 may be used for frequencies 10-times higher than the switching frequency. Synchronization filters (also known as zero-cross filters) that are not in the signal path may be used additionally.

For power measurement, the three-wattmeter method is preferred. All cables used to transmit measurement signals shall be shielded. It must 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 min^{-1} for speeds up to 3 600 min^{-1}, and 0,03 % above.

The instrumentation used to measure the torque shall have a minimum class of 0,2 if the rated efficiency is below 92 %, 0,1 below 95 % and 0,05 or better for higher efficiencies, when applying the preferred method as in Table 1. In case of applying method 2-3-B according to Table 2, the instrumentation shall follow the requirements of IEC 60034-2-1 as minimum. 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 shall be understood as a voltage source independent of load current.

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 motor efficiency regulations, in particular the 90 % speed and 100 % torque load point. For all other purposes including the interpolation procedure, preferably the original system configuration should be used.