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Električni rotacijski stroji - 2-3. del: Posebne preskusne metode za ugotavljanje izgub in izkoristka motorja na izmenični tok, napajanega prek pretvornikov

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

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IEC TC 2 : ROTATING MACHINERY

SECRETARIAT: United Kingdom	SECRETARY: Mr Charles Whitlock
OF INTEREST TO THE FOLLOWING COMMITTEES:	PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CDV to the secretary.

FUNCTIONS CONCERNED:

☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☐ SAFETY

☒ SUBMITTED FOR CENELEC PARALLEL VOTING

☐ NOT SUBMITTED FOR CENELEC PARALLEL VOTING

Attention IEC-CENELEC parallel voting

The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this Committee Draft for Vote (CDV) is submitted for parallel voting.

The CENELEC members are invited to vote through the CENELEC online voting system.

This document is still under study and subject to change. It should not be used for reference purposes.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

TITLE:

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

PROPOSED STABILITY DATE: 2021

NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ROTATING ELECTRICAL MACHINES –

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

INTRODUCTION

The objective of this standard 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 standard are intended to allow comparison of losses and efficiency of different motors when fed by converters.

Furthermore, the standard 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 standard 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 standard 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.

It is not the purpose of this standard 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 generally increase much with load. The methods in this standard 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 standard 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 standard.

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 standard specifies test methods and an interpolation procedure for determining losses and efficiencies of converter-fed motors within the scope of IEC 60034-1. 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 standard is applicable for comparison of different motor designs only.

The standard 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 for operation on a variable frequency and variable voltage power supply.

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

IEC 60034-2-2, *Rotating electrical machines – Part 2-2: Specific methods for determining separate losses of large machines from test – Supplement to IEC 60034-2-1*

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

IEC TS 61800-8, *Adjustable speed electrical power drive systems. – Part 8: Specification of voltage on the power interface*

IEC 61800-9-2:2017, *Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics & 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 60034-2-1:2014 as well as the following apply.

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
The 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
The switching frequency is the 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 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

For the purposes of this document the symbols given in IEC 60034-2-1, IEC TS 61800-8 as well as the following apply.

PWM	Pulse width modulation,
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 interior permanent magnet 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,
$P_{1\_60034\text{-}2\text{-}1}$	Motor input power as tested according to IEC 60034-2-1:2014, W,
P_{2C}	Motor output power at converter supply, W,
$P_{2\_60034\text{-}2\text{-}1}$	Motor output power as tested according to IEC 60034-2-1:2014, W,
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 standard, 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 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 should be 0,2% of √3 times 4000 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 transformers.

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 3000 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 90% and 0,1 or better for higher efficiencies. The minimum torque measured shall be at least 10% of the torque meter’s nominal 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 standard 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 3600 min^{-1}, the switching frequency shall not be higher than 4 kHz.