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PUBLICATION GROUPEE SUR L'EFFICACITE ENERGÉTIQUE

**Adjustable speed electrical power drive systems (PDS) –
Part 9-2: Ecodesign for motor systems – Energy efficiency determination and
classification**

**Entraînements électriques de puissance (PDS) à vitesse variable –
Partie 9-2: Écoconception des systèmes moteurs – Détermination et
classification de l'efficacité énergétique**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS (PDS) –**Part 9-2: Ecodesign for motor systems –
Energy efficiency determination and classification****FOREWORD**

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IEC 61800-9-2 has been prepared by subcommittee 22G: Adjustable speed electric drive systems (PDS), of IEC technical committee 22: Power electronic systems and equipment. It is an International Standard.

It has the status of a group energy efficiency publication in accordance with IEC Guide 118.

This second edition cancels and replaces the first edition published in 2017. This edition constitutes a technical revision.

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

- a) Additional IES Classes defined to IES5;
- b) Removed reference motor loss data and now point to IEC 60034-30-2;



- c) Expanded and modified factors in Clause 6 for CDMs;
- d) Annex C is now the Mathematical Model for CDM Losses;
- e) Moved the mathematical model for the CDM to Annex C;
- f) Added Sub Drive Input Module and Sub Drive Output Modules to Annex B;
- g) Annex D is now the Converter Topology (old Annex C);
- h) Annex E is now the Interpolation of Motor Losses (Old Annex D);
- i) Annex E expanded to include various motor connections and updated interpolation method;
- j) New Annex E for determination of Interpolation Coefficients;
- k) Annex F is the old Annex E;
- l) New Annex J Explanation of Correction Factors for the Reference Losses in Table 8.

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

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

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

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

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

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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, CEN/TC 197) in order to provide a comprehensive standard for energy efficiency and ecodesign requirements.

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.

The IEC 61800 series does not deal with mechanical engineering components.

NOTE 1 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 adjustable speed AC power drive systems
- Part 3: EMC requirements and specific test methods
- 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

Some parts are further subdivided into several subparts, published either as International Standards or as Technical Specifications or Technical Reports and will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61800-9-2).

NOTE 2 It is understood that Formula (13) is for Direct-on-Line motors. Formula (13) will be modified in the next amendment to account for Variable Frequency Drive motors.

NOTE 3 A new figure will be developed to demonstrate the use of a star point for measuring the converter phase voltages to determine the $\cos\phi_i$ for each phase in 7.5.3.1.

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS (PDS) –

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 group energy efficiency publication according to IEC Guide 119 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 load equipment. It provides a link for the energy efficiency evaluation and classification of the extended product.

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, 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, not defined as RCDM or SDM, are given and compared to the IES class limits and the 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 the RCDM and RM, limits for the PDS 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. They can be used for various types of PDS with other types of motors as well, for example but not limited to, electronically commutated motors (ECM), permanent magnet motors (PM) or synchronous reluctance motors (SYN-RM), and line-start permanent magnet motors (LSPM).

PDS requirements in this document 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 are 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.
- SDM with DC input and DC output.

NOTE The IEC 61800-9 series 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 60034-1:2022, *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 60038:2009/AMD1:2021

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Part 161: Electromagnetic compatibility*, available at www.electropedia.org

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, *Electromagnetic compatibility (EMC) – Part 3-12: 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 Guide 118:2017, *Inclusion of energy efficiency aspects in electrotechnical publications*

3 Terms, definitions and symbols

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 terminology databases for use in standardization at the following addresses:

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

3.1.1

active infeed converter

AIC

self-commutated electronic power converter of any technology, topology, voltage and size which is 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 (from AC to DC and from DC to AC) and can control the reactive power or the power factor

Note 1 to entry: See IEC TS 62578.

Note 2 to entry: The IEV defines VSC and CSC as voltage stiff AC/DC converter (551-12-03) and current stiff AC/DC converter (551-12-04) respectively. 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

alternative efficiency determination method

AEDM

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

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 are not limited to, line filters, input harmonic filters, EMI filters, fuses, chokes, motor output filters, communications, control or input/output interface kits, additional ventilation kits, mechanical bonding and cable support kits or additional measuring device and instruments.

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

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 1. The SDIM and SDOM are parts of the BDM.

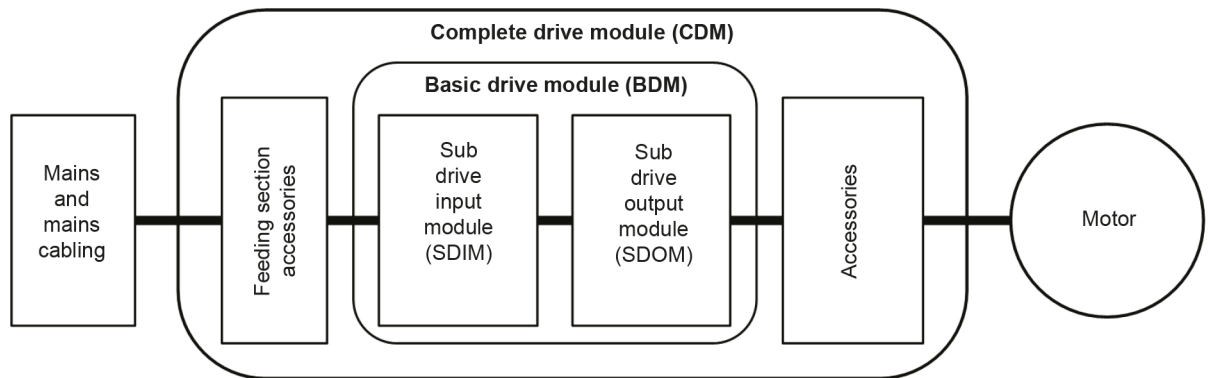


Figure 1 – Example of complete drive module (CDM) built by sub drive modules (SDM)

[SOURCE: IEC 61800-2:2021, 3.6, modified – In the definition, the word "auxiliaries" has been replaced with "accessories". The notes to entry and Figure 1 have been added, and 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 coupled to the motor but not limited to external transmissions, gears, fans, pumps, compressors, etc.

3.1.7**energy efficiency index****EEl**

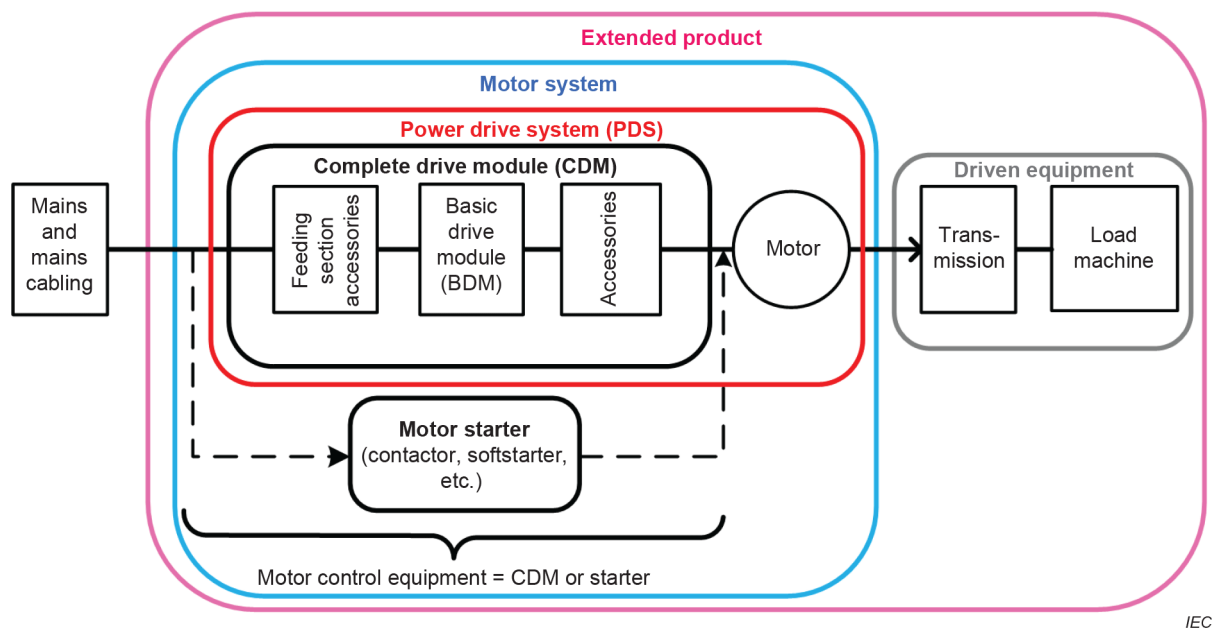
value describing the energy efficiency of an application (fan, pump compressor, etc.), resulting from the extended product approach (EPA)

Note 1 to entry: If the extended product is a pump system, the EEl 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.



IEC

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 control equipment

CDM or motor starter

3.1.12

motor system

system consisting of one or more complete drive module(s) (CDM) and a motor or motors, and any sensors which are mechanically coupled to the motor shaft, but not including the driven equipment

3.1.13

power drive system

PDS

system consisting of one or more complete drive modules (CDMs) and a motor or motors

Note 1 to entry: Any sensors which are mechanically coupled to the motor shaft are also part of the PDS; however, the driven equipment is not included.

3.1.14

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

3.1.15**reference complete drive module****RCDM**

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

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

3.1.16**reference motor****RM**

motor that is to be used for IES classification and is to be selected from IEC TS 60034-30-2

3.1.17**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: The servo PDS 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 Figure 3).

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: $n_{\text{max}} > a_0 \cdot e^{-a_1 \cdot R_N + a_2} + a_3$; with $a_0 = 6\,000\ 1/\text{min}$; $a_1 = 0,02\ 1/\text{kW}$; $a_2 = -0,4$; $a_3 = 3\,200\ 1/\text{min}$;
- angular acceleration capability criterion: $c_{\text{coeff}} = \frac{T_{\text{max}}}{J} > b_0 \cdot e^{-b_1 \cdot R_N + b_2} + b_3$; with $b_0 = 18\,000\ 1/\text{s}^2$; $b_1 = 1,3\ 1/\text{kW}$; $b_2 = -1$; $b_3 = 5\,800\ 1/\text{s}^2$.

Note 5 to entry: Typical applications for servo PDS are such as CNC (computerized numerical control) machinery, automated manufacturing or robotics.

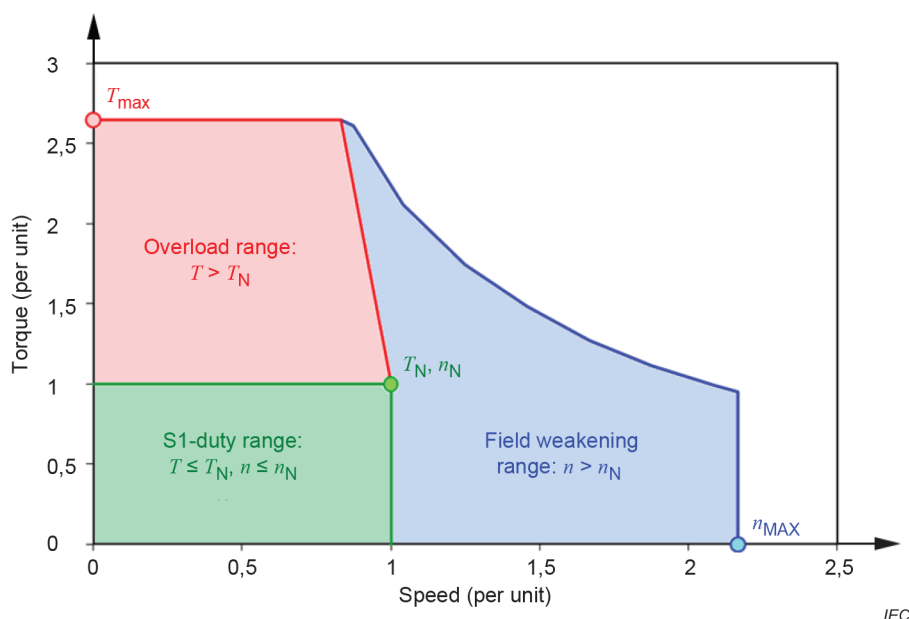


Figure 3 – Torque-speed-characteristic of servo PDS

3.1.18**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.

3.1.19**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

Note 1 to entry: SDM or SDIM with a DC input and DC output are out of scope of this document. See Clause 1.

3.1.20**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 can also include an AC or DC choke, input filter combination or DC link capacitors

Note 1 to entry: SDM or SDIM with a DC input and DC output are out of scope in this document. See Clause 1.

3.1.21**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 can also include DC link capacitors or a three-phase output filter assembly

3.1.22**test load**

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

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

3.1.23**test load current**

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

3.1.24**torque current**

part of the test load current in amperes (see 3.1.23) that produces a certain torque

Note 1 to entry: See Figure 6 and Table 1.

Note 2 to entry: For an asynchronous motor, the torque current is the rotor current.

3.2 Symbols**3.2.1**

c_{liquid}

specific heat capacity of liquid

3.2.2

DF_U

voltage distortion factor as the ratio of the RMS voltage without fundamental component to the RMS 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: f_{sw} 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.

Note 2 to entry: Turn on and turn off of the semiconductor is counted as a single switching event as it is in IEC 60034-2-3).

3.2.6 I_{motor_cable}

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

Note 1 to entry: I_{motor_cable} typically represents a capacitive current, which is normally for shielded motor cables.

3.2.7 $I_{1,r CDM}$

fundamental current in amperes of the rated CDM or PDS input current waveform

3.2.8 I_r

rated CDM or PDS input current in amperes

3.2.9 I_{out}

output current in amperes

3.2.10 $I_{r,out}$

rated CDM output current in amperes

3.2.11 I_{rM}

rated motor current in amperes

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

3.2.13

$k_{1\text{choke}}$

choke impedance, relative to the rated CDM impedance

3.2.14

$k_{2\text{DC_link}}$

load dependent DC link loss parameter [$\Omega \cdot \text{A}$]

3.2.15

$k_{2\text{choke}}$

relative voltage drop on the resistive part of the choke

3.2.16

k_{cf}

correction factor for RCDM losses to consider topologies with different characteristic

3.2.17

k_{fe}

segregation of eddy current and hysteresis losses in a motor

3.2.18

k_{fw}

segregation of friction and windage losses in a motor

3.2.19

k_{LL}

distribution of load losses

3.2.20

k_{VD}

ratio of rated motor voltage to maximum CDM output voltage

3.2.21

$P_{\text{L,cooling}}$

power losses in watts generated by the cooling equipment of a CDM (e.g. fan losses), in relation to the BDM (see IEC 61800-2) losses if the CDM needs to be separately cooled

3.2.22

m

modulation index, relation of CDM output frequency to the nominal motor stator frequency

3.2.23

n_i

speed [min^{-1}] at operating point i

3.2.24

n_r

rated speed [min^{-1}]

3.2.25

P_i

power consumption in kW at operating point i

3.2.26 $P_{\text{in,CDM}}$

input power in watts of the CDM obtained from the power loss measurement

3.2.27 $P_{\text{in,PDS}}$

input power in watts of the PDS obtained from the power loss measurement

3.2.28 $P_{\text{L,Acc}}$

power losses in watts of the drive accessories

3.2.29 P_{LHL}

additional harmonic losses in watts of a motor caused by non-sinusoidal power supply

Note 1 to entry: See also IEC 60034-2-3.

3.2.30 $P_{\text{L,RM}}$

relative losses of the reference motor

3.2.31 $P_{\text{L,RM}}$

losses in watts of the reference motor

3.2.32 P_{LTsin}

total losses in watts of a motor at sinusoidal power supply

Note 1 to entry: According to IEC 60034-2-1:2014, method 2-1-1B.

3.2.33 $P_{\text{LT,Mot}}$

total losses in watts of a motor when supplied by a converter (non-sinusoidal power supply)

Note 1 to entry: According to IEC 60034-2-1:2014, method 2-1-1B.

3.2.34 $P_{\text{out,CDM}}$

output power in watts of CDM obtained from the power loss measurement

3.2.35 $P_{\text{out,PDS}}$

output power in watts of PDS obtained from the power loss measurement

3.2.36 P_{r}

rated power in watts of equipment which is assigned by its manufacturer

3.2.37 P_{proc}

power demand in watts of the mechanical or fluid-mechanical process

3.2.38

P_L

electrical power losses in watts

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.

3.2.39

p_L

relative power losses based on per unit losses related to the rated apparent power of the device

3.2.40

$P_{L,CDM}$

power losses in watts of a CDM

3.2.41

$P_{L,CDM}$, determined

power losses in watts of CDM from the power loss determination method

3.2.42

$p_{L,CDM}$

relative power losses of the CDM, in relation to its rated apparent power

3.2.43

$P_{L,choke}$

power losses in watts in the choke section of a CDM

3.2.44

$P_{L,control}$

power losses in watts of the motor control system

3.2.45

P_{L,DC_link}

power losses in watts of the DC link section of the CDM

3.2.46

$P_{L,inverter}$

power losses in watts in the inverter section of a CDM

3.2.47

$P_{L,PDS}$, determined

power losses in watts of the PDS from the power loss determination method

3.2.48

$P_{L,rectifier}$

power losses in watts in the rectifier section of a CDM

3.2.49

$P_{L,resistor}$

measured power losses in watts of the resistor in comparative calorimetric measurement

3.2.50

$P_{L,on,D}$

on state power losses in watts of a power diode

3.2.51 $P_{L,on,D}$, rectifier

on state power losses in watts of a rectifier diode

3.2.52 $P_{L,on,T}$

on state losses in watts of a power transistor

3.2.53 $P_{L,sw,D}$

switching power losses in watts of a power diode

3.2.54 $P_{L,sw,T}$

switching power losses in watts of a power transistor

3.2.55 $P_{r,M}$

rated output power in kilowatts of motor

Note 1 to entry: In the IEC 60034 series related to motors, this is named P_N .

3.2.56 $P_{r,RM}$

rated power of the reference motor in kilowatts

3.2.57 $P_{L, stby}$

standby losses in watts of a PDS

Note 1 to entry: Standby losses in watts are losses that are generated when the PDS is powered up, but not providing current to the load. They are typically two to three orders of magnitude lower than the losses during operation.

Note 2 to entry: The influence of standby losses on the overall losses strongly depends on the duty profile of the extended product. Besides this, they also depend on the requirements of the extended product in terms of wake-up time and communication.

3.2.58 p_N

relative losses of a motor

3.2.59 Q

flow rate of a pump unit in cubic meters per second

3.2.60 Q_{BEP}

flow rate of the pump at the best efficiency point in cubic meters per second

3.2.61 Q_{cooler}

volumetric flow rate of the cooler in the calorimeter

3.2.62 Q_{ISI}

interpolation error (stability index)

3.2.63 r_{HL}

ratio of additional harmonic losses when a motor is operated with a CDM compared to the losses at sinusoidal supply of a motor

3.2.64 $S_{r, equ}$

rated apparent power in kilovolt amperes of a piece of equipment

3.2.65 $S_{r, RCDM}$

rated apparent power in kilovolt amperes of the reference CDM

3.2.66 T

torque in newton meters of a motor

3.2.67 t_w

working time in hours of an equipment

3.2.68 T_i

torque in newton meters at operating point i

3.2.69 THD

total harmonic distortion in percent of an alternating quantity as the ratio of the RMS value of the harmonic content to the RMS 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 volts 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 uk

ratio of line impedance to system impedance

3.2.78 $U_{T,r}$

on state voltage of a power transistor at rated CDM current

3.2.79 $U_{T,th}$

threshold voltage of a power transistor

3.2.80 W_w

electrical energy in kilowatt hours demand of extended product during working time

3.2.81 λ

power factor as ratio between active power and apparent power

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

3.2.82 $\Delta p_{L,CDM}$

uncertainty in percent of power loss determination method for CDM

3.2.83 $\Delta P_{L,CDM}$

uncertainty in watts of power loss determination method for CDM

3.2.84 $\Delta p_{L,PDS}$

uncertainty in percent of power loss determination method for PDS

3.2.85 $\Delta P_{L,PDS}$

uncertainty in watts of power loss determination method for PDS

3.2.86 θ_{CDM}

temperature in degrees Celsius of CDM

3.2.87

θ_{in}

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

3.2.88

θ_{inside}

temperature in degrees Celsius of cooling air between two calorimetric measurement chambers

3.2.89

θ_M

temperature in degrees Celsius of motor

3.2.90

θ_{out}

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

3.2.91

θ_{SDIM}

temperature in degrees Celsius of sub drive input module (SDIM)

3.2.92

θ_{SDOM}

temperature in degrees Celsius of sub drive output module (SDOM)

3.2.93

φ

phase angle in degrees between the fundamental CDM input voltage and the fundamental CDM input current

3.2.94

Φ

phase angle in degrees between the fundamental CDM output voltage and the fundamental CDM output current

3.2.95

Φ_r

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

3.2.96

c_{WHf}

loss separation coefficient for winding losses and high frequency losses

3.2.97

c_{BH}

loss separation coefficient for friction and windage losses and hysteresis losses

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 provider.

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 60034-30-1,
- limiting the assessment to only a few appropriate measured or calculated operating points, and
- determination of the energy consumption of various driven applications.

Examples of relevant input values (operating points) for classification of different driven applications: some typical loads have square-law torque-speed characteristics (e.g. most pump units) while others require constant torque (e.g. hoisting equipment).

This document establishes relative losses or input powers at the operating points $p_{L, PDS (50; 25)}$, $p_{L, PDS (90; 50)}$ and $p_{L, PDS (90; 100)}$ and 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.

If other load points are necessary, use the interpolation method found in Annex E.

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 (speed, torque) 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.

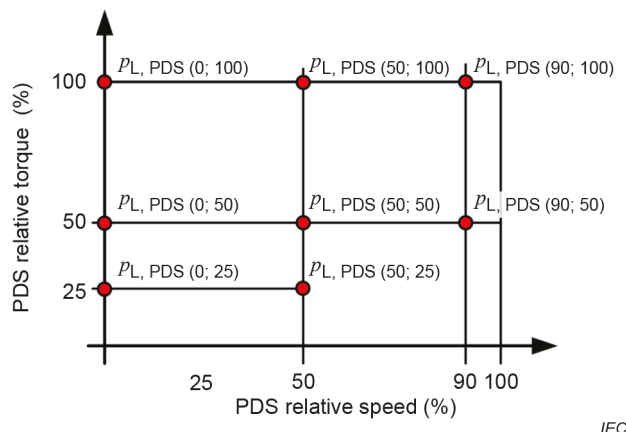


Figure 4 – Illustration of the operating points (shaft speed, torque) for the determination of relative losses of the power drive system (PDS)

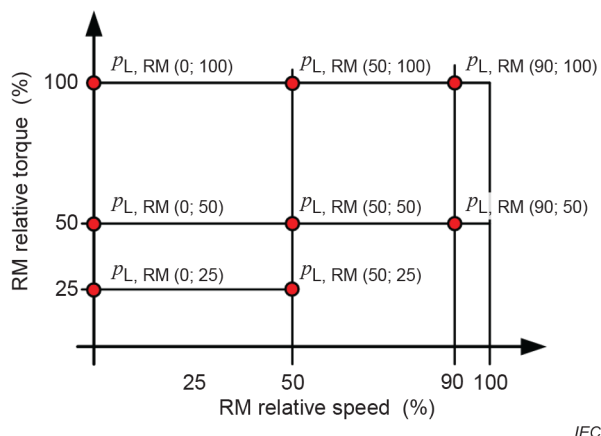
As defined, the absolute losses of the PDS shall be the sum of the CDM losses plus the motor losses. Therefore, those losses shall be calculated point by point at the operating points of Figure 5 and Figure 6 by Formula (1):

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

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 shown in Formula (2):

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



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.

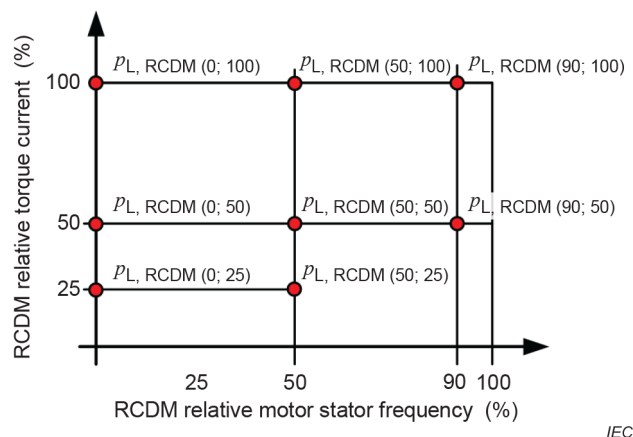


Figure 6 – Illustration of the operating points (relative motor stator frequency, relative torque current) for the determination of losses of the reference complete drive module (RCDM)

NOTE 1 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 2 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 by an extended procedure according to Annex E (see also IEC 60034-2-3).

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.

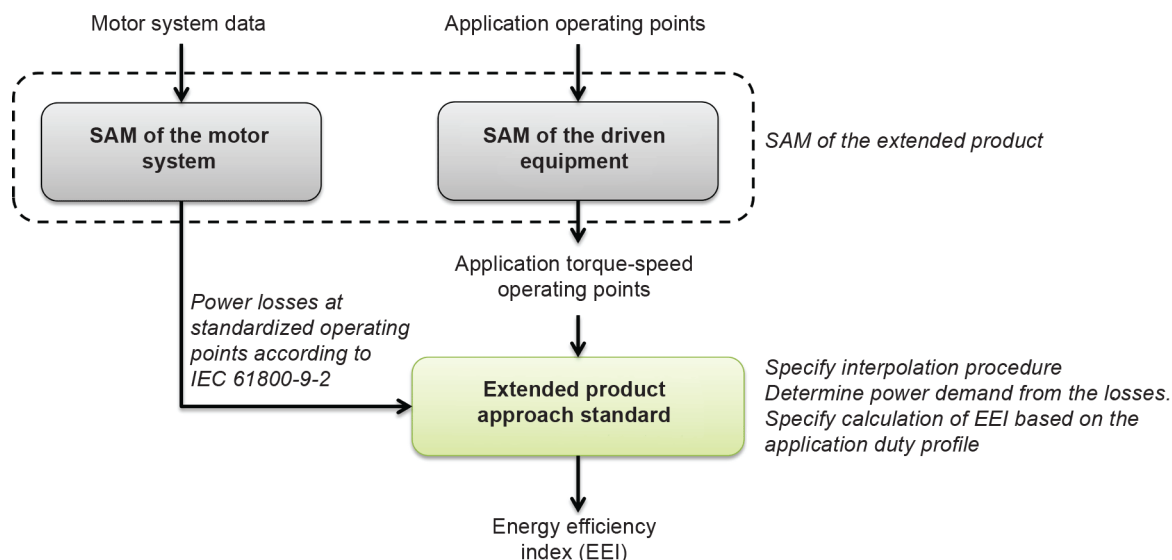
4.3 Combining PDS losses with the driven equipment – Workflow for the semi-analytical model (SAM)

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.

If a SAM exists of the driven equipment (right side), then it permits linking to the SAM of the motor system (left side). Then the link between both semi analytical models shall be the load loss points of the PDS and their permissible tolerances. The needed operating points shall be provided by the semi analytical model of the driven equipment.

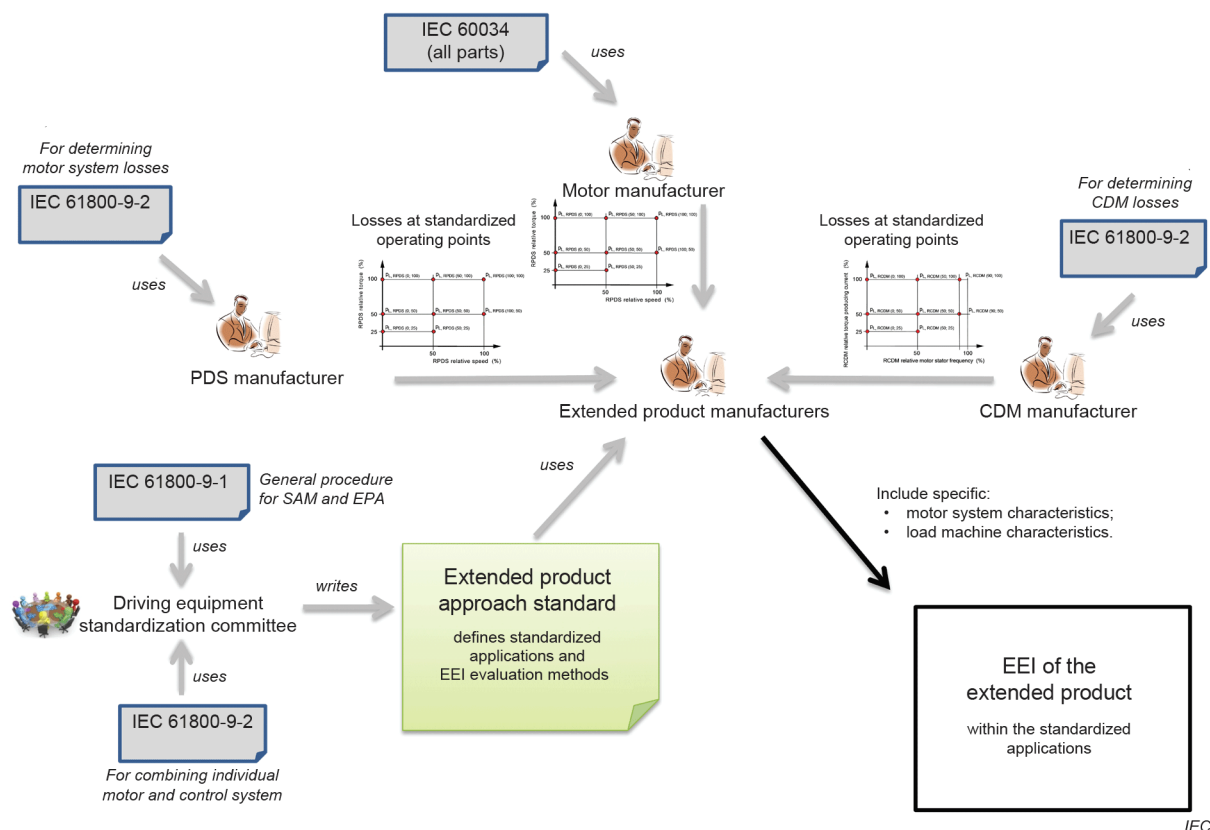
The PDS data containing the PDS losses according to Figure 2 (left hand side of Figure 7) are defined in this document, whereas it is the responsibility of the technical committees for the specific EP to standardize publicly available SAMs for their applications (right side of Figure 7). An extended product of pumps is given in IEC 61800-9-1. Figure 8 shows how the different data sources shall be combined.



IEC

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 providers can provide data directly to the motor system provider.

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 that fall under both IEC 60034-30-1 and IEC TS 60034-30-2, i.e. that are AC and rated for both direct-on-line (grid) operations and variable speed operation (dual rated motors), shall bear the IE efficiency class according to the procedure laid out in IEC 60034-30-1 only. Examples of such motors are most induction motors or line start permanent magnet motors. Losses for the defined 7 operating points can be extrapolated from Annex E. Losses for these points shall be provided by the motor provider by using IEC 60034-2-3. The alternative efficiency determination method (AEDM) determined may also be used in 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.

The operating point for the IE Class determination is 90 % speed and 100 % torque and shall be taken according to Clause 6.

CDMs with modified functionality such as AIC according to IEC TS 62578 or CDMs having a mains current THC of 10 % or lower (according to IEC 61000-3-12) are classified using the correction factor concept according to 6.3.2.

4.7 IES Classes of a PDS

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

Relative losses of a PDS shall be determined by calculation or measurement. This is a requirement for integrated products and optional for others. The calculation shall be done by arithmetic summation of the absolute losses of the converter-fed motor plus the converter and the accessories or of an AEDM. See Clause 1 for details.

The operating point for the IES Class determination is 90 % speed and 100 % torque and shall be taken according to Clause 6.

4.8 Consistency of IE and IES Classes

It is important to understand that the IE Classes of individual components such as converter fed AC motors, direct-on-line or CDMs cannot be added in order to determine the IES Class of a PDS.

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

Individual IE Classes are required for the classification of components without prior knowledge of the extended product.

Generally, higher IE or IES Classes will demonstrate increased efficiency or decreased relative power losses. Figure 9 shows an example for IE and IES Classes for a 7,5 kW / 1 500 rpm motor and a 9,95 kVA CDM.

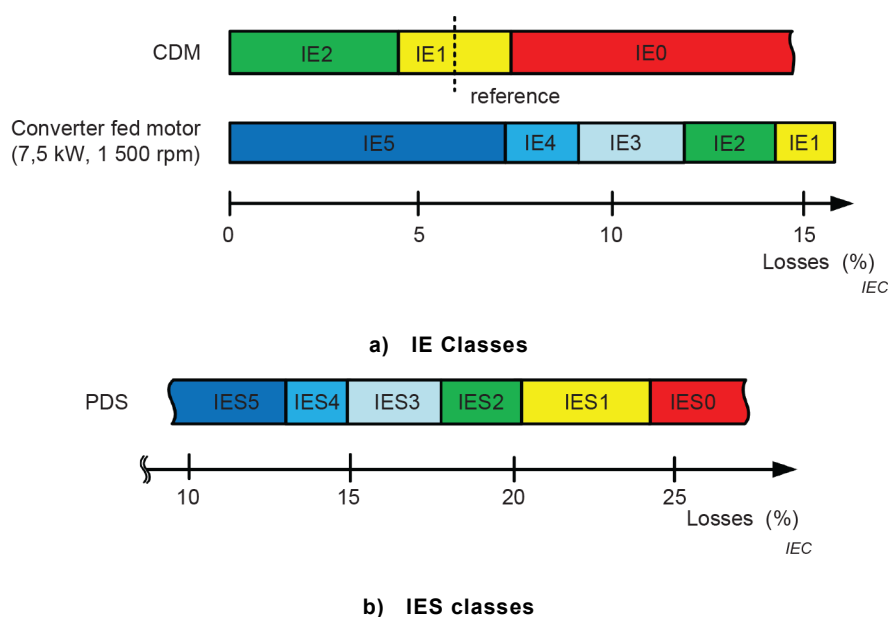


Figure 9 – Metrical relation

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

Methods for the determination of losses and IE Classes of a motor are given in the IEC 60034-30 series – see also Figure 9. Providers may also define an IES class for a PDS that is using their motor. In that case, the relative losses of the selected motor when operated on a RCDM shall be determined.

A CDM provider shall declare the losses of its dedicated CDM and display an IE Class according to Figure 16. The provider may also declare an IES class for a PDS equipped with a CDM. In that case, the losses of the selected CDM shall be measured or calculated. When actual motor data is not available, the losses of the RM shall be used.

The CDM provider 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 are shown in Figure 10. It also gives guidance to sole CDM or sole motor providers regarding the determination of the IES class of a resulting PDS in combination with "test" or "reference" devices.

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

The interpolation coefficients c_{Ln} calculated in formula (E.8) can then be used to calculate the losses at any arbitrary operating point using formula (E.4) or formula (E.5) as appropriate.

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

A reference motor is a motor that is to be used for IES classification and is to be selected from IEC TS 60034-30-2.

Figure 10 – Guidance for CDM and motor providers 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 C. 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 physical product. In order to determine the losses of a product, these parameters need to be set according to specific design of the product.

Providers of CDMs may use their own analytical model to determine CDM losses with more details; however, providers 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), the reference parameters are defined in 5.2 and Annex C.

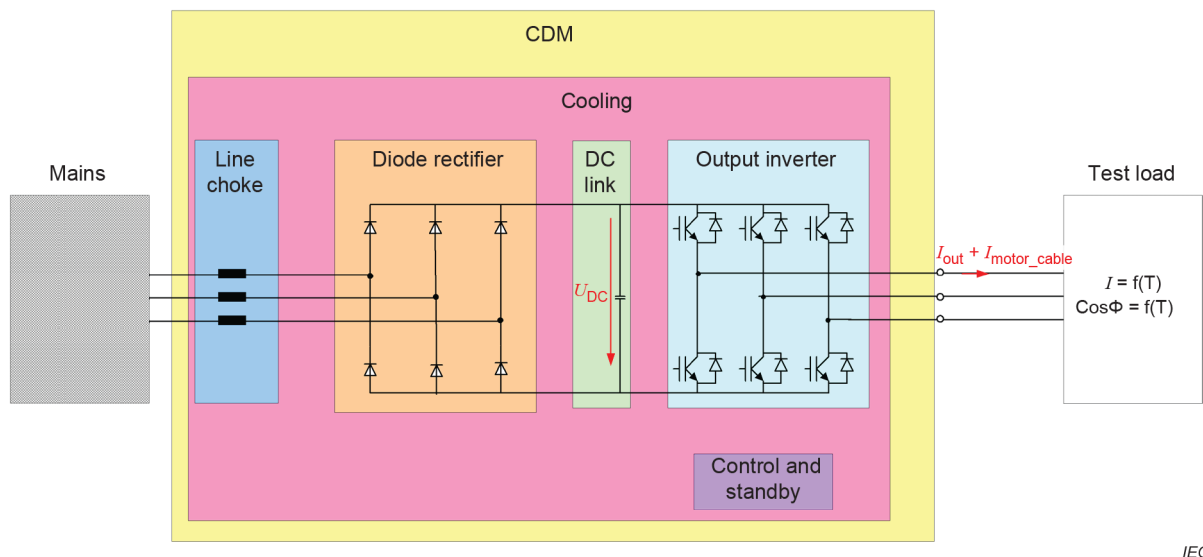
For reference motor (RM), 5.3.3 refers to the reference parameters.

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.



IEC

Figure 11 – Illustration of a typical CDM and test load

The goal is 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).

The first step is to convert the motor speed into a CDM output frequency. The motor torque shall also be converted to a 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 data shown in Table 1 and Table 2, obtained by measurements on physical motors, shall be used as 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

Torque current %	Test load displacement factor $\cos \phi$ for the apparent power range S 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 ^a	0,73	0,79	0,85	0,86	0,87
All required displacement factors in Table 2 apply when loading a CDM or SDOM at 25 – 75 % with an electronic load.					
^a When loading a CDM or SDOM with a motor, only the 100 % requirement applies.					

NOTE When calculating CDM or SDOM losses, the requirement for the displacement factor is equal to when using an electronic load.

When loading a CDM or SDOM with a motor, the requirement to the displacement factor is only at 100 % load current. This shall be achieved within a tolerance of $\pm 0,08$. If unsuccessful, the load motor shall be changed.

Test load current in Table 1 and test load phase angle in Table 2 for different related torque values depend on the rated power. 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.

The mathematical model of a CDM or SDOM shall be calculated by using its rated output current. If a CDM is not specified with a rated output current, but only with a rated real power $P_{r,M}$, its rated CDM output current shall be calculated from the rated real power by Formula (3), using the phase angle from Table 2 and the IE2 efficiency η defined in IEC 60034-30-1:

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

The rated apparent CDM output power shall be calculated as shown in Formula (4):

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

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

- losses of output inverter stage;
- losses of input converter;
- input choke losses;
- DC link losses;
- current rail losses;
- control and standby losses;
- cooling loss factor.

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

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

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

5.2.2 Overall CDM losses

All the losses in the CDM shall be with reference to the rated apparent output power of the PDS, which is formed by the rated output phase voltage and rated output current of the CDM. As a final result of 5.2 and Annex C, the absolute CDM losses result in Formula (5):

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

The relative losses of the CDM result in Formula (6):

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

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

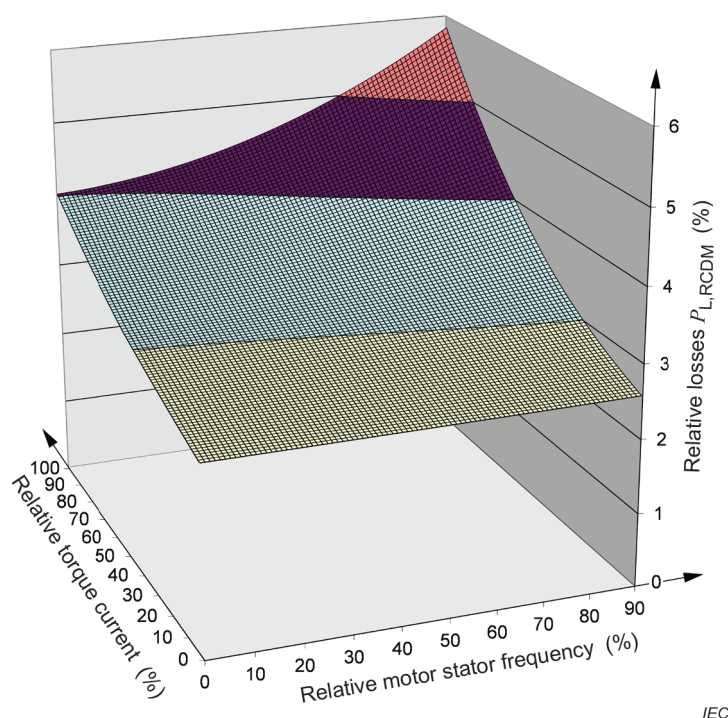


Figure 12 – Example of relative losses $p_{L,CDM}$ of the 9,95 kVA RCDM

The following Table 3 shows the relative losses of the 400 V/9,95 kVA reference CDM at the operating points defined in Figure 6.

Table 3 – Example of relative losses of the 400 V/9,95 kVA reference CDM at the operating points described in Figure 6

$S_{r,eq}$	I_{rout}	$p_{L,RCDM}$ (0;25)	$p_{L,RCDM}$ (0;50)	$p_{L,RCDM}$ (0;100)	$p_{L,RCDM}$ (50;25)	$p_{L,RCDM}$ (50;50)	$p_{L,RCDM}$ (50;100)	$p_{L,RCDM}$ (90;50)	$p_{L,RCDM}$ (90;100)
kVA	A	%	%	%	%	%	%	%	%
9,95	14,4	2,80	3,09	4,02	2,86	3,28	4,64	3,61	5,84

The value of 5,84 % of losses refers to the rated apparent output power of 9,95 kVA, resulting in absolute loss value of 581 W. The relative losses of CDMs with a different rated power are given for the operating point (90;100) in Table 7 and in Table A.1 for all operating points defined in Figure 6.

5.2.3 Loss determination of CDMs composed by combination of submodules

Losses of a CDM composed by a combination of SDIM and SDOM shall be determined by adding the losses of the sub modules, taking into account that they are representing the same operating point.

$$P_{L,CDM} = P_{L,SDIM} + P_{L,SDOM} \quad (7)$$

For the determination of SDOM losses, the CDM operation points are defined and shall be used. For these operating points, the corresponding losses of the SDIM shall be determined. Thereto, the CDM equivalent output current of the SDIM $I_{CDMe,SDIM,out}$ needs to be calculated.

Assuming that the active power at the resulting CDM/SDOM output and the SDIM output are identical:

$$P_{\text{out,CDM}} = \sqrt{3} U_{1,r,\text{out}} I_{r,\text{out}} \cos\Phi_{(90,100)} = P_{\text{CDMe,SDIM}} = U_{dc} I_{\text{CDMe,SDIM,out}} \quad (8)$$

the CDM equivalent SDIM output current can be calculated by

$$I_{\text{CDMe,SDIM,out}} = \sqrt{3} \frac{U_{1,r,\text{out}}}{U_{\text{DC}}} I_{r,\text{out}} \cos\Phi_{(90,100)} \quad (9)$$

NOTE SDOM losses are quite small compared to the rated SDOM power and are therefore neglected for this calculation.

The DC link voltage of the SDIM is dependent on the converter technology. For a diode bridge rectifier, the ratio between DC link voltage and CDM output voltage is about 1,35, which is a minimum for this relationship without significant overmodulation.

To get part load information of SDIM operating points comparable to the operating points of the CDM, the active power at the SDIM in the part load operating points shall be used. Assuming that the active power at the resulting CDM output and the SDIM output are identical also at part load condition, the active SDIM power at part load operating point (f_{op} , i_{op}) is given by

$$P_{\text{SDIM}}(f_{\text{op}}, i_{\text{op}}) = P_{\text{CDMe,SDIM}} m(f_{\text{op}}) \frac{I_{\text{out}}(i_{\text{op}})}{I_{1,r,\text{out}}} \frac{\cos\Phi(f_{\text{op}}, i_{\text{op}})}{\cos\Phi_{(90,100)}} \quad (10)$$

where

$I_{\text{out}}/I_{1,r,\text{out}}$ is the test load current given in Table 1;

$\cos\Phi(f_{\text{op}}, i_{\text{op}})$ is the corresponding test load displacement factor given in Table 2.

The modulation index m is proportional to the inverter output voltage and therefore proportional to f_{op} .

These factors are dependent on the power rating of the CDM, and the appropriate factors of Table 1 and Table 2 apply. Thus, the loss calculation can be done at every operating point and for every nominal power rating.

For the CDM operating points defined in 4.2, the SDIM active power $P_{\text{SDIM}}(f_{\text{op}}, i_{\text{op}})$ given in Table 4, or calculated/measured values for any point, shall be used to determine SDIM losses by calculation or measurement. Linear interpolation between neighbouring operating points can be used for loss determination at operating points not defined in 7.5.4.

Detailed information on the calculation of the corresponding power ratio for the defined operating points can be found in Clause F.5.

Table 4 – Active SDIM power ratio to be used for loss calculation at the CDM operating points

CDM operating point (f; i)	Active SDIM power $\frac{P_{SDIM}}{P_{CDMe,SDIM}}$ %
(90; 100)	90
(50; 100)	50
(0; 100)	10
(90; 50)	50
(50; 50)	25
(0; 50)	5
(50; 25)	10
(0; 25)	5

5.2.4 Validation of loss calculation method

The loss calculation method shall be validated by comparing the calculation results with loss measurements taken from the CDM and SDM using one of the measurement methods given in 7.5.

- Validation of single CDM/SDM size

The qualification is made at the (90;100) operation point, the same point as used for determining the IE Class. The calculation/simulation shall be validated by comparing with a measurement result. The calculated loss value shall be within $\begin{smallmatrix} -10 \\ +30 \end{smallmatrix}$ % of the measured value.

- Validation of a range of CDMs/SDMs

When a range of CDMs/SDMs with similar design (e.g. same product family) is validated, there shall be at least one validation by means of measurement within one decade of the power or current rating. For example, if the rating is 1 kVA to 10 kVA, as a minimum one test validation is needed.

5.3 Motor losses

5.3.1 General

Three-phase asynchronous motors are widely used in industrial applications. They are standard products and generally run direct on-line. Many are also capable of operation on variable voltage and frequency supplied by a CDM.

In order to determine losses, efficiencies and the efficiency class of a PDS, the user needs information on motor losses. Such information can be obtained either

- from the motor provider, or
- from efficiency of the reference motor as given in IEC 60034-30-1:2014, Annex A, and IEC TS 60034-2-3 (0 % to 100 % torque and speed), or
- from typical losses of standard machines as given in Annex E.

The interpolation procedure given in Annex E shall be applied to obtain losses and efficiency at any required operating point (load, torque), for example those of 4.2, from the losses provided by the provider at the seven reference points (see Table E.1).

5.3.2 Additional harmonic losses of three-phase asynchronous motors fed by a CDM

Often, losses of three-phase induction motors are only available for on-line operation at purely sinusoidal voltage. When such a motor is operated on a CDM, additional harmonic losses P_{LHL} are caused by the non-sinusoidal voltage supply.

Preferably, the motor should be re-tested on a CDM to determine these losses (see Annex E).

Alternatively, the additional harmonic losses can be determined by using a fixed ratio r_{HL} as an estimation.

r_{HL} represents the ratio of additional harmonic losses of converter supply to losses of the motor supplied with sinusoidal input voltage at nominal power and nominal frequency (see IEC 60034-2-3).

The total losses are:

$$P_{LHL} = (1 + r_{HL}) \cdot P_{LTsin} \quad (11)$$

where

P_{LTsin} are the total losses determined at sinusoidal power supply at any operating point;

P_{LHL} are the total losses estimated for CDM power supply at that operating point.

Additional harmonic losses due to a converter supply shall be considered constant and independent of load and speed. They are dependent on the switching frequency.

Unless r_{HL} is known from measurements according to IEC TS 60034-30-2, the following estimations shall be used:

- $r_{HL} = 0,15$ (15 %) for motors with a rated output power up to 90 kW and 4 kHz switching frequency;
- $r_{HL} = 0,25$ (25 %) for motors with a rated output power above 90 kW and 2 kHz switching frequency

NOTE For switching frequencies higher than the given values, the given r_{HL} values are considered conservative approaches.

5.3.3 Motor loss data

Motor values shall be taken from IEC TS 60034-30-2.

IEC TS 60034-31 is applicable to all electrical machines covered by IEC 60034-1, IEC 60034-30-1 and IEC TS 60034-30-2.

5.4 Power drive system (PDS) losses

5.4.1 PDS losses

The resulting electrical power losses of the PDS at a specific speed (n) and torque (T) operation point will be the sum of the electrical power losses of the subcomponents of the PDS according to Formula (12):

$$P_{L,PDS(n;T)} = P_{L,CDM(f;I)} + P_{L,Acc(f;I)} + P_{L,Mot(n;T)} \quad (12)$$

where

$P_{L,CDM}$ are the losses of the CDM according to methods from 5.2 and Annex C;

$P_{L,Mot}$ are the losses of the motor according to methods from 5.3;

$P_{L,Acc}$ are the losses of the accessories according to Annex B.

The calculation of losses is generally performed according to Formula (12). However, PDS losses at 100 % speed and 100 % torque are determined according to Formula (13) by using the 90 % frequency and 100 % torque point of the RCDM and the 100 % speed and 100 % torque point of the motor.

The 90 % frequency of the CDM is used in order to avoid overmodulation, which would appear for 100 % frequency of the CDM. Overmodulation decreases the losses of the CDM but increases harmonic motor losses due to higher harmonic contents in the motor's voltages and currents.

The loss calculation of the PDS is using the assumption that the CDM losses at the operating point 100 % frequency and 90 % voltage are the same as for the operating point at 90 % frequency and 90 % voltage. It is further assumed that fundamental losses of the RM increase with a correction factor $k_{VD} = 1,11$ (according to 10 % voltage drop) compared to Formula (12).

$$P_{L,PDS}(100;100) = P_{L,RCDM}(90;100) + k_{VD} \cdot P_{L,RM}(100;100) \quad (13)$$

The default parameter for Formula (13) is given in Table 5.

Table 5 – Reference parameter for Formula (13)

Abbreviation	Description	Value	Unit
k_{VD}	Correction factor of motor losses for the PDS	1,11	

It is in the responsibility of the PDS supplier to add all losses that are part of the PDS, for example motor, CDM, accessories (filter, cable, etc.), for the calculation of losses of an actual PDS.

Table 6 shows the relative losses of a 400 V/7,5 kW PDS (RCDM and RM) at the operating points defined in Figure 6.

Table 6 – Relative losses of the 400 V/7,5 kW PDS

$P_{r, M}$	$P_{L, PDS}$, relative (0;25)	$P_{L, PDS}$, relative (0;50)	$P_{L, PDS}$, relative (0;100)	$P_{L, PDS}$, relative (50;25)	$P_{L, PDS}$, relative (50;50)	$P_{L, PDS}$, relative (50;100)	$P_{L, PDS}$, relative (90;50)	$P_{L, PDS}$, relative (90;100)
kW	%	%	%	%	%	%	%	%
7,5	6,14	7,83	15,10	7,74	9,69	17,90	12,02	21,86
NOTE This PDS example is based on a 7,5 kW 1 500 rpm IE2 motor and a 9,95 kVA IE2 CDM with no correction factors applied.								

An example for the relative losses is shown in Figure 13. All relative values are related to the rated output power of the PDS.

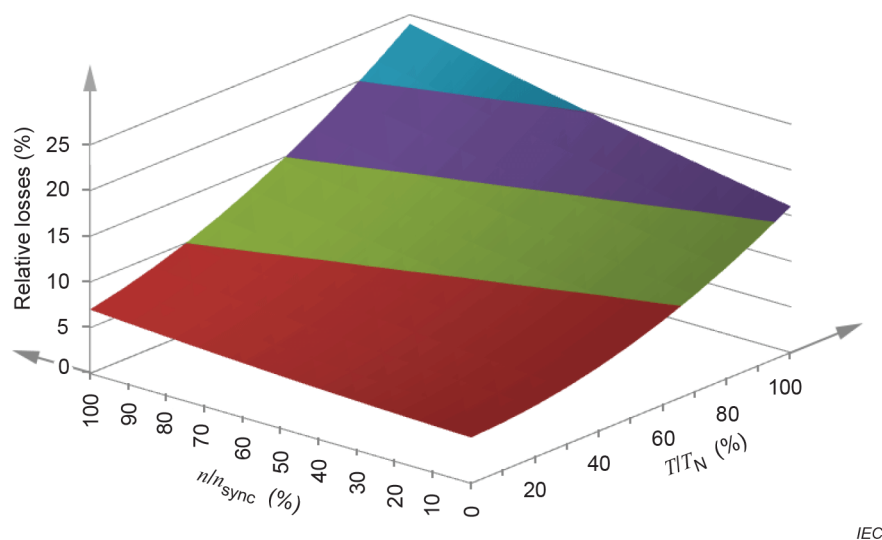


Figure 13 – Example of the relative power losses of PDS as function of speed and torque

5.4.2 PDS losses at different switching frequencies

PDS are often operated at various or different switching frequencies. An important parameter for the loss calculation of the CDM is the switching frequency. An increased switching frequency will increase the losses of the CDM but the additional harmonic losses of the motor will decrease.

The resulting power losses of a PDS for a dedicated switching frequency will be the sum of the electrical power losses of the subcomponents of the PDS – see Formula (14) and example in Figure 14 – when the operating point (speed, torque) is kept constant.

$$P_{L,PDS}(f_{sw}) = P_{L,CDM}(f_{sw}) + P_{L,Acc}(f_{sw}) + P_{L,Mot}(f_{sw}) \quad (14)$$

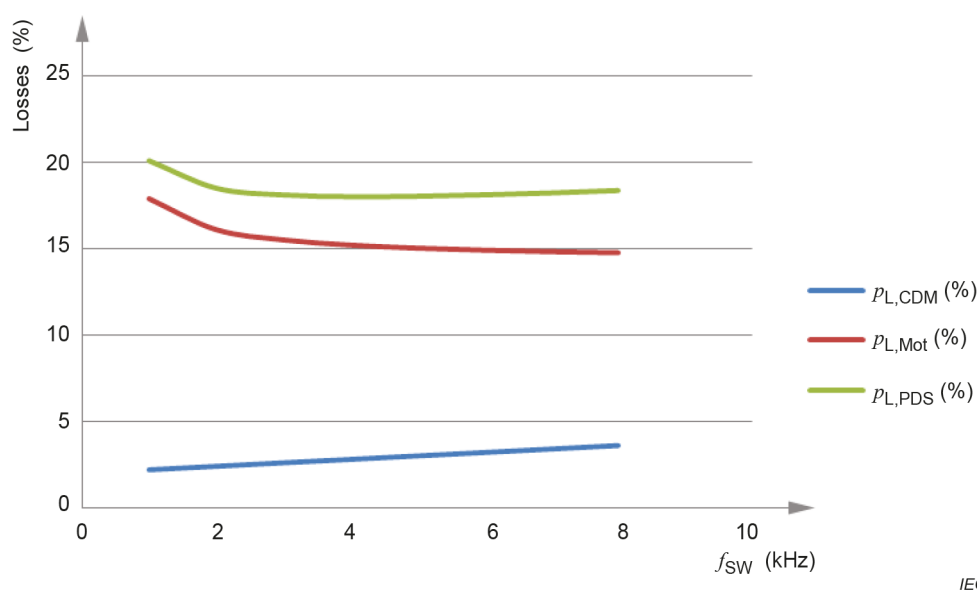


Figure 14 – Example representation of the relative power losses versus switching frequency of a 7,5 kW to 11 kW PDS

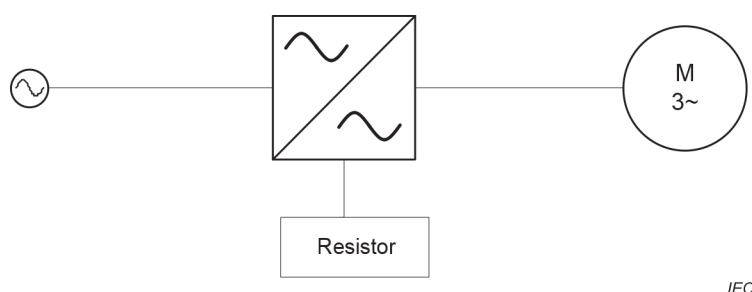
5.5 PDS losses for regenerative operation

Some PDSs have the capability of handling regenerative loads, i.e. loads that generate electrical power. Power can be generated from decelerating the inertia of a load or motor, or from torque produced by the load (for example wind milling of a fan caused by external air).

Some CDMs have the capability to feed the generated power into the mains by using an active infeed converter (AIC). The power fed into the mains is the generated electrical power of the generator/motor minus the losses of the CDM.

A CDM can also have the capability to dissipate the generated power into heat, which is distributed inside or outside of the CDM (for example by a resistor) – see Figure 15.

A CDM can also have the capability to store electrical energy in batteries, capacitors or similar technologies. This energy can later be reused when active motor power is needed. Such storage devices cause losses that shall be added as accessory losses when calculating the losses of the extended product.



IEC

Figure 15 – Example of a CDM with resistor for dissipating generated power

5.6 Losses of motor starters

For the purpose of loss calculations, the power losses of motor starters (including control losses) according to the product standard IEC 60947-4-1 shall be calculated as 0,1 % of the rated motor power.

Soft starters according to the product standard IEC 60947-4-2 are usually mechanically bypassed at longer duty cycle (S1 operation) and therefore calculated like motor starters.

The power losses of motor starters are sufficiently small so that the same IE Class is used for a motor as well as for a motor controlled by a starter.

6 Limits of IE and IES Classes

6.1 General

The losses or efficiency of the reference CDM and standardized motor are used as a basis for assessing compliance with an IE and IES class of an existing motor, SDM, CDM or PDS.

Reference CDM is associated with IE1. Existing devices with losses lower than the reference losses (i.e. better efficiency) are identified by levels higher than 1. The threshold and tolerance of each level are specified in 6.2 to 6.5.

Compliance with an IE and IES class can be shown by either measurements or by calculations, which are described in Clause 7. The various test points shown in Figure 4 can be used to determine the losses and energy efficiency of an overall system for a specific application.

In order to minimize the certification process, compliance with an IE Class shall be shown for the SDOM or CDM at rated current and 90 % rated motor stator frequency, respectively rated motor voltage, only. Compliance with an IE Class for an SDIM shall only be evaluated for 100 % rated power.

Compliance with an IES class shall be shown for the PDS 90 % rated motor speed and 100 % rated torque only.

Losses in regenerative operation is not taken into account when determining an IE or IES class for an SDIM, CDM or a PDS.

NOTE The rated output current of a CDM is typically its maximum continuous output current.

6.2 CDM

The reference CDM is described by the parameters given in Annex C and 5.2. Its losses are given in Table 7.

The power rating of a RCDM is defined according to its apparent output power, which is of most influence on CDM losses.

As CDMs are usually rated according to output current rather than apparent output power, examples of rated RCDM output currents are given in Table 7 for typical standard line voltages. The relation to standard motor power ratings defined in IEC 60034-30-1 can be found in Table A.1.

Table 7 – Reference CDM losses for class IE1 definition

Apparent output power $S_{r, \text{equ}}$	Relative losses $P_{L, \text{RCDM}} (90, 100)$	Absolute losses $P_{L, \text{RCDM}} (90, 100)$	Examples for CDM output current at typical line voltages $I_{r, \text{out}} = \frac{S_{r, \text{equ}}}{\sqrt{3} \cdot U_{1, \text{r, out}}}$			
kVA	%	kW	$U_{1, \text{r, out}} =$ 200 V	$U_{1, \text{r, out}} =$ 400 V	$U_{1, \text{r, out}} =$ 460 V	$U_{1, \text{r, out}} =$ 690 V
			A			
0,278	35,85	0,100	0,803	0,401	0,349	0,233
0,381	27,30	0,104	1,10	0,550	0,478	0,319
0,500	21,80	0,109	1,44	0,722	0,627	0,418
0,697	16,84	0,117	2,01	1,01	0,875	0,583
0,977	13,21	0,129	2,82	1,41	1,23	0,818
1,29	11,02	0,142	3,73	1,86	1,62	1,08
1,71	9,51	0,163	4,94	2,47	2,15	1,43
2,29	8,21	0,188	6,62	3,31	2,88	1,92
3,30	7,20	0,237	9,54	4,77	4,15	2,76
4,44	6,72	0,299	12,8	6,41	5,58	3,72
5,85	6,39	0,374	16,9	8,44	7,34	4,89
7,94	6,01	0,477	22,9	11,5	9,96	6,64
9,95	5,84	0,581	28,7	14,4	12,5	8,32
14,4	5,43	0,781	41,6	20,8	18,1	12,1
19,5	5,18	1,01	56,2	28,1	24,4	16,3
23,9	5,05	1,21	68,9	34,4	30,0	20,0
28,3	4,97	1,41	81,6	40,8	35,5	23,6

Apparent output power $S_{r, \text{equ}}$	Relative losses $p_{L, \text{RCDM}} (90, 100)$	Absolute losses $P_{L, \text{RCDM}} (90, 100)$	Examples for CDM output current at typical line voltages $I_{r, \text{out}} = \frac{S_{r, \text{equ}}}{\sqrt{3} \cdot U_{1, r, \text{out}}}$			
kVA	%	kW	$U_{1, r, \text{out}} = 200 \text{ V}$	$U_{1, r, \text{out}} = 400 \text{ V}$	$U_{1, r, \text{out}} = 460 \text{ V}$	$U_{1, r, \text{out}} = 690 \text{ V}$
			A			
38,2	4,87	1,86	110	55,2	48,0	32,0
47,0	4,79	2,25	136	67,8	58,9	39,3
56,9	4,75	2,70	164	82,1	71,4	47,6
68,4	4,74	3,24	197	98,7	85,8	57,2
92,8	4,69	4,35	268	134	116	77,6
111	4,66	5,17	321	160	139	93,0
135	4,11	5,55	391	195	170	113
162	4,10	6,65	468	234	203	136
196	4,09	8,02	566	283	246	164
245	4,07	10,0	706	353	307	205
302	4,10	12,4	872	436	379	253
381	4,09	15,6	1 099	550	478	319
429	4,09	17,5	1 239	619	539	359
483	4,09	19,8	1 396	698	607	405
604	4,08	24,7	1 745	872	758	506
677	4,08	27,6	1 954	977	850	566
761	4,08	31,1	2 198	1 099	956	637
858	4,08	35,0	2 477	1 239	1 077	718
967	4,08	39,4	2 791	1 396	1 214	809
1 088	4,08	44,3	3 140	1 570	1 365	910
1 209	4,08	49,3	3 489	1 745	1 517	1 011
NOTE 1 The change of the switching frequency from 4 kHz at 111 kVA to 2 kHz at 135 kVA causes a discontinuity in the relative RCDM loss values $p_{L, \text{RCDM}}$ between those power ratings.						
NOTE 2 For an SDIM, the active output power is equal to the apparent output power.						

If the rated apparent output power of a CDM or SDM is between two values in Table 7, the relative loss value $p_{L, \text{RCDM}}$ of the RCDM with the next higher power rating shall be used for the IE Class determination. The RCDM losses in Table 7 shall be used for all low voltage CDMs.

If a CDM is composed of any combination of SDIM and SDOM which are already IE classified, the CDM does not need to be classified.

A CDM shall be classified as IE1 if its relative losses are within ± 25 % of the RCDM value.

A CDM shall be classified as IE0 if its relative losses are more than 125 % of the RCDM value.

A CDM shall be classified as IE2 if its relative losses are less than 75 % of the RCDM value.

These definitions are illustrated in Figure 16.

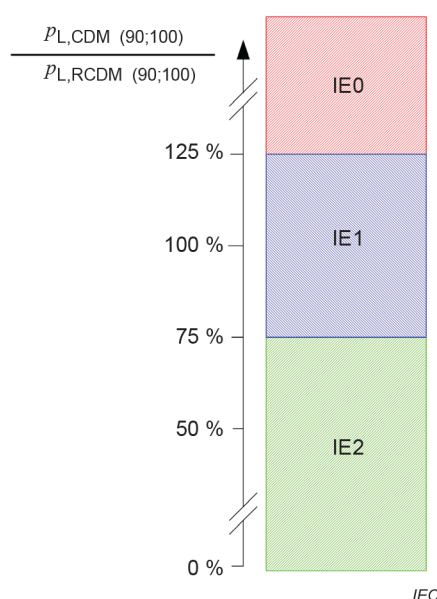


Figure 16 – Illustration of IE Classes for a CDM

NOTE 3 In this document, limit classes for CDMs are defined up to IE2 only. Classes IE 3 up to IE 9 are reserved to describe future technological improvements of CDMs.

6.3 Correction factors for CDMs with modified functionality

6.3.1 General

CDM topologies other than the defined reference CDM show advantages or drawbacks over the reference CDM which may not be directly visible in the relative losses and corresponding IE classification of the CDM. A low-harmonic drive with sinusoidal input currents, for instance, considerably reduces losses in the grid by mitigation harmonic currents but shows higher losses in the CDM. The total system efficiency, also considering losses in the grid, can therefore be higher. Other drive elements such as sine motor filter improve EMI behaviour of a PDS considerably but show higher losses compared to a drive without any output filter.

In order to take these advantages into account, correction factors for RCDM losses are used.

The basic concept is to compare measured or calculated CDM or SDM losses with modified reference CDM losses $p_{L,RCDM,m}$ where the benefit of this topology is expressed by correction factors $k_{cf,i}$.

The reference CDM losses defined in 6.2 and Table 7 consider the following drive elements:

- input converter losses of a three-phase diode bridge rectifier with a line choke of $u_k = 2\%$ and THD_i of input currents of approximately 60 %;
- DC link losses;
- output inverter losses without any output filter;
- current conductor losses;
- cooling losses of an integrated fan;
- control and standby losses.

For topologies with other characteristics, modified reference losses $p_{L,RCDM,m}$ are calculated by:

$$p_{L,RCDM,m(90;100)} = \frac{1}{n} \left(1 + \sum_{i=1}^N k_{cf,i} \right) \cdot p_{L,RCDM(90;100)} \quad (15)$$

For SDIM, Formula (16) is applied:

$$p_{L,SDIM,m(90;100)} = \frac{1}{n} \left(1 + \sum_{i=1}^N k_{cf,i} \right) \cdot p_{L,RCDM(90;100)} \quad (16)$$

For SDOM, Formula (17) is applied:

$$p_{L,SDOM,m(90;100)} = \frac{1}{n} \left(1 + \sum_{i=1}^N k_{cf,i} \right) \cdot p_{L,RCDM(90;100)} \quad (17)$$

For a CDM built from SDIM and SDOM, Formula (18) is applied:

$$p_{L,RCDM(SDIM+SDOM),m(90\%;100\%)} = p_{L,SDIM,m(90\%;100\%)} + p_{L,\frac{SDOM,m(90\%;100\%)}{S_{r,SDOM,out}}} \quad (18)$$

For these calculations, the correction factors $k_{cf,i}$ given in Table 8 for the different characteristics shall be used. The converter losses of the CDM or SDM shall then be compared to the modified reference losses $p_{L,RCDM,m}$ for determination of IE Classes. Examples of the application of this concept can be found in Clause F.6.

The applied converter characteristic and corresponding correction factors $k_{cf,i}$ shall be stated in user documentation.

6.3.2 Correction factors

Correction factors to be applied in Formula (18) are given in Table 8 for topologies with different characteristic. The given correction factors are only used for determination of IE Classes of an individual CDM or SDM or during IES determination for the CDM as part of a PDS. Information on combining a SDIM and SDOM to a CDM and corresponding loss calculation is given in 5.2.3.