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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



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SUPERSEDES DOCUMENTS:

22G/426/CD, 22G/444/CC

IEC SC 22G : ADJUSTABLE SPEED ELECTRIC POWER DRIVE SYSTEMS (PDS)

SECRETARIAT:

United States of America

SECRETARY:

Mr Christopher Johnson

OF INTEREST TO THE FOLLOWING COMMITTEES:

TC 2, SC 121A

PROPOSED HORIZONTAL STANDARD:



Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.

FUNCTIONS CONCERNED:

☐ EMC

☐ ENVIRONMENT

☐ QUALITY ASSURANCE

☐ SAFETY

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TITLE:

Adjustable speed electrical power drive systems - Part 9-2: Ecodesign for motor systems - Energy efficiency determination and classification

NOTE FROM TC/SC OFFICERS:

The title has been changed from "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" to "Part 9-2: Ecodesign for motor systems – Energy efficiency determination and classification" (see 22G/444/CC).

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

**Part 9-2: Ecodesign for motor systems
Energy efficiency determination and classification**

FOREWORD

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International Standard IEC 61800-9-2 has been prepared by subcommittee 22G: Adjustable speed electric drive systems incorporating semiconductor power converters, of IEC technical committee 22: Power electronic systems and equipment.

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

FDIS	Report on voting
22G/349/FDIS	22G/352/RVD

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

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

A list of all parts in the IEC 61800 series, published under the general title *Adjustable speed electrical power drive systems*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 61800 has been developed to allow evaluation of power losses of SDMs (sub drive modules), CDMs (complete drive modules) and PDSs (power drive systems).

The requirements for measuring energy efficiency of motors with non-sinusoidal supply are under the responsibility of IEC/TC 2 and will be published under the IEC 60034 series.

IEC SC 22G includes the standardization task force for dealing with this topic. It has close collaboration with several other technical committees (for example, IEC TC 2, IEC SC 121A, ISO/TC 115, ISO/TC 117, ISO/TC 118).

IEC SC 22G maintains responsibility for all relevant aspects in the field of energy efficiency and ecodesign requirements for power electronics, switchgear, control gear and power drive systems and their industrial applications.

IEC 61800 (all parts) does not deal with mechanical engineering components.

NOTE Geared motors (motors with directly adapted gearboxes) are treated like power drive systems (converter plus motor). See IEC 60034-30-1 for classification of the losses of a geared motor. The efficiency classes of gearboxes as individual components are under consideration.

IEC 61800-9-2 is a subpart of the IEC 61800 series, which has the following structure:

- *Part 1: General requirements – Rating specifications for low voltage adjustable speed DC power drive systems*
- *Part 2: General requirements – Rating specifications for low voltage adjustable speed AC power drive systems*
- *Part 3: EMC requirements and specific test methods*
- *Part 4: General requirements – Rating specifications for AC power drive systems above 1 000 V AC and not exceeding 35 kV*
- *Part 5: Safety requirements*
- *Part 6: Guide for determination of types of load duty and corresponding current ratings*
- *Part 7: Generic interface and use of profiles for power drive systems*
- *Part 8: Specification of voltage on the power interface*
- *Part 9: Ecodesign for motor systems*

Each part is further subdivided into several subparts, published either as International Standards or as Technical Specifications or Technical Reports, some of which have already been published. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61800-9-2).

This document has been developed in close collaboration with other technical committees (IEC TC 2, IEC SC 121A) and with a customer's stakeholder committee CEN/TC 197 in order to provide a comprehensive standard for energy efficiency and ecodesign requirements.

Key points:

- Requirements for energy-efficient design of electric drive systems in accordance with the driven load
- Requirements and IE-classification of complete drive modules (CDM)
- Requirements and IE-classification of sub drive modules (SDM)
- Requirements and IES-classification of power drive systems (PDS)

- 399 • Determination of PDS losses and requirements for the link to the driven equipment for the
400 determination of energy efficiency classification/evaluation of the extended product
- 401 • Requirements for an environmentally conscious system design and environmental
402 declaration of a motor system

403

404

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

Part 9-2:

Ecodesign for motor systems

Energy efficiency determination and classification

1 Scope

This part of IEC 61800 specifies energy efficiency indicators of power electronics (complete drive modules (CDM), input or output sub drive modules (SDM)), power drive systems (PDS) and motor starters, all used for motor driven equipment.

This document is a product Energy Efficiency Publication according to IEC Guide 118 and specifies the methodology for the determination of losses of the complete drive module (CDM), the sub drive module (SDM), the power drive system (PDS) and the motor system.

It defines IE and IES-classes, their limit values and provides test procedures for the classification of the overall losses of the motor system.

Furthermore, this document proposes a methodology for the implementation of the best energy efficiency solution of drive systems. This depends on the architecture of the motor driven system, on the speed/torque profile and on the operating points over time of the driven equipment.

The methodology of the extended product approach and the semi analytical models are defined in IEC 61800-9-1.

The structure of this document is as follows:

- the losses of standardized PDS (PDS), standardized reference CDM (RCDM) and the mathematical model for their calculation are given and classified;
- the reference motor (RM) and the reference CDM (RCDM) are defined. They are used for determining the efficiency class of a PDS if either the physical motor or physical CDM is unknown;
- the requirements for the determination of the losses of a physical PDS and a physical CDM including correction factors for other types of CDM as defined as RCDM or SDM are given and compared to the PDS and RCDM;
- the requirements for type testing and user documentation are given;
- some exemplary losses of an overall system are illustrated in annexes;
- information about system and drive topologies are given in annexes.

Specific data for power losses of RCDM, RM, RPDS and IE/IES-classes are given for low voltage (100 V up to and equal to 1 000 V), single axis AC/AC power drive systems with three-phase motors. Geared motors are treated as standard motors when motor and gearbox can be separated. A methodology is given in addition how this reference data can also be applied to other topologies like AC/DC or DC/AC converters.

All provided reference data is derived from PDS with induction motors. It may be used for all types of PDS with other types of motors as well, for example, Electronically Commutated Motors (ECM), Permanent Magnet Motors (PM) or Synchronous Reluctance Motors (SYN-RM).

PDS requirements in this standard only apply to PDSs that are placed on the market as one single product, i.e. combination of motor and CDM that are not intended to be used separately.

CDM requirements only apply to a CDM where the included SDMs have not already been evaluated according to SDM requirements.

The following equipment is excluded from the scope:

- High voltage CDM, SDM and PDS with a rated voltage above 1,0 kV AC or 1,5 kV DC;
- Low voltage CDM, SDM and PDS with a rated voltage below 100 V AC;
- High power PDS above a rated power of 1 000 kW;
- High power CDM and SDM above a rated apparent output power of 1 209 kVA;
- Low power PDS below a rated power of 0,12 kW;
- Low power CDM and SDM below a rated apparent output power of 0,278 kVA;
- PDS with geared motors where motor and gearbox cannot be separated, for example because of a common housing;
- Servo PDS (consisting of frequency converter, motor and position feedback sensor);
- CDM, BDM and SDM that is exclusively designed to drive servo motors;
- PDS, CDM, BDM and SDM specifically designed for DC motor applications according to IEC 61800-1;
- PDS where several motors are connected in parallel to a single CDM with one three-phase output.

NOTE IEC 61800-9 (all parts) does not cover energy efficiency classification of driven equipment but provides input for the assessment according to the extended product approach.

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 60034-2-3:2020, *Rotating electrical machines – Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC induction motors*

IEC 60034-30-1:2014, *Rotating electrical machines – Part 30-1: Efficiency classes of line operated AC motors (IE Code)*

IEC TS 60034-30-2:2016, *Rotating electrical machines – Part 30-2: Efficiency classes of variable speed AC motors (IE Code)*

IEC TS 60034-31:2021 *Rotating electrical machines – Part 31: Selection of energy-efficient motors including variable speed applications – Application guidelines*

IEC 60038:2009, *IEC standard voltages*

IEC 60050-161:1990/AMD10:2021, *International Electrotechnical Vocabulary – Part 161: Electromagnetic compatibility*

IEC 60947-4-1:2018, *Low voltage switchgear and controlgear – Part 4-1: Contactors and motor-starters – Electromechanical contactors and motor-starters*

IEC 61000-3-12:2011, *Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase*

IEC TS 61800-8:2010, *Adjustable speed electrical power drive systems – Part 8: Specification of voltage on the power interface*

IEC 61800-9-1, *Adjustable speed electrical power drive systems – Part 9-1: Energy efficiency of motor systems– General requirements for setting energy efficiency standards*

IEC TS 62578:2015, *Power electronics systems and equipment – Operation conditions and characteristics of active infeed converter (AIC) applications including design recommendations for their emission values below 150 kHz*

IEC Guide 118:2017, *Inclusion of energy efficiency aspects in electrotechnical publications*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 and 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>

3.1.1

active infeed converter

AIC

self-commutated electronic power converters of all technologies, topologies, voltages and sizes which are connected between the AC power supply system (mains) and a stiff DC-side (current source or voltage source), which can convert electric power in both directions (generative or regenerative) and can control the reactive power or the power factor

Note 1 to entry: See IEC TS 62578.

Note 2 to entry: The IEC defines terms (VSC and CSC) as voltage stiff AC/DC converter [551-12-03] and current stiff AC/DC converter [551-12-04]. Most of the AICs are bi-directional converters and have sources on the DC side. Therefore, they are known as voltage source converters and current source converters.

3.1.2

AEDM

alternate efficiency determination method

analytical model used by motor manufacturers for calculation of the losses that can be used to determine the energy efficiency index of an extended product

3.1.3

Accessory

Accessories

Additional part, component or equipment intended to expand capabilities of the BDM/CDM/PDS, but not required for the general function of the BDM/CDM/PDS

Note 1 to entry: Examples of accessories include but not limited to line filter, input harmonic filter, EMI filter, fuses, chokes, motor output filter, communication, control or input/output interface kits, additional ventilation kits, mechanical bonding or cable support kits or additional measuring device, instrument

3.1.4**CDM****complete drive module**

drive module consisting of, but not limited to, the BDM and extensions such as protection devices, transformers and accessories, but excluding the motor and the sensors which are mechanically coupled to the motor shaft

Note 1 to entry: A CDM is the AC/AC frequency converter which feeds the motor. Some countries use the term "drive" instead of CDM.

Note 2 to entry: An example of a CDM containing an SDIM and SDOM is shown in Figure 2. The SDIM and SDOM are parts of the BDM.

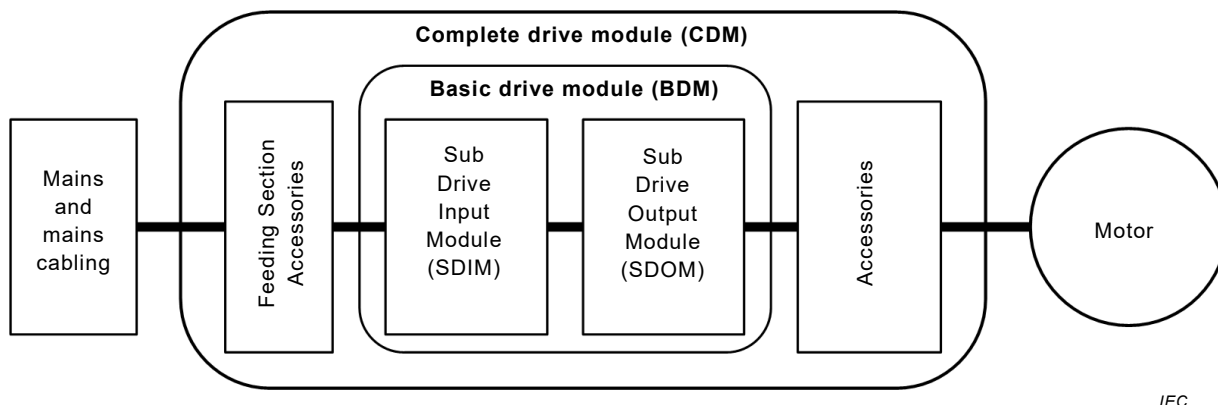


Figure 1 – Example of Complete Drive Module (CDM) built by Sub Drive Modules (SDM)

[SOURCE: IEC 61800-2:2021, 3.6, modified – The Notes to entry and Figure 1 have been added, the reference to Figure 3 has been deleted]

3.1.5**crest factor**

ratio of the peak absolute value to the RMS value of the waveform

3.1.6**driven equipment**

equipment mechanically connected to the shaft of a motor

3.1.7**EEI**

energy efficiency index value describing the energy efficiency of an application, resulting from the extended product approach (EPA)

Note 1 to entry: If the extended product is a pump system, the EEI is the ratio of the demanded energy (actual plus losses) to the theoretical energy required for the application.

3.1.8**extended product****EP**

driven equipment together with its connected motor system (e.g. a PDS)

Note 1 to entry: See Figure 2

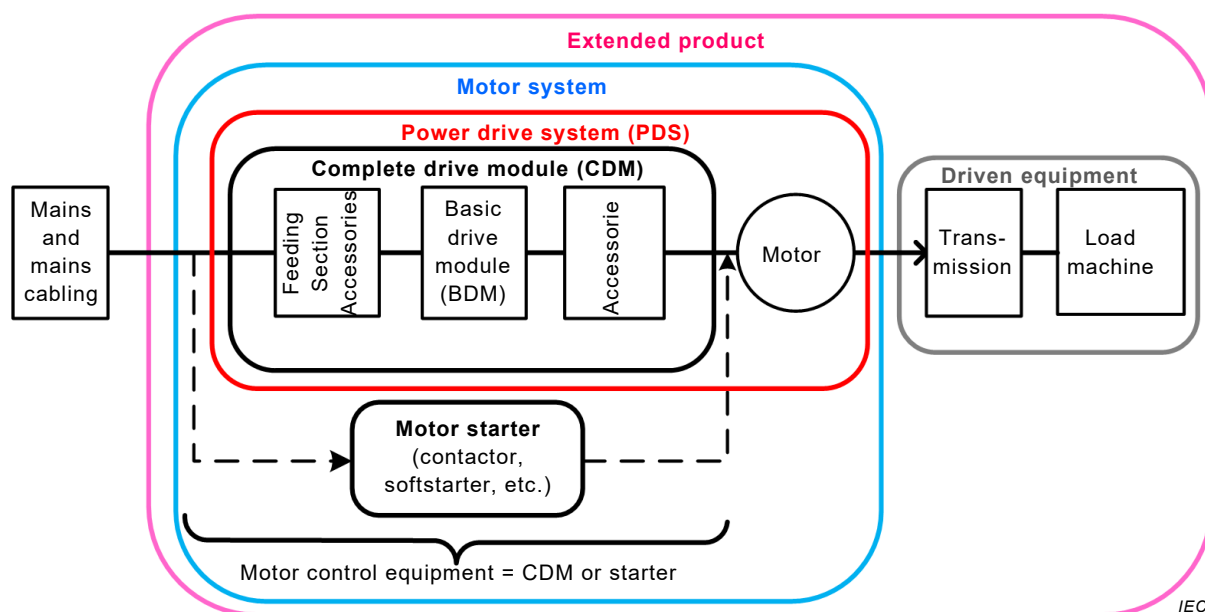


Figure 2 – Illustration of the extended product with included motor system

3.1.9

IE class

efficiency classification of components of a motor system (3.1.11)

Note 1 to entry: IE is an abbreviation for "international efficiency".

3.1.10

IES class

efficiency classification of a motor system (e.g. PDS or a gear drive motor)

Note 1 to entry: IES is an abbreviation for "international efficiency of systems".

3.1.11

motor system

motor control equipment and motor

3.1.12

PDS

power drive system

system consisting of one or more *complete drive module(s)* (CDM) and a *motor* or *motors*; any sensors which are mechanically coupled to the *motor* shaft are also part of the *PDS*, however, the driven equipment is not included

3.1.13

pulse pattern

pattern of the switched phase-to-phase voltage or phase current at the unfiltered output terminals of the converter, resulting from pulse frequency and modulation scheme

3.1.14

reference complete drive module

RCDM

complete drive module defined by mathematical equations and/or power losses

Note 1 to entry: It is used as a basis for determining the IE class of an individual CDM and SDM.

3.1.15**reference motor****RM**

A reference motor is a motor according to IEC TS 60034-31

3.1.16**servo PDS**

closed-loop controlled electric drive system for precise and dynamical control of angular or linear position, velocity and acceleration for the driven servomechanism

Note 1 to entry: See Figure 3.

Note 2 to entry: It consists of a frequency converter, a motor and a position feedback sensor.

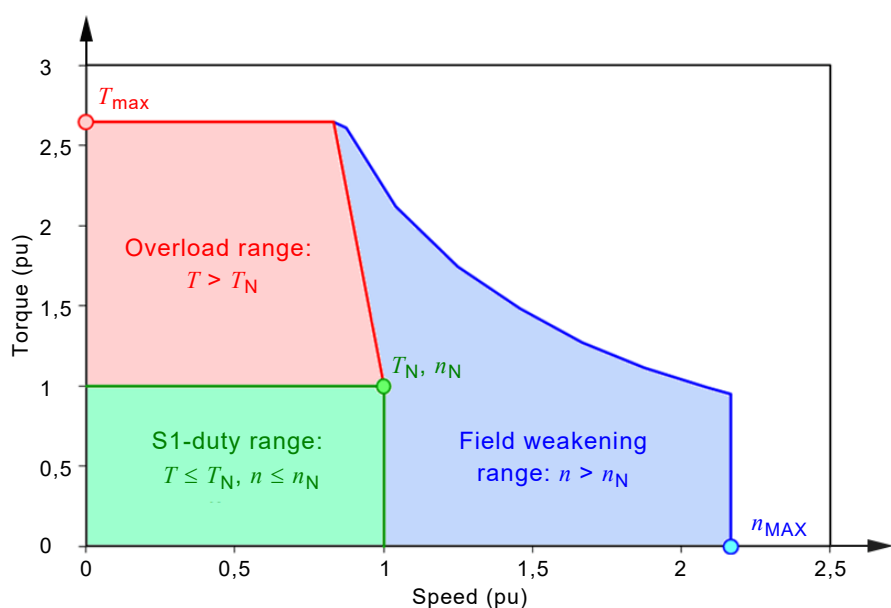
Note 3 to entry: Such servo applications are characterised with non-periodically (duty type S9) or periodically variable load and speed within the permissible 4-quadrant operating range ($\pm T_{\text{MAX}}$, $\pm n_{\text{MAX}}$) and includes frequently applied operation in overload ($T > T_N$) and/or field weakening range ($n > n_N$) of the motor (see diagram below).

Note 4 to entry: PDS are regarded as servo PDS when their motor typically meets one of the following criteria (see IEC TS 60034-30-2:2016):

Maximum speed criterion: $n_{\text{max}} > a_0 \cdot e^{-a_1 \cdot P_N + a_2} + a_3$; with $a_0 = 6000$ 1/min; $a_1 = 0,02$ 1/kW; $a_2 = -0,4$; $a_3 = 3200$ 1/min

Angular acceleration capability criterion: $\text{acc}_{\text{coeff}} = \frac{T_{\text{max}}}{J} > b_0 \cdot e^{-b_1 \cdot P_N + b_2} + b_3$; with $b_0 = 18000$ 1/s²; $b_1 = 1,3$ 1/kW; $b_2 = -1$; $b_3 = 5800$ 1/s²

Note 5 to entry: Typical applications for Servo PDS are such as CNC machinery, automated manufacturing or robotics.



IEC

Figure 3 – Torque-speed-characteristic of servo PDS

3.1.17**single axis**

single mechanical output shaft of an individual motor

Note 1 to entry: Applies to CDM supplying one motor or PDS that includes only one motor.

3.1.18**Sub Drive Module (SDM)**

electrical drive module to convert AC input to DC output, DC input to DC output or DC input to AC output, intended to form part of a BDM

3.1.19**Sub Drive Input Module (SDIM)**

SDM to convert AC input to DC output or DC input to DC output intended to feed at least one SDOM where the SDIM may also include an AC or DC choke, input filter combination or DC link capacitors

3.1.20**Sub Drive Output Module (SDOM)**

SDM to convert DC input to three-phase AC output to control current, torque or speed of an electric motor where this SDOM may also include DC link capacitors or a three-phase output filter assembly

3.1.21**test load**

electrical device that determines the output current I_{out} and the output fundamental displacement factor $\cos \Phi$ of a CDM or a SDOM for testing or calculation purposes

Note 1 to entry: Test load may be a test motor or a different kind of load.

3.1.22**test load current**

total apparent current into the test load to produce a certain torque (see Table 1)

3.1.23**torque current**

part of the test load current (see 3.1.22) that produces a certain torque (see Figure 6, Table 1)

Note 1 to entry: For an asynchronous motor, the torque current is the rotor current.

3.2 Symbols and abbreviated terms**3.2.1**

c_{liquid}

specific heat capacity of liquid

3.2.2

DF_U

voltage distortion factor as the ratio of the r.m.s voltage without fundamental component to the r.m.s. voltage of the fundamental component

$$DF_U = \sqrt{\frac{U_{rms}^2 - U_1^2}{U_1^2}}$$

3.2.3

E_D

switching loss energy per volt and per ampere of a power diode

3.2.4

E_T

switching loss energy per volt and per ampere of a power transistor

3.2.5

f_{sw}

number of switching events of one semiconductor within one second

Note 1 to entry: It determines, together with the selected pulse pattern and the converter topology, the lowest frequency of non-controllable harmonics or inter-harmonics at the IPC (in-plant point of coupling, see IEC 61800-3) or the motor.

666 Note 2 to entry: Turn on and turn off of the semiconductor is counted as a single switching event. Therefore, the
 667 switching frequency and the pulse frequency (also called the carrier frequency) are identical.

668 3.2.6

669 $I_{\text{motor_cable}}$

670 current in the motor cable of one power port (see IEC 61800-2) of the PDS, used for calculating
 671 switching losses

672 Note 1 to entry: This typically represents a capacitive leakage current, which is normally for shielded motor cables.

673 3.2.7

674 $I_{1,r \text{ CDM}}$

675 fundamental of the rated CDM or PDS input current waveform

676 3.2.8

677 I_r

678 rated CDM or PDS input current

679 3.2.9

680 I_{out}

681 output current

682 3.2.10

683 $I_{r,\text{out}}$

684 rated CDM output current

685 3.2.11

686 I_{rM}

687 rated motor current

688 3.2.12

689 $kI_{\text{DC_link}}$

690 load independent DC link loss parameter $\left(\frac{1}{\Omega \cdot A}\right)$

691 3.2.13

692 kI_{choke}

693 choke impedance, relative to the rated CDM impedance

694 3.2.14

695 $k^2_{\text{DC_link}}$

696 load dependent DC link loss parameter ($\Omega \cdot A$)

697 3.2.15

698 k^2_{choke}

699 relative voltage drop on the resistive part of the choke

700 3.2.16

701 k_{cf}

702 correction factor for RCDM losses to consider topologies with different characteristic

703 3.2.17

704 k_{fe}

705 segregation of eddy current and hysteresis losses in a motor

- 706 **3.2.18**
707 k_{fw}
708 segregation of friction and windage losses in a motor
- 709 **3.2.19**
710 k_{LL}
711 Distribution of load losses
- 712 **3.2.20**
713 k_{VD}
714 ratio of rated motor voltage to maximum CDM output voltage
- 715 **3.2.21**
716 $P_{L,cooling}$
717 power losses generated by the cooling equipment of a CDM (e.g. fan losses), in relation to the
718 BDM (see IEC 61800-2) losses if the CDM needs to be separately cooled
- 719 **3.2.22**
720 m
721 modulation index, relation of CDM output frequency to the nominal motor stator frequency
- 722 **3.2.23**
723 n_i
724 speed [r/min] at operating point i
- 725 **3.2.24**
726 n_r
727 rated speed [r/min]
- 728 **3.2.25**
729 P_i
730 power consumption [kW] at operating point i
- 731 **3.2.26**
732 $P_{in,CDM}$
733 input power of the CDM obtained from the power loss measurement
- 734 **3.2.27**
735 $P_{in,PDS}$
736 input power of the PDS obtained from the power loss measurement
- 737 **3.2.28**
738 $P_{L,Acc}$
739 power losses of the drive accessories
- 740 **3.2.29**
741 P_{LHL}
742 additional harmonic losses of a motor caused by non-sinusoidal power supply
- 743 Note 1 to entry: see also IEC 60034-2-3.
- 744 **3.2.30**
745 $P_{L,RM}$
746 relative losses of the reference motor

747 3.2.31**748 $P_{L,RM}$** **749 losses of the reference motor****750 3.2.32****751 P_{LTsin}** **752 total losses of a motor at sinusoidal power supply****753** Note 1 to entry: According to IEC 60034-2-1:2014, method 2-1-1B.**754 3.2.33****755 $P_{LT,Mot}$** **756 total losses of a motor when supplied by a converter (non-sinusoidal power supply)****757** Note 1 to entry: According to IEC 60034-2-1:2014, method 2-1-1B.**758 3.2.34****759 $P_{out,CDM}$** **760 output power of CDM obtained from the power loss measurement****761 3.2.35****762 $P_{out,PDS}$** **763 output power of PDS obtained from the power loss measurement****764 3.2.36****765 P_r** **766 rated power of equipment which is assigned by its manufacturer****767 3.2.37****768 P_{proc}** **769 power demand of the mechanical or fluid-mechanical process****770 3.2.38****771 P_L** **772 electrical power losses**

773 Note 1 to entry: In $P_{L,CDM}$, $P_{L,Mot}$, $P_{L,PDS}$ and $P_{L,Acc}$, the index CDM refers to the complete drive module; Mot refers to the motor, PDS to the power drive system and Acc to the accessory devices like cables, transformers or filters.

776 3.2.39**777 p_L** **778 the relative power losses based on per unit losses related to the rated apparent power of the device****780 3.2.40****781 $P_{L,CDM}$** **782 power losses of a CDM****783 3.2.41****784 $P_{L,CDM, determined}$** **785 power losses of CDM from the power loss determination method****786 3.2.42****787 $p_{L,CDM}$** **788 relative power losses of the CDM, in relation to its rated apparent power**

- 789 **3.2.43**
790 $P_{L,choke}$
791 power losses in the choke section of a CDM
- 792 **3.2.44**
793 $P_{L,control}$
794 power losses of the motor control system
- 795 **3.2.45**
796 P_{L,DC_link}
797 power losses of the DC link section of the CDM
- 798 **3.2.46**
799 $P_{L,inverter}$
800 power losses in the inverter section of a CDM
- 801 **3.2.47**
802 $P_{L,PDS, determined}$
803 power losses of the PDS from the power loss determination method
- 804 **3.2.48**
805 $P_{L,rectifier}$
806 power losses in the rectifier section of a CDM
- 807 **3.2.49**
808 $P_{L,resistor}$
809 measured power losses of the resistor in comparative calorimetric measurement
- 810 **3.2.50**
811 $P_{L,on,D}$
812 on state power losses of a power diode
- 813 **3.2.51**
814 $P_{L,on,D, rectifier}$
815 on state power losses of a rectifier diode
- 816 **3.2.52**
817 $P_{L,on,T}$
818 on state losses of a power transistor
- 819 **3.2.53**
820 $P_{L,sw,D}$
821 switching power losses of a power diode
- 822 **3.2.54**
823 $P_{L,sw,T}$
824 switching power losses of a power transistor
- 825 **3.2.55**
826 $P_{r,M}$
827 rated power of a motor
- 828 Note 1 to entry: In IEC 60034 (all parts) related to motors, this is named P_N .

829 3.2.56**830 $P_{r, RM}$** **831 3.2.57 rated power of the reference motor****832 $P_{L, stby}$** **833 standby losses of a PDS**

834 Note 1 to entry: Standby losses are generated when the PDS is powered up, but not providing current to the load.
835 They are typically two to three orders of magnitude lower than the losses during operation. Their influence on the
836 overall losses strongly depends on the duty profile of the extended product. Besides this, they also depend on the
837 requirements of the extended product in terms of wake-up time and communication.

838 3.2.58**839 p_N** **840 relative output losses of a motor****841 3.2.59****842 Q** **843 flow rate of a pump unit****844 3.2.60****845 Q_{BEP}** **846 flow rate of the pump at the best efficiency point****847 3.2.61****848 Q_{cooler}** **849 volumetric flow rate of the cooler in the calorimeter****850 3.2.62****851 Q_{ISI}** **852 interpolation error (stability index)****853 3.2.63****854 r_{HL}** **855 ration of additional harmonic losses when a motor is operated with a CDM compared to the**
856 losses at sinusoidal supply of a motor**857 3.2.64****858 $S_{r, equ}$** **859 rated apparent power of a piece of equipment****860 3.2.65****861 $S_{r, RCDM}$** **862 rated apparent power of the reference CDM****863 3.2.66****864 T** **865 the torque of a motor****866 3.2.67****867 t_w** **868 working time of an equipment****869 3.2.68****870 T_i** **871 torque [Nm] at operating point i**

3.2.69*THD*

Total harmonic distortion of an alternating quantity as the ratio of the r.m.s. value of the harmonic content to the r.m.s. value of the fundamental component of the quantity

Note 1 to entry: The total harmonic ratio may be restricted to a certain harmonic order (recommended notation “*H*”).

$$THD = \sqrt{\sum_{h=2}^{h=H} \left(\frac{Q_h}{Q_1}\right)^2}$$

3.2.70 $U_{1,r,out}$

fundamental rated phase-to-phase CDM output voltage

Note 1 to entry: For the reference CDM, this value is assumed to be 400 V unless stated otherwise.

3.2.71 U_{DC}

DC link voltage of a CDM

3.2.72 $U_{D,r}$

on state voltage of a power diode at rated CDM current

3.2.73 $U_{D,r,rectifier}$

on state voltage of a rectifier diode at rated CDM current

3.2.74 $U_{D,th}$

threshold voltage of a power diode

3.2.75 $U_{D,th,rectifier}$

threshold voltage of a rectifier diode

3.2.76 U_{mL1}

line to neutral voltage of the power supply system in phase L1

3.2.77 $U_{T,r}$

on state voltage of a power transistor at rated CDM current

3.2.78 $U_{T,th}$

threshold voltage of a power transistor

3.2.79 W_w

electrical energy demand of extended product during working time

3.2.80 λ

power factor as ratio between active power and apparent power

912 Note 1 to entry: Equipment input power factor is given by $\lambda = P_{\text{equ}} / S_{r,\text{equ}}$

913 **3.2.81**

914 $\Delta p_{L,\text{CDM}}$

915 uncertainty [%] of power loss determination method for CDM

916 **3.2.82**

917 $\Delta P_{L,\text{CDM}}$

918 uncertainty [W] of power loss determination method for CDM

919 **3.2.83**

920 $\Delta p_{L,\text{PDS}}$

921 Uncertainty [%] of power loss determination method for PDS

922 **3.2.84**

923 $\Delta P_{L,\text{PDS}}$

924 uncertainty [W] of power loss determination method for PDS

925 **3.2.85**

926 θ_{CDM}

927 temperature of CDM

928 **3.2.86**

929 θ_{in}

930 input temperature of cooling medium (air, liquid) in a calorimetric measurement

931 **3.2.87**

932 θ_{inside}

933 temperature of cooling air between two calorimetric measurement chambers

934 **3.2.88**

935 θ_{M}

936 temperature of motor

937 **3.2.89**

938 θ_{out}

939 output temperature of cooling medium (air, liquid) in a calorimetric measurement

940 **3.2.90**

941 θ_{SDIM}

942 temperature of sub drive input module (SDIM)

943 **3.2.91**

944 θ_{SDOM}

945 temperature of sub drive output module (SDOM)

946 **3.2.92**

947 φ

948 phase angle between the fundamental CDM input voltage and the fundamental CDM input current

950 **3.2.93**

951 Φ

952 phase angle between the fundamental CDM output voltage and the fundamental CDM output current

953

3.2.94 Φ_r

phase angle between the fundamental CDM output voltage and the fundamental CDM output current at rated torque and speed

4 PDS efficiency, reference CDM (RCDM) and reference motor (RM)**4.1 General**

In order to determine the most efficient extended product for a given application, a direct comparison of several drive topologies and/or several control strategies is required. The extended product approach described in IEC 61800-9-1 allows for this.

To support this approach, the concept of IES classification of PDS is introduced.

The definition of the PDS efficiency is generic and independent of a specific product or manufacturer.

It allows

- setting the limiting values for classifications,
- classification of the PDS,
- classification of the CDM,
- application of IEC TS 60034-30-2,
- application of IEC TS 60034-30-1,
- limiting the assessment to only a few appropriate measured or calculated operating points, and
- determining the energy consumption of various driven applications.

Examples of relevant input values (operating points) for classification of different driven applications:

Loads with square-law torque-speed characteristics (e.g. most pump units) will typically require relative losses or input powers at the operating points $p_{L, PDS} (50; 25)$, $p_{L, PDS} (100; 50)$ and $p_{L, PDS} (100; 100)$ for calculation of the losses of the motor system where the notation $p_{L, PDS} (\text{speed; torque})$ is used.

Constant torque loads (e.g. hoisting equipment) will need the additional points $p_{L, PDS} (0; 25)$, $p_{L, PDS} (0; 50)$ and $p_{L, PDS} (0; 100)$ in order to determine the losses of the motor system.

4.2 Reference operating points of the PDS, RCDM, RM and associated losses

All driven equipment can be described by the power required by the machine/application. The power requirements are the product of torque and speed at any working point. At each operating point there is an associated power loss in the motor system.

The collection of (torque, speed) operating points at which the motor system may potentially be operated is infinite. Theoretically, it is necessary to know the amount of power losses generated at each point. In practice however, it is sufficient to know the power losses at a limited number of specific points (eight), which are specified for the PDS in Figure 4, for the RM in Figure 5 and for the RCDM in Figure 6.

For operating points with speeds greater than zero, the losses are usually given as a percentage of the mechanical output power. In other approaches the rated efficiencies (η) are defined as the ratio of rated mechanical output power to electrical input power (including the losses).

In this document, losses related to the nominal output power of the power drive system (p in %) are considered instead of efficiency. This is done to secure the generality of the extended product approach.

Driven equipment, for which a standstill torque is required, exists. For such equipment the efficiency is not an appropriate value to be used in the extended product approach.

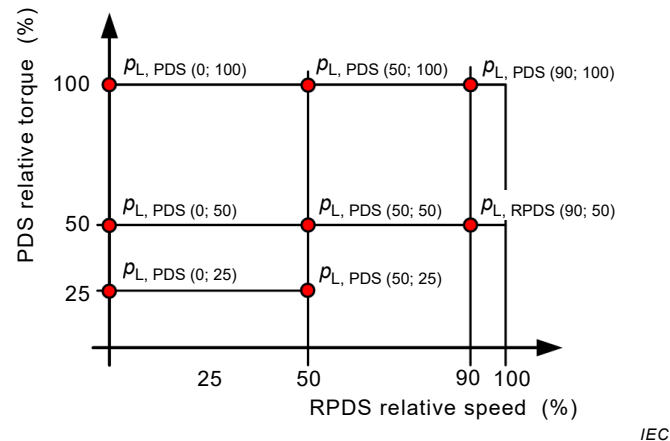


Figure 4 – Illustration of the operating points (shaft speed, torque) for the determination of relative losses of the power drive system (PDS)

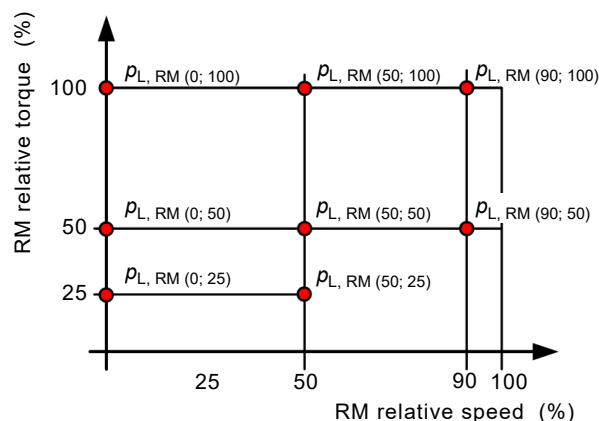
As defined, the absolute losses of the PDS shall be the sum of the CDM losses plus the motor losses. Therefore, those losses shall be calculated point by point at the operating points of Figure 5 and Figure 6 by the following formula:

$$P_{L,PDS} = P_{L,M} + P_{L,CDM} \quad (1)$$

At rated speed and torque, a modified formula according to formula (13) shall be used.

The relative losses of the PDS are calculated from the relative losses of the CDM and the motor as follows:

$$p_{L,RPDS} = \frac{p_{L,M} \cdot P_{r,M} + p_{L,CDM} \cdot S_{r,CDM}}{P_{r,M}} \quad (2)$$



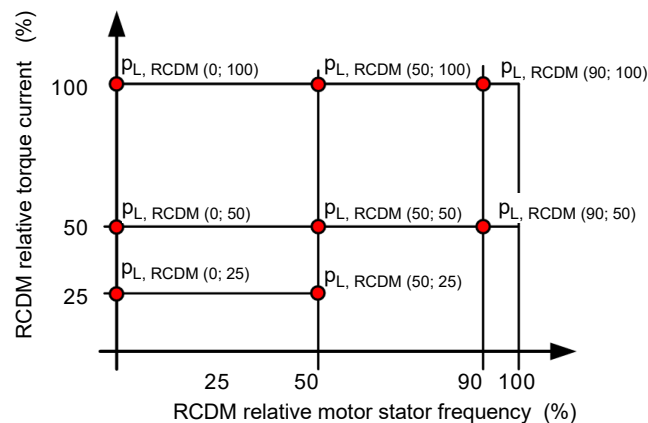
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NOTE These operating points are calculated from the standardized operating points given in IEC 60034-2-3 using interpolation formulas given in IEC 60034-2-3 and in Annex E.

Figure 5 – Illustration of the operating points (shaft speed, torque) for the determination of relative losses of the reference motor (RM)

The operating points of the reference CDM (RCDM) cannot be given as a percentage of speed and torque of the corresponding rated values as the CDM provides only currents and voltages at its output. To allow a reproducible comparison and to avoid overmodulation, the fundamental AC output voltage shall be limited to 90 % of the AC input voltage.

NOTE 1 RCDM losses at 90 % output voltage are very similar to the RCDM losses at 100 % output voltage (inverter losses are slightly higher whereas rectifier losses are slightly lower) and can consequently be used to calculate the RCDM losses at 100 % speed.



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Figure 6 – Illustration of the operating points (relative motor stator frequency, relative torque current) for the determination of losses of the reference complete drive module (RCDM)

NOTE 2 For asynchronous motors, the torque current is the rotor current. The relation between the overall motor current and the torque current is given in Table 1.

NOTE 3 For physical reasons, the illustrated operating points on the y-axis of Figure 6 $p_{L, RCDM} (0, n)$ are achieved only with a non-zero output voltage in order to let current flow through the resistance of the motor windings.

If required, the losses for intermediate operating points may be determined by one of the calculation methods presented in F.2.1:

- two-dimensional linear interpolation between neighbouring operating points;
- loss calculation of the CDM according to the mathematical model described in 5.2.

Motor losses are interpolated according to IEC 60034-2-3. (see also Annex E)

In every operating point deviation due to motor slip is allowed. However, only in the operating points with zero speed it is allowed to deviate up to 25% of the nominal frequency.

For losses at additional operating points and at part load conditions and reduction of operating points, see 8.4 and Annex E.

4.3 Combining PDS losses with the driven equipment – Workflow for the semi-analytical model (SAM)

The model for the losses or the energy efficiency index of an extended product is called "semi analytical model" (SAM), which includes physical and mathematical parameters and calculation algorithms of the subparts of an EP.

The workflow for determining the efficiency classification of an extended product is shown in Figure 7.

It also illustrates how the SAM of the motor system (left hand side) shall be linked to the SAM of the driven equipment (right hand side). The link in between both semi analytical models shall be the load loss points of the PDS and their permissible tolerances. The actual needed operating points shall be required by the semi analytical model of the driven equipment.

The PDS data containing the PDS losses according to Figure 2 (left hand side of Figure 7) is defined in this document, whereas the semi analytical energy consumption models of the PDS-driven application (right hand side of Figure 7) shall be drafted by their responsible product committees by using the same approach. An example for PDS driven pump units is given in IEC 61800-9-1. Figure 8 shows how the different data sources shall be combined.

It is the responsibility of the technical committees for specific applications to standardize publicly available SAM's for their applications.

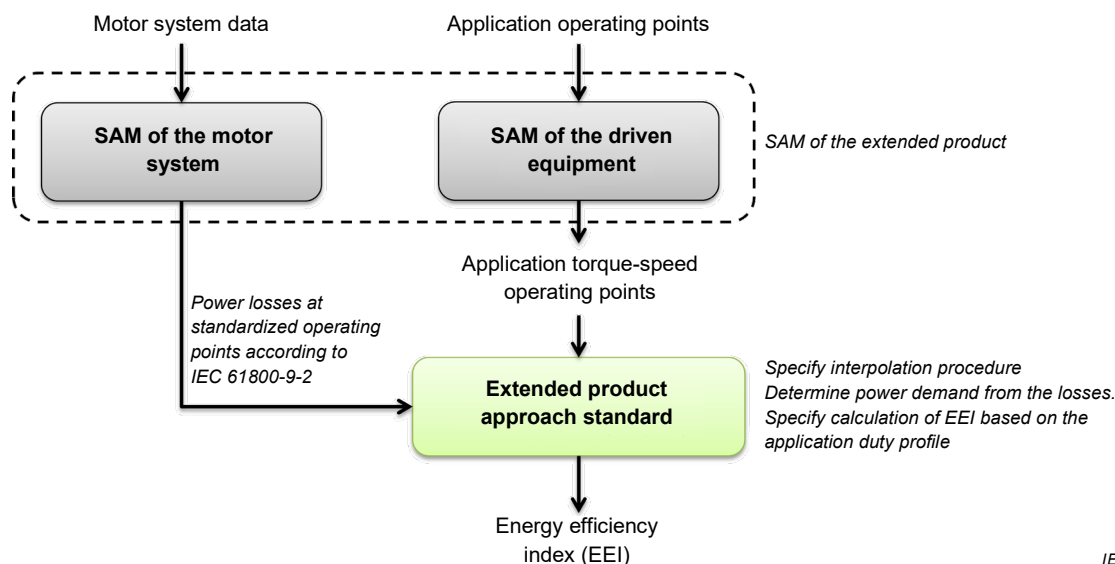
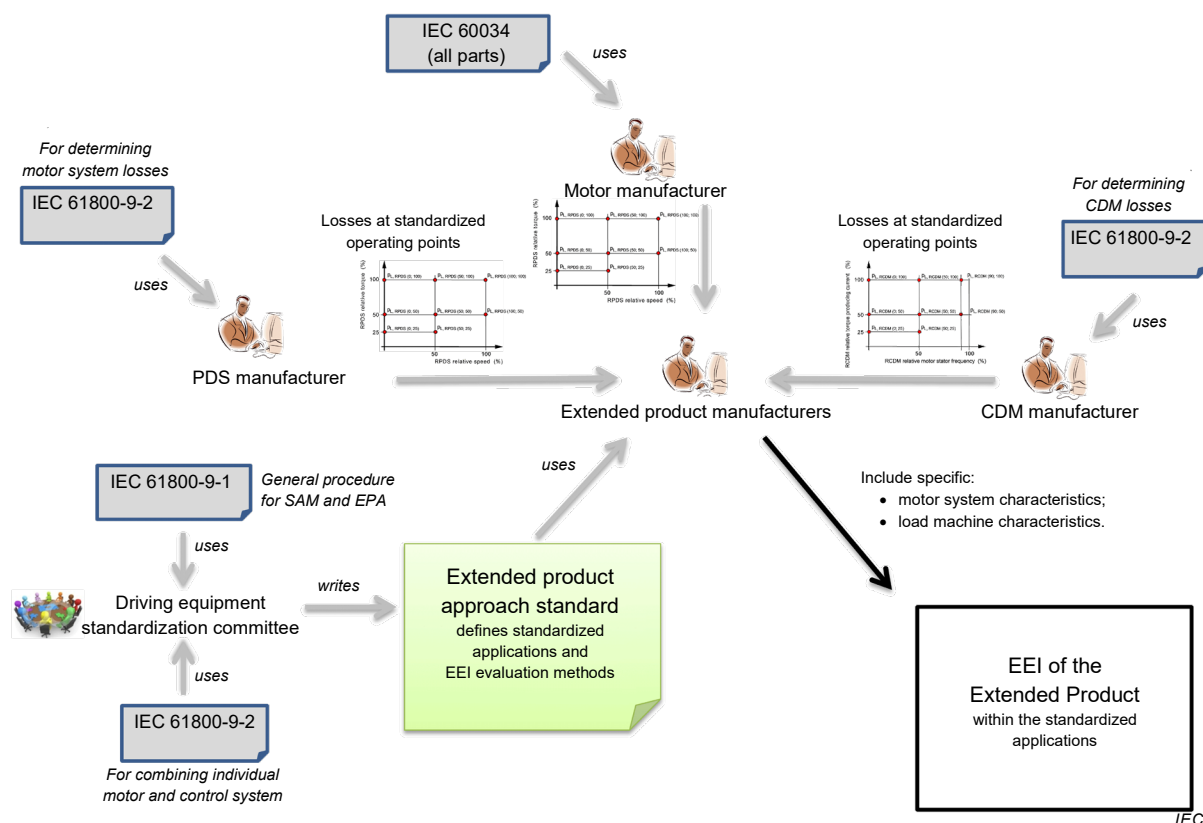


Figure 7 – Illustration of the workflow to determine the energy efficiency index (EEI) of an extended product

This document specifies how to determine the power losses of the motor system. The extended product committee specifies the tolerances that apply to this process.



NOTE 1 Motor and CDM manufacturers can provide data directly to the motor system manufacturer.

NOTE 2 If the motor system is based on a starter, then only the motor losses are needed as input to the EPA.

Figure 8 – Illustration how to combine different data sources to determine the energy efficiency index (EEI) of an extended product

4.4 IE classes of line-fed motors

IEC 60034-30-1 defines the IE classes for motors operated direct-on-line from IE1 up to IE4. The range above IE4 is currently not in use for line-fed motors.

4.5 IE classes of converter-fed motors

According to IEC 60034-2-3, the harmonic voltage contents of CDM increases motor losses for induction machines by approximately 15 % to 25 %.

Motors not designed to be supplied directly from mains for operation (DOL, direct on line) will be classified with an IE-class according to their losses at rated speed and torque (rated power) according to IEC TS 60034-30-2.

The IE Class for motors that are capable of running DOL is defined for fixed speed operation in IEC 60034-30-1 or for converter capable motors as defined in IEC TS 60034-30-2. Losses for the defined 7 operating points can be extrapolated from Annex E. Losses for these points shall be provided by the motor manufacturer per the alternative efficiency determination method (AEDM) determined by using IEC 60034-2-3.

4.6 IE Classes of frequency converters (complete drive modules, CDM)

The IE class of a CDM, IE0 to IE2, is determined by comparing the losses of the CDM to the losses of the RCDM, according to clause 6.

To declare the efficiency class of the CDM without considering the complete resulting PDS and to reflect the technological impact of the most significant parameter, the so-called "test load" shall be used as a defined unit.

1087 The operating point for the IE class determination is 90 % speed and 100 % torque and shall
1088 be taken according to clause 6.

1089 CDMs with modified functionality such as AIC according to IEC TS 62578 or CDMs having a
1090 mains current THC of 10 % or lower (according to IEC 61000-3-12) are classified using the
1091 correction factor concept according to clause 1.

1092 4.7 IES Classes of a PDS

1093 The classification of the PDS shall be declared in a range of IES0 up to IES5.

1094 Relative losses of a PDS shall be determined by calculation or measurement. The calculation
1095 shall be done by arithmetic summation of the absolute losses of the converter-fed motor plus
1096 the converter and the accessories.

1097 The operating point for the IES class determination is 90 % speed and 100 % torque and shall
1098 be taken according to clause 6.

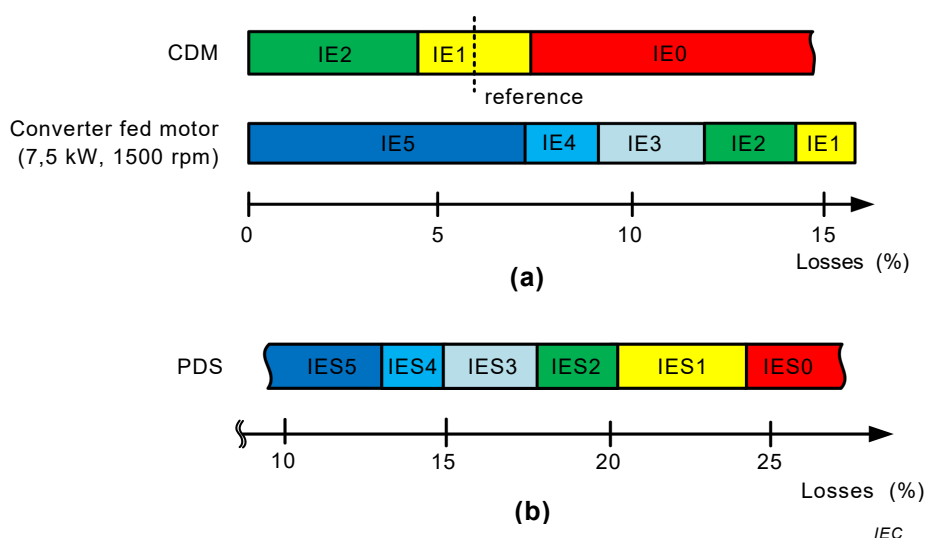
1099 4.8 Consistency of IE and IES classes

1100 It is important to understand that the IE classes of individual components such as converter-fed
1101 motors, grid operated motors or CDMs cannot be added in order to determine the IES class of
1102 a PDS.

1103 The IES classification of PDSs can only be determined by the procedures laid out in 4.9 with a
1104 detailed knowledge of the losses of all components.

1105 Individual IE classes are required for the classification of components without prior knowledge
1106 of the EP.

1107 Generally, higher IE or IES classes will demonstrate increased efficiency or decreased relative
1108 power losses. Figure 9 shows an example for IE and IES classes for a 7.5 kW / 1500 rpm Motor
1109 and a 9.95 kVA CDM.



1110
1111 **Figure 9 – Metrical relation of (a) IE classes and (b) IES classes**

4.9 Determination of the IES class of a PDS by application of "reference" and "test" devices and guidance for the manufacturers

Methods for the determination of losses and IE classes of a motor are given in IEC 60034-30 (all parts) – see also Figure 9. Manufacturers may also define an IES class for a PDS that is using their motor. In that case, the manufacturer shall determine the relative losses of his motor when operated on a RCDM.

A CDM manufacturer shall declare the losses of his dedicated CDM and display an IE class according to Figure 9. The manufacturer may also declare an IES class for a PDS equipped with his CDM. In that case, the manufacturer shall measure or calculate the losses of his CDM. When real motor data is not available, the losses of the RM shall be used.

The CDM manufacturer may provide information in the documentation which determination methods described in clause 7 have been used. This includes the expected IES classes for different combinations of a CDM and selected specific motors using the methods of this document.

Any or all available control features of the CDM may be employed to minimize losses during the PDS evaluation and shall be reported as part of the record of evaluation.

A spreadsheet on the application of "test" and "reference" devices for the determination of IE and IES classes is shown in Figure 10. It also gives guidance to sole CDM or sole motor manufacturers regarding the determination of the IES class of a resulting PDS in combination with "test" or "reference" devices.

For PDS manufacturers, the upper left-hand intersection field of "Motor" and "CDM" is applicable.

Combination of	CDM	Test CDM	Reference CDM (RCDM)	
Motor	Determine the IES class of the resulting PDS	Determine the IE class of the given motor (IEC TS 60034-2-3)	Determine the IES class of the resulting PDS	Guidance for motor manufacturer
Test load	Determine the IE class of the given CDM	Combination not used	Combination not used	
Reference Motor (RM)	Determine the IES class of the resulting PDS	Combination not used	Calculation model of a reference PDS	
	Guidance for CDM manufacturer			

IEC

NOTE A reference motor (RM) is a motor according to IEC TS 60034-31

Figure 10 – Guidance for CDM and Motor manufacturers for the usage of "test" and "reference" devices to determine the IE/IES classes

This approach allows the determination of the IES efficiency class of a final PDS even when only one component (the motor or the CDM) is available.

5 Determination of CDM, motor and PDS loss by calculation

5.1 General

Mathematical models can be used for the determination of losses of the CDM, motor and PDS. They allow for the calculation of losses of a product without measurements.

Simple state of the art models for loss calculation are given in Annex B. These models consist of formulae, variables and parameters. The formulae and loss calculation procedures are generally accepted today and published in literature. The variables depend on the operating point of the evaluated CDM, motor or PDS. The parameters are physical values describing a real product. In order to determine the losses of a product, these parameters need to be set according to specific design of the product.

Manufacturers of CDM may use their own analytical model to determine CDM losses in more detail, however, manufacturers are responsible for correct accuracy of the model.

If an extended product committee needs to define a typical CDM or PDS for their dedicated application(s), typical CDM or PDS parameters for those specific applications may be used. These deviations shall be provided in the extended product standard.

For the reference CDM (RCDM) and reference motor (RM), reference parameters are defined respectively in 5.2 and 5.3.3.

The procedure of the loss determination is illustrated in Clause 7.

5.2 CDM losses

5.2.1 General procedure and definition of the CDM and the test load

A typical CDM and test load are illustrated in Figure 11.

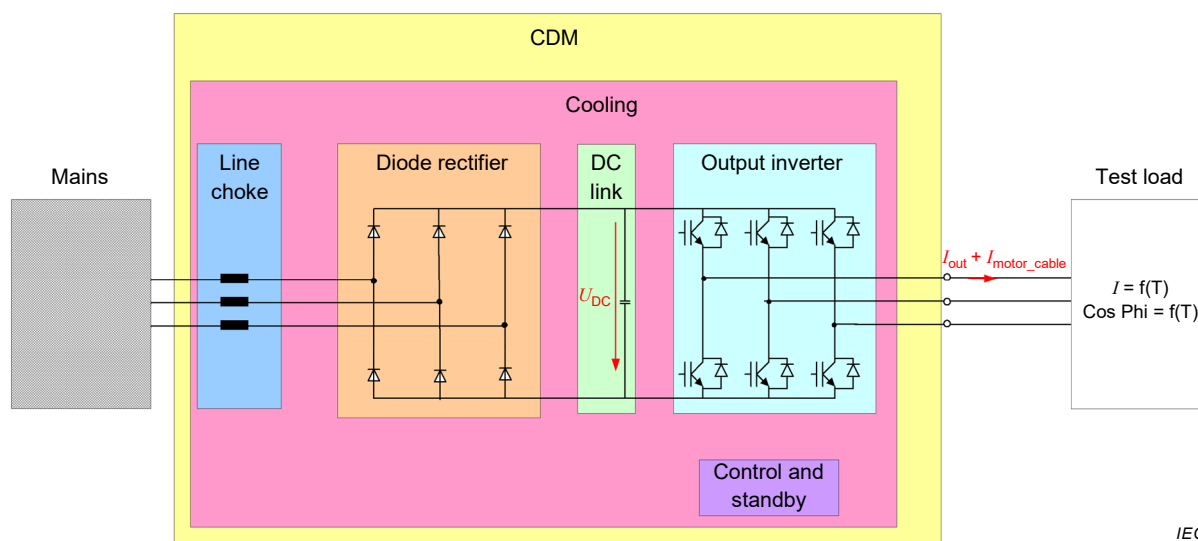


Figure 11 – Illustration of a typical CDM and test load

Basically, it is the goal to describe the CDM losses as a function of torque and speed of the PDS. However, the CDM losses depend on its relative fundamental output voltage, its relative fundamental output current and the phase angle between the fundamental CDM output voltage and fundamental CDM output current.

The relative output voltage is approximately the same as the relative output frequency. This is at least true in the operating field up to the nominal motor speed. In the range of field weakening, the relative CDM output voltage remains 1,00 for all motor speeds above the nominal motor speed (see also Annex I).

In the first step, the motor speed shall be transferred into a CDM output frequency, and the motor torque shall be converted to an CDM output current and a phase angle between the fundamental output current and output voltage of the CDM.

In a first order approximation, the relative output speed of the PDS can be regarded as being identical to the relative CDM output frequency.

For CDM or SDOM evaluation, the following data obtained by measurements on real motors shall be used as a test load data for all frequencies within scope:

Table 1 – Minimum test load currents at different points of operation

Torque current %	Test load current $\frac{I_{out}}{I_{r,out}}$ for the apparent power range $S_{r,eq}$ of				
	0,278 kVA (0,12 kW) to < 1,29 kVA (0,75 kW)	1,29 kVA (0,75 kW) to < 7,94 kVA (5,5 kW)	7,94 kVA (5,5 kW) to < 56,9 kVA (45 kW)	56,9 kVA (45 kW) to < 245 kVA (200 kW)	245 kVA (200 kW) to < 1 209 kVA (1 000 kW)
25	0,79	0,58	0,45	0,42	0,39
50	0,81	0,71	0,60	0,58	0,56
75	0,89	0,82	0,79	0,78	0,77
100	1,00	1,00	1,00	1,00	1,00

Table 2 – Test load displacement factor between fundamental output current and fundamental output voltage at different points of operation ^a

Torque current %	Test load displacement factor $\cos \phi$ for the apparent power range $S_{r,eq}$ of				
	0,278 kVA (0,12 kW) to < 1,29 kVA (0,75 kW)	1,29 kVA (0,75 kW) to < 7,94 kVA (5,5 kW)	7,94 kVA (5,5 kW) to < 56,9 kVA (45 kW)	56,9 kVA (45 kW) to < 245 kVA (200 kW)	245 kVA (200 kW) to < 1 209 kVA (1 000 kW)
25	0,34	0,38	0,49	0,54	0,57
50	0,51	0,60	0,71	0,75	0,78
75	0,64	0,72	0,80	0,83	0,85
100 ^b	0,73	0,79	0,85	0,86	0,87
^a Points at 25 - 75 % are for testing with electronic load only.					
^b Point at 100 % is valid for testing with motor.					

NOTE For CDM or SDOM testing with a motor only the test load displacement factor at 100 % torque current stated in Table 2 with a tolerance of $\pm 0,08$ applies. The given factors for 25 % - 75 % torque current are for testing with electronic load only and when calculating SDM or CDM losses

Test load current in Table 1 and test load phase angle in Table 2 for different related torque values depend on the rated power. In order to limit the amount of required data, motors in a certain power range are classified within one class. The amount of uncertainty on the resulting power losses of the CDM introduced thereby is small enough to justify the simplification. The test load data in Table 1 and Table 2 can be used for any CDM relative output frequency. Data for torque currents different from the defined operating points in Table 1 and Table 2 shall be obtained by linear inter- and extrapolation from the defined values.

1193 The mathematical model of a CDM or SDOM shall be calculated with its rated output current. If
 1194 a CDM is not specified with a rated output current, but only with a rated real power $P_{r,M}$, its
 1195 rated CDM output current shall be calculated from the rated real power by the following formula,
 1196 using the phase angle from Table 2 and the IE2 efficiency η_{nMotor} defined in IEC 60034-30-1:

$$I_{r,out} = \frac{P_{r,M}}{\sqrt{3} \cdot U_{1,r,out} \cdot \cos \Phi \cdot \eta_{nMotor}} \quad (3)$$

1197 The rated apparent CDM output power shall be calculated as follows:

$$S_{r,equ} = \sqrt{3} \cdot U_{1,r,out} \cdot I_{r,out} = \frac{P_{r,M}}{\cos \Phi \cdot \eta_{nMotor}} \quad (4)$$

1198 For loss calculation of a CDM the following loss elements shall be considered:

- 1199 • Losses of output inverter stage.
- 1200 • Losses of input converter.
- 1201 • Input choke losses.
- 1202 • DC link losses.
- 1203 • Current conductor losses.
- 1204 • Control and standby losses.
- 1205 • Cooling loss factor.

1206 All losses in other parts of the CDM can be neglected in the mathematical model, as they are
 1207 significantly lower than the losses described above.

1208 For calculating the losses of a CDM with the input variables from Table 1 and Table 2, the
 1209 analytical Formulae (C.1) to (C.10) in Annex C and (5) and (6) given below can be used. In order
 1210 to calculate the losses of a real CDM, the parameter values of the real CDM shall be used. Only
 1211 the included elements of the modules shall be considered for calculating the losses of a SDIM
 1212 or a SDOM.

1213 The results of the RCDM calculations are given in Table 7 for the IE class determination and in
 1214 Table A.1 for the eight operating points defined in Figure 6. The RCDM is based on 400V supply
 1215 voltage.

1216 5.2.2 Overall CDM losses

1217 All the losses in the CDM shall be with reference to the rated apparent output power of the PDS,
 1218 which is formed by the rated output phase voltage and rated output current of the CDM. As a
 1219 final result of 5.2 and Annex C, the absolute CDM losses result in:

$$P_{L,CDM} = P_{L,inverter} + P_{L,rectifier} + P_{L,choke} + P_{L,rails} + P_{L,DC_link} + P_{L,control} + P_{L,cooling} \quad (5)$$

1220 The relative losses of the CDM result in:

$$p_{L,CDM} = \frac{P_{L,CDM}/kW}{S_{r,equ}/kVA} \quad (6)$$

1221 The following Figure 12 shows the relationship between relative torque current, relative motor
 1222 stator frequency and relative losses $p_{L,CDM,relative}$ of the 9,95 kVA (see Table 7) reference CDM
 1223 operated at 400 V: