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BSI Standards Publication

Rotating electrical machines

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

National foreword

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colour inside

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

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

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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 induction motors

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC/TS 60034-2-3, which is a technical specification, has been prepared by IEC technical committee 2: Rotating machinery.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
2/1696/DTS	2/1719/RVC

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

NOTE A table of cross-references of all IEC TC 2 publications can be found on the IEC TC 2 dashboard 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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The objective of this technical specification is to define test methods for determining the additional harmonic motor losses of converter-fed induction motors. These 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 specification are intended to allow for comparison of the harmonic losses of different AC induction motors when fed by converters.

In power-drive systems (PDS), the motor and the frequency converter are often manufactured by different suppliers. While 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.) may influence the system efficiency as well. It is impractical to determine the additional harmonic motor losses for every combination of motor, frequency converter, connection cable, output filter and parameter settings. Accepting that it is extremely difficult to specify motor efficiency for converter operation, this specification describes a limited number of approaches, depending on the voltage level and the rating of the machine under test.

The procedures described in this specification result in a single number, the harmonic loss ratio r_{HL}, which is the ratio of the additional harmonic motor losses and the motor losses measured using a nominally sinusoidal voltage power supply.

The losses determined according to this specification 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.

The methods in this technical specification apply to induction motors used with variable frequency drives. However, the application to other AC motors or DC motors and converters, is not excluded. The methods are mainly intended for motors fed by voltage source converters.

In general, when fed from a converter, the motor losses are higher than during operation on a nominally sinusoidal system. The additional harmonic losses depend on the 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.

This technical specification is aimed at evaluating the additional harmonic motor losses resulting from non-sinusoidal power supply and consequently the efficiency of the converter-fed motor. It is not the purpose of this technical specification to define test procedures either for power drive systems or for frequency converters alone.

This technical specification is applicable to motors rated for 50 Hz or 60 Hz fundamental frequency. However, for other rated motor frequencies the test procedure may be applied provided a suitable power source is available, e.g. a 4-pole motor used at 3 000 rpm can be tested with 100 Hz and actual voltage rating.

Low-voltage motors

Experience has shown that the additional harmonic motor losses generally increase with load. The methods in this technical specification are based on supplies from converters with pulse width modulation (PWM) and constant pulse pattern. This is generally the case for voltage source converters except for over-modulation. Such voltage source converters have by far the largest market share in the low-voltage industrial drive market.

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

In principle, the test converter is a voltage source with a clearly defined and reproducible harmonic content to supply the machine under test. The motor efficiency is to be determined at rated load for 50 Hz or 60 Hz. Defining 50 Hz or 60 Hz as test conditions has the advantage of providing a direct comparison of motor efficiency for grid and converter operation.

The above outlined test converter concept is a new approach to weigh the converter impact on an electrical machine without being forced having the final converter for testing. By releasing this technical specification, test facilities are invited to gain practical experience with this approach and to provide feedback for further refinement of the test procedure.

Limitations for low-voltage motors and high-voltage motors with multi-level converters

It has to be noted that the test method described herein is only 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 possible to determine the actual motor losses for operation with a specific converter which would require a test of the whole power drive system (PDS).

Deviations are also expected for motors driven by multi-level voltage source or current source converters where the additional harmonic 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 harmonic motor losses by calculation. If this is requested by the customer, the converter manufacturer has to provide the pulse pattern for the motor manufacturer.

ROTATING ELECTRICAL MACHINES –

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

1 Scope

This technical specification specifies test methods for determining losses and efficiencies of converter-fed AC induction motors within the scope of IEC 60034-1. The AC induction motor is then part of a variable frequency power drive system (PDS) as defined in IEC 61800-2, IEC 61800-4 or IEC/TS 61800-8.

The additional harmonic losses determined by use of this technical specification are for comparison of different motor designs, but they are not appropriate to be used for efficiency determination of a PDS in a driven application with its wide range of torque versus speed operating points.

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 60034-2-1:2007, *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*

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.

3.1
motor losses with converter supply
when powered by a converter, motor losses are a combination of losses caused by fundamental frequency (usually 50 Hz or 60 Hz) and losses caused by the converter harmonics

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 rated voltage at fundamental frequency (usually 50 Hz or 60 Hz), without any harmonics.

3.3
harmonic losses
harmonic losses are produced in the motor by the non-sinusoidal voltage and current waveforms generated by the converter and are in addition to the fundamental losses of iron, rotor-winding, stator-winding and additional-load loss.

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	Pulsewidth modulation,
f	Frequency, Hz,
f_{Mot}	Fundamental motor frequency, Hz,
f_{N}	Rated motor frequency, Hz,
f_{sw}	Switching frequency, Hz,
f_{r}	Maximum frequency of measuring equipment, Hz,
n	Speed, s^{-1}
p	Number of pole pairs,
P_{C}	Constant losses according to IEC 60034-2-1:2007, method 2-1-1B at nominally sinusoidal power supply, W,
P_{CC}	Constant losses according to IEC 60034-2-1:2007, method 2-1-1B at test-converter supply, W,
P_{fe}	Iron losses at rated frequency, W,
P_{fw}	Friction and windage losses at rated speed, W,
P_{fw0}	Friction and windage losses at synchronous speed, W,
P_{HL}	Total additional harmonic motor losses, W,
$P_{\mathrm{HL\ Load}}$	Load-dependent part of the additional harmonic motor losses, W,
$P_{\mathrm{HL\ No\text{-}Load}}$	Constant part of the additional harmonic motor losses, W,
P_{LL}	Additional load losses at rated load according to IEC 60034-2-1:2007, method 2-1-1B at nominally sinusoidal power supply, W,
P_{LLC}	Additional load losses at rated load according to IEC 60034-2-1:2007, method 2-1-1B at converter supply, W,
P_{Lr}	Residual losses according to IEC 60034-2-1:2007, method 2-1-1B at nominally sinusoidal power supply, W,
P_{LrC}	Residual losses according to IEC 60034-2-1:2007, method 2-1-1B at converter supply, W,
P_{r}	Rotor winding losses according to IEC 60034-2-1:2007, method 2-1-1B at nominally sinusoidal power supply, W,
P_{s}	Stator winding losses according to IEC 60034-2-1:2007, method 2-1-1B at nominally sinusoidal power supply, W,

P_{Tsin}	Total losses according to IEC 60034-2-1:2007, method 2-1-1B at nominally sinusoidal power supply, W,
$P_{\mathrm{T\ test\text{-}converter}}$	Total losses according to IEC 60034-2-1:2007, method 2-1-1B when supplied by the test converter, W,
P_1	Input power at nominally sinusoidal power supply, W,
$P_{1\mathrm{C}}$	Input power at converter supply, W,
P_2	Output power at nominally sinusoidal power supply, W,
$P_{2\mathrm{C}}$	Output power at converter supply, W,
r_{HL}	Ratio of harmonic voltage losses related to nominally sinusoidal voltage losses expressed in percentage and rounded to a full number,
s	Slip,
T	Machine torque at sinusiodal power supply, Nm,
T_{C}	Machine torque at converter supply, Nm,
U_{Mot}	Fundamental motor voltage, V,
U_{N}	Rated motor voltage, V.

5 Basic requirements

5.1 Instrumentation

5.1.1 General

In the case of AC machines, unless otherwise stated in this technical specification, the arithmetic average of the three line currents and voltages shall be used.

When testing electric motors under load, fluctuations in the output power and other measured quantities may be unavoidable. Therefore for each load point several measurements over a period of time (approximately 30 s) shall be simultaneously sampled and the average of these values shall be used for the determination of efficiency.

Considering the harmonics 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 thermo-sensor installed in the hot-spot may be optionally used, as described in IEC 60034-2-1:2007.

5.1.2 Power analyzer and transducers

The instrumentation for measuring power and current at the motor's input shall basically meet the requirements of IEC 60034-2-1:2007, but due to higher frequency components the following additional requirements have to be met.

The nominal accuracy of the power meters shall be 0,2 % or better at 50 Hz/60 Hz and 0,5 % up to a frequency f_{r} of at least:

$f_{\mathrm{r}} = 10 \times f_{\mathrm{sw}}$ for PWM converter output.

The measurement range shall be chosen adequately in relation to the measured currents and voltages.

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.

The bandwidth of the current sensors and acquisition channels shall range at least from 0 Hz to 100 kHz.

Internal filters in digital power meters shall be turned off.

For power measurement the three-wattmeter method is recommended. The two-wattmeter method (Aaron-connection) is acceptable, but it has to be noted that not all available equipment is capable to compensate the possible errors of this method. This capability shall be verified from the equipment manufacturer data sheets.

All cables used to transmit measurement signals shall be shielded.

5.1.3 Mechanical output of the motor

The instrumentation for measuring torque and speed at the motor's output shall meet the requirements of IEC 60034-2-1:2007.

5.2 Converter set up

5.2.1 General

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

5.2.2 Test converter set up for rated voltages up to 1 kV

The test converter has to be understood as a voltage source independent of load current, set at rated voltage and fundamental frequency (50 Hz or 60 Hz) of the motor under test.

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

The following reference conditions are defined:

- Two level voltage source converter.
- No motor current feedback control activated (to be deactivated, if necessary).
- “Slip compensation” shall not be applied.
- No additional components influencing output voltage or output current shall be installed between the test converter and the motor, except those required for the measuring instruments.
- Fundamental motor voltage equal to rated motor voltage $U_{\mathrm{Mot}} = U_{\mathrm{N}}$ at 50 Hz or 60 Hz. The input voltage of the test converter shall be set to a value that allows rated motor voltage to be applied and to avoid overmodulation. However the converter input voltage shall not be higher than just needed to fulfill the above.
- Fundamental motor frequency equal to rated motor frequency $f_{\mathrm{Mot}} = f_{\mathrm{N}}$ (50 Hz, 60 Hz).
- Switching frequency f_{SW} = 4 kHz for rated output powers up to 90 kW.
- Switching frequency f_{SW} = 2 kHz for output powers above 90 kW.

Annex A defines the test converter output stage and establishes test methods to check its conformity. The test converter can be fed by an appropriate AC or DC input.

A shielded cable shall connect the test converter to the motor. The cable length shall be less than 100 m. The cable size shall be selected according to the motor rating.

5.2.3 Testing with the converter for the final application

For converters with voltage ratings above 1 kV a generally accepted test converter and cable length cannot be specified. Such motors, cables and 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.

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

6.1 Test method (see Table 1)

Table 1 – Test methods

Ref	Method	Description	Subclause	Required facility
2-3-A	**Summation of losses:** **Test converter supply**	Harmonic loss determination with test-converter according to Annex A	6.2	Sinusoidal supply and test converter supply for full-load operation
2-3-B	**Summation of losses:** **Supply with specific converter for final application**	Harmonic loss determination with converter for final application	6.3	Sinusoidal supply and specific converter supply for full-load operation
2-3-C	**Input-output**	Torque measurement	6.4	Dynamometer for full-load; specific converter supply
2-3-D	**Calorimetric**	Loss determination from coolant temperature rise	6.5	Specific converter supply. Measurement according to IEC 60034-2-2

6.2 Method 2-3-A: Summation of losses with test converter supply

6.2.1 General

Even for voltage source converters with an output voltage and pulse pattern which is independent of load, experience has shown that the additional harmonic motor losses basically increase with load. For low voltage converters, a constant pulse pattern is generally the case as long as the voltage modulation amplitude is not reaching the limit of the intermediate circuit voltage.

Therefore, the total additional loss caused by converter supply can be determined from a load-test at fundamental frequency supply and a load-test at converter supply. The additional harmonic loss is the difference of the measured losses of both tests.

A sinusoidal voltage source according to IEC 61000-2-4, class 1, shall be available in addition to the converter to perform these tests (nominally sinusoidal power supply).

The converter used for these tests is a test converter as specified in Annex A. Using the test-converter allows for comparison of efficiency figures of different machines, because the pulse pattern is fixed and comparable. This is not the case for a specific converter with a specific control mechanism as described by method 2-3-B. In that case the output voltage depends on manufacturer specific control schemes.

6.2.2 Test procedure

The sequence of tests is as follows:

- Perform a load test with sinusoidal power supply of rated frequency and rated voltage according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.1 for the determination of the total losses P_{Tsin}.
- Determine the load losses according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.2.
- Perform a load curve test with sinusoidal power supply of rated frequency and rated voltage according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.3 and determine the losses accordingly.
- Perform a no-load test with sinusoidal power supply of rated frequency and rated voltage according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.4.
- Determine the constant losses P_C at sinusoidal power supply according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.5.
- Perform a load curve test with test converter supply of rated frequency and rated voltage according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.3 and determine the losses accordingly.
- Perform a no-load test with test converter supply of rated frequency and rated voltage according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.4.
- Determine the constant losses P_{CC} at test converter supply according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.5.

Load-dependent additional harmonic losses – Residual losses P_{LL} and P_{LLC}

Based on the above mentioned tests, the residual losses shall be determined according to IEC 60034-2-1:2007, method 2-1-1B, 6.1.2.1.6.

The residual losses shall be determined for each load point by subtracting from the input power: the output power, the uncorrected stator winding losses at the resistance of the test, the iron losses, the windage and friction losses, and the uncorrected rotor winding losses corresponding to the determined value of slip.

This has to be done for sinusoidal power supply

$$P_{Lr} = P_1 - P_2 - P_s - P_r - P_{fe} - P_{fw}$$

and test converter supply

$$P_{LrC} = P_{1C} - P_{2C} - P_s - P_r - P_{fe} - P_{fw} .$$

P_{LrC} to be determined for the same load points as P_{Lr} .

Where

$$P_{fw} = P_{fw0} \cdot (1 - s)^{2,5} \text{ with } s = 1 - \frac{p \times n}{f}$$

are the corrected friction and windage losses according to IEC 60034-2-1:2007.

For both cases the residual loss data shall be smoothed by using the linear regression analysis in accordance to IEC 60034-2-1, based on expressing the losses as a function of the square of the load torque:

$$P_{Lr} = A \cdot T^2 + B \quad \text{and} \quad P_{LrC} = A_C \cdot T_C^2 + B_C$$

When the slope constants A and A_C are established, a value of additional load losses for rated load point shall be determined for sinusoidal and converter supply respectively by using the formulas:

$$P_{LL} = A \cdot T_N^2 \quad \text{and} \quad P_{LLC} = A_C \cdot T_N^2$$

The additional load losses P_{LLC} cover now all load-dependent additional losses, i.e. those caused by the fundamental load current and the load-dependent part of those caused by the harmonics of the test converter.

The difference between the additional load losses for operation with the test converter and with a sinusoidal power supply gives the load-dependent part of the additional harmonic motor losses:

$$P_{HL_{Load}} = P_{LLC} - P_{LL}$$

Constant additional harmonic losses – Constant losses P_C and P_{CC}

The difference between the no-load losses for operation with the test converter P_{CC} and with a sinusoidal power supply P_C is the constant part of the additional harmonic motor losses:

$$P_{HL_{No-Load}} = P_{CC} - P_C$$

6.2.3 Efficiency determination

The difference between the additional load losses for operation with the test converter and with a sinusoidal power supply are the additional harmonic motor losses.

$$P_{HL} = P_{HL_{No-Load}} + P_{HL_{Load}}$$

The additional harmonic motor losses shall be added to the fundamental motor losses as determined with a sinusoidal power supply according to IEC 60034-2-1:2007, method 2-1-1B in order to obtain the motor efficiency under frequency converter operation.

$$P_{T\ \text{test-converter}} = P_{T\sin} + P_{HL}$$

The efficiency at test converter supply is determined from

$$\eta = \frac{P_2}{P_2 + P_{T\ \text{test-converter}}}$$

The harmonic loss ratio is given by

$$r_{HL} = \frac{P_{HL}}{P_{T\sin}} \cdot 100\ \%$$

It should be rounded to a full (integer) number.

6.3 Method 2-3-B: Summation of losses with specific converter supply

The total additional loss caused by converter supply shall be determined from a load-test at fundamental frequency supply and a load-test at converter supply with the specific converter for the final application. Apart from using the specific converter system, the test procedure is equal to method 2-3-A.

6.4 Method 2-3-C: Input-output method

6.4.1 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.

6.4.2 Test procedure

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

Couple the motor under test to a load machine with a dynamometer. Operate the machine under test at rated torque until thermal equilibrium (rate of change of 1 K or less per half hour) has been reached.

At the end of the test, record:

T Output torque

n Speed

P_{1C} Input power at specific converter supply

6.4.3 Efficiency determination

Calculate the output power: $P_{2C} = 2\pi \cdot T \cdot n$

Calculate the efficiency: $\eta = \frac{P_{2C}}{P_{1C}}$

6.5 Method 2-3-D: Calorimetric method

Efficiency may also be determined by calorimetric measurement of the total losses of the tested equipment within the primary or secondary water cooling circuit. Test procedures for this method shall be in accordance with IEC 60034-2-2.

7 Other procedures

If the motor rating exceeds the available testing capabilities, the determination of the additional harmonic losses caused by converter operation based on calculations may be an alternative procedure to give an order of magnitude of the additional losses. This calculation has to be based on the real pulse patterns of the converter, the frequency-dependent equivalent circuit parameters of the electric motor and by using motor models capable to cover the effects of the harmonics.

Annex A
(informative)

Definition of the output voltage of the test converter

A.1 Definitions and schematic

For the purposes of this part of the document, the following terms and definitions apply in addition to Clause 4.

NP	Neutral point
SP	Star point
U_d, U_{d+}, U_{d-}	DC link voltages of the converter section. U_{d+} means the voltage of the positive rail, U_{d-} the potential of the negative rail with reference to NP.
U_U, U_V, U_W	Phase to NP voltages at the inverter output; block shaped in steady state operation.
U^*_U, U^*_V, U^*_W	Set-points of the phase to NP voltages at the inverter output.
U_{UD}, U_{VD}, U_{WD}	Phase to starpoint voltages at the inverter output; block shaped in steady state operation.
U^*_{UD}, U^*_{VD}, U^*_{WD}	Set-points of the phase to starpoint voltages; sinusoidal in steady state operation.
U_{CCM}	Common mode voltage related to the star point of the motor.
U_{ref}	Amplitude of set-points of the phase voltages of the motor; constant in steady state operation.
f_{1ref}	Frequency set-point of the motor voltage; constant in steady state operation.
U^*_{ext}	Linearity extension voltage. Common mode voltage used in the modulator.
S_U, S_V, S_W	Switching commands for the inverter phases.

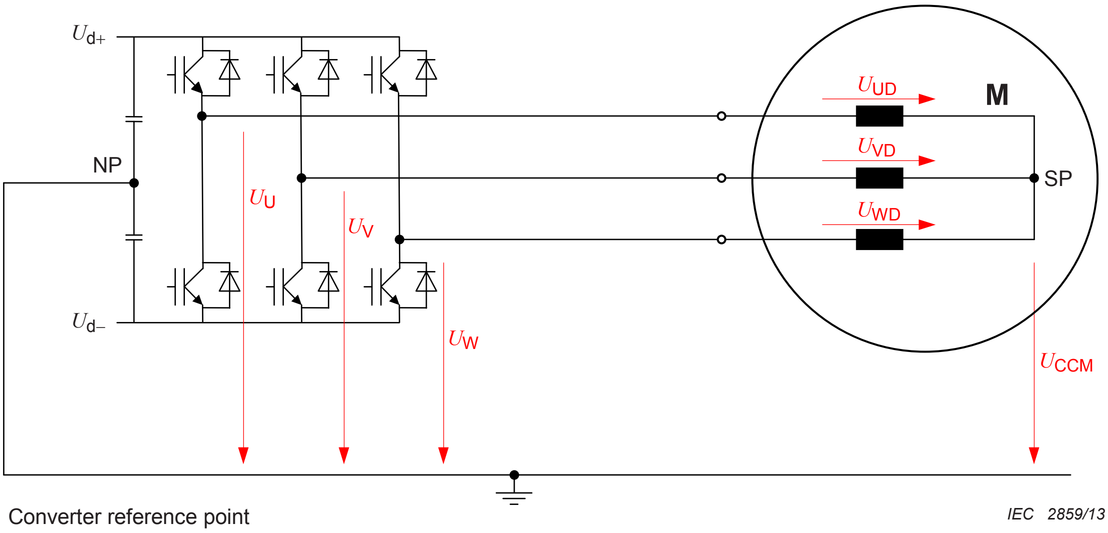

Figure A.1 – Schematic for PDS

Figure A.1 shows star-connected motor, nevertheless the technical specification can also be applied to delta-connected motors with internal or external star-points.

The output voltage of the inverter (U_U, U_V, U_W) can be divided into the differential mode (also known as symmetrical) voltage system (U_{UD}, U_{VD}, U_{WD}) and the common mode voltage to the reference point of the converter (U_{CCM}).

The differential mode voltage expresses the voltages of the three motor phases. For each phase, it can be calculated as the difference of the inverter output voltage and the common mode voltage.

This is e.g. for phase U:

$$U_{UD} = U_U - U_{CCM}$$

The common mode voltage can be calculated as follows:

$$U_{CCM} = (U_U + U_V + U_W)/3$$

A.2 Voltage reference and generation of output voltage waveform

This clause describes a method to realize the pulse pattern of the test inverter and it explains, why the measurements should look like shown in Figure A.3.

A basic controller generates the set points of the absolute value of the desired motor voltage and the motor frequency U_{ref}, f_{1ref} for steady state operation.

The sinusoidal voltage set points (U^*_{UD}, U^*_{VD}, U^*_{WD}) to be applied to the motor are computed in the converter controller.

$$U^*_{UD} = U_{ref} \cdot \sin(2\pi \cdot f_{1ref} \cdot t)$$

$$U^*_{VD} = U_{ref} \cdot \sin(2\pi \cdot f_{1ref} \cdot t - 2\pi/3)$$

$$U^*_{WD} = U_{ref} \cdot \sin(2\pi \cdot f_{1ref} \cdot t + 2\pi/3)$$

Then a linearity extension signal U^*_{ext} is added to all voltage set points. The linearity extension signal is a common mode voltage that increases the voltage range, in which the motor voltage corresponds to the set point without low order harmonics.

$$U^*_U = U^*_{UD} + U^*_{ext}$$

$$U^*_V = U^*_{VD} + U^*_{ext}$$

$$U^*_W = U^*_{WD} + U^*_{ext}$$

Finally these signals are compared to a switching triangle to compute the pulse pattern S_u, S_v, S_w. The switching triangle is a periodic symmetrical triangle waveform, the frequency of which defines the switching frequency of the inverter. The inverter generates the output voltages (U_U, U_V, U_W) according to the pulse pattern. The block diagram in Figure A.2 describes the system.

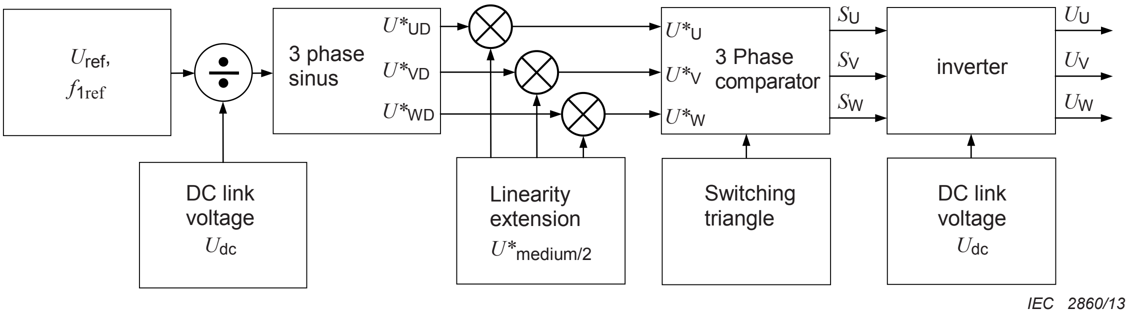

Figure A.2 – Functional schematic for voltage generation system

The linearity extension signal U^*_{ext} to be used in the test inverter is defined as half of the medium of the 3 sinusoidal voltage set points (U^*_{UD}, U^*_{VD}, U^*_{WD}). The medium voltage is the one with the lowest absolute value. The correlation is illustrated in Figure A.3 below:

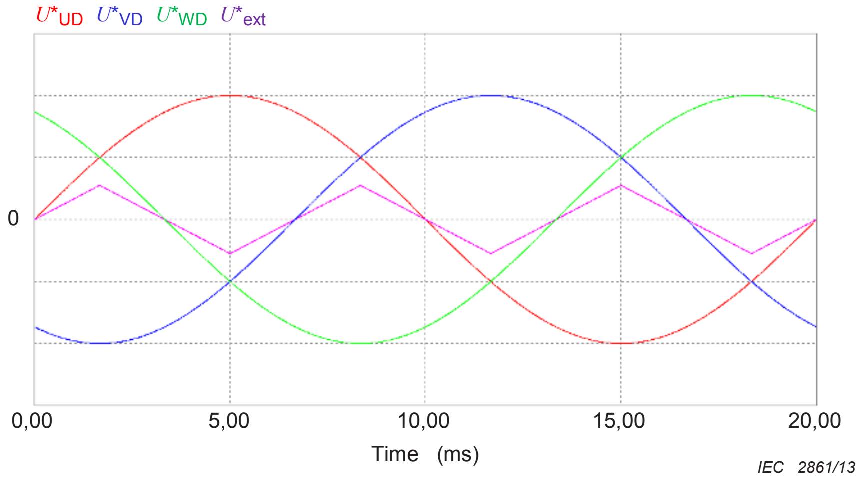

Figure A.3 – Sinusoidal voltage set point and linearity extension voltage

The sinusoidal voltage set point and the resulting reference voltage to be compared to the switching triangle are shown Figure A.4 for phase U:

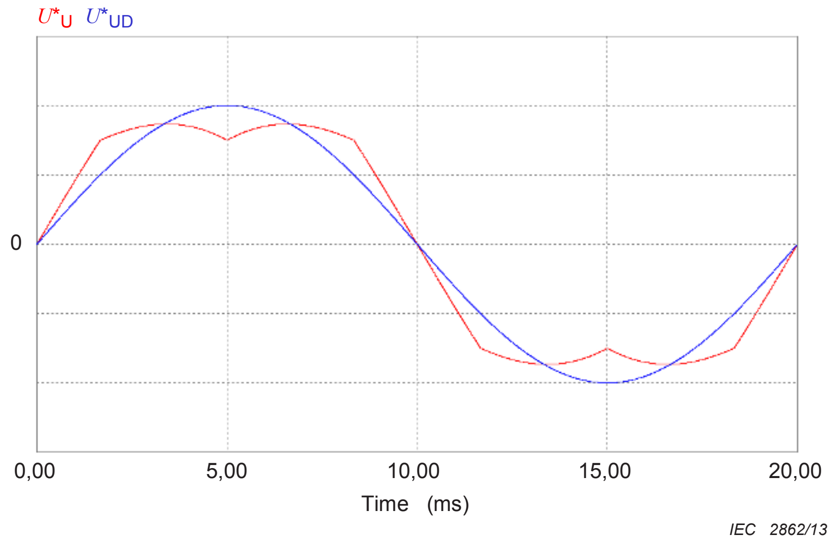

Figure A.4 – Voltage set point and extended reference voltage

The output voltage of the inverter measured between the inverter terminal and NP corresponds to the pattern resulting from the comparison of the extended reference voltage with the switching triangle (see A.2). It is exemplified in Figures A.5 and A.6 for a fundamental frequency of 50 Hz and a switching triangle frequency of 4 kHz.

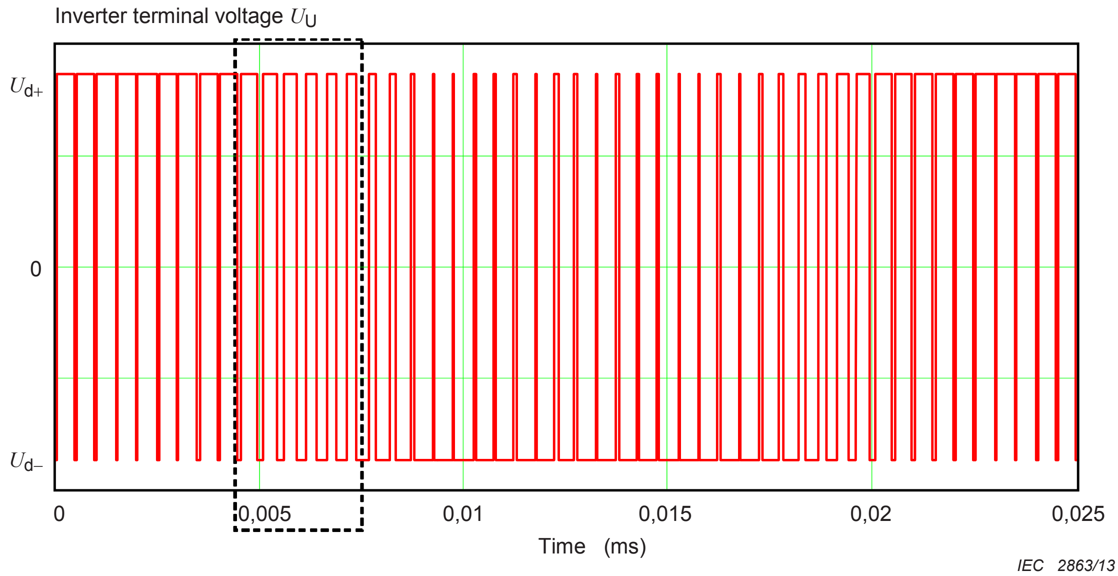

Figure A.5 – Pulse pattern of motor terminal voltage
(fundamental frequency 50 Hz; switching triangle frequency 4 kHz)

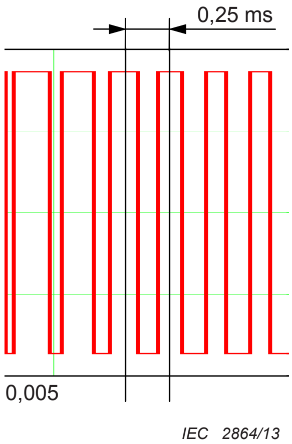

Figure A.6 – Magnification of marked area of Figure A.5

The distance between the centers of any two adjacent blocks is the reciprocal value of the switching triangle frequency which is identical with the switching frequency of the inverter.

A.3 Checking in the time domain

To check the correct pattern of voltage and frequency applied to the motor, a measurement shall be done at the operation point defined in 5.2.2.

The terminal voltage U_U of the inverter shall look as shown in Figures A.5.and A.6. No pulse shall be missing. The distance between the centers of two adjacent blocks shall be 0,25 ms for a switching frequency of 4 kHz or 0,5 ms for a switching frequency of 2 kHz.

If there are missing pulses, the DC link voltage shall be increased.

To check whether the linearity extension is correctly applied, the terminal voltage U_U shall be measured through a low pass filter. Figure A.7 shows how the signal should look like.

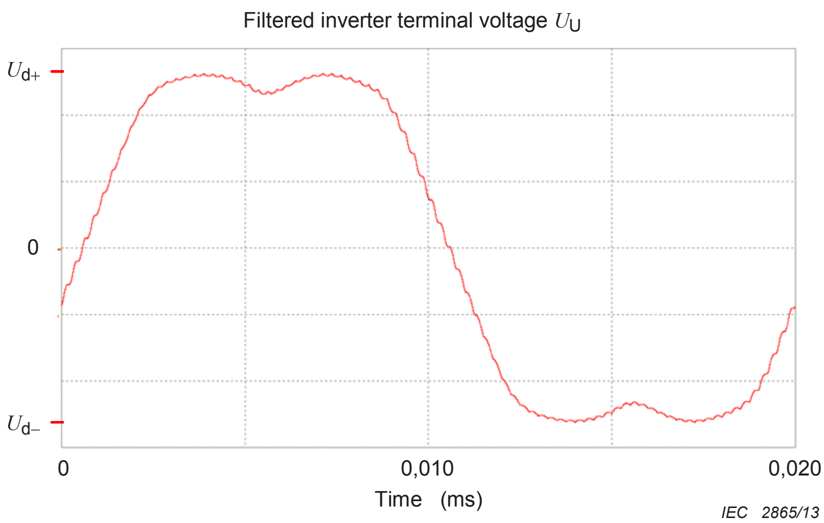

Figure A.7 – Filtered inverter terminal voltage (fundamental frequency of 50 Hz; 2nd order low pass filter 500 Hz / 0,7)

Only the shape form with double extrema is specific, the signal shall not show any sign of saturation such as a flat segment at the top or at the bottom.

Alternatively the terminal voltage may be measured with respect to the positive or the negative DC rail potential, resulting in an offset of $-/+U_d/2$.

The earth potential is not suitable as reference potential.

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IEC 61800-2, *Adjustable speed electrical power drive systems – Part 2: General requirements – Rating specifications for low voltage adjustable frequency a.c. power drive systems*

IEC 61800-4, *Adjustable speed electrical power drive systems – Part 4: General requirements – Rating specifications for high voltage adjustable frequency a.c. power drive systems above 1000 V a.c., and not exceeding 35 kV*

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