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Adjustable Speed Electrical Power Drive Systems

Part 1: General Requirements — Rating Specifications for Low Voltage Adjustable Speed d.c. Power Drive Systems

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Foreword

1) This document is an adaptation of the IEC Standard 61800-1 with the addition of requirements pertinent to use of these devices in the US.

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International Standard IEC 61800-1 was prepared by IEC technical sub-committee 22G: Semiconductor power converters for adjustable speed electric drive systems, of IEC technical committee 22: Power electronics.

Annexes A, B, C, D, E, F, and G are for information only.

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ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS
Part 1: General Requirements – Rating Specifications for Low Voltage Adjustable Speed D.C. Power Drive Systems

1 GENERAL

1.1 SCOPE AND OBJECT

This part of IEC 61800 applies to general purpose adjustable speed d.c. drive systems which include the power conversion, control equipment, and also a motor or motors. Excluded are traction and electrical vehicle drives.

It applies to systems connected to line voltages up to 1 kV a.c., 50 Hz or 60 Hz.

NOTE – In the United States, the line voltage is not more than 600 V a.c.

EMC aspects are covered in IEC 61800-3.

U.S. NOTE - EMC Immunity and Emission requirements of IEC 61800-3 are not applicable within the US.
This part of IEC 61800 gives the characteristics of the converters and their relationship with the complete d.c. drive system. It also states their performance requirements with respect to ratings, normal operating conditions, overload conditions, surge withstand capabilities, stability, protection, a.c. line earthing, and testing. Furthermore, it deals with application guidelines, such as control strategies, diagnostics, and topologies.

1.2 NORMATIVE REFERENCES

NEMA ICS 1-1993	*Industrial Control and Systems General Requirements*
NEMA ICS 1.3-1986 (R1991)	*Preventive Maintenance of Industrial Control and Systems Equipment*
NEMA ICS 7.1-1995	*Safety Standards for Construction and Guide for Selection, Installation, and Operation of Adjustable-Speed Drive Systems*
NEMA ICS 6-1993	*Industrial Control and Systems Enclosures*
NEMA MG 1-1999	*Motors and Generators*
NEMA 250-1997	*Enclosures for Electrical Equipment (1000 Volts Maximum)*
ANSI/IEEE 519-1992	*IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems*
ANSI/IEEE 597-1983	*Practice and Requirements for General Purpose Thyristor DC Drives*
ANSI/NFPA 70-1999	*National Electrical Code*
UL 508C	*Standard for Power Conversion Equipment*

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61800. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 61800 are encouraged to investigate the possibility of applying the most recent editions of the normative

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documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

NOTE – Where appropriate, reference in the text of this standard to the following IEC documents is superceded by the preceeding references to US documents.

IEC 60034-1-1994	*Rotating Electrical Machines - Part 1: Rating and Performance*
IEC 60034-2-1972	*Rotating Electrical Machines - Part 2: Methods for Determining Losses and Efficiency of Rotating Electrical Machinery from Tests (Excluding Machines for Traction Vehicles)*
IEC 60034-9-1990	*Rotating Electrical Machines - Part 9: Noise Limits*
IEC 60038-1983	*IEC Standard Voltages*
IEC 60050 (111)-1996	*International Electrotechnical Vocabulary - Chapter 111: Physics and Chemistry*
IEC 60050 (151)-1978	*International Electrotechnical Vocabulary - Chapter 151: Electrical and Magnetic Devices*
IEC 60050 (441)-1984	*International Electrotechnical Vocabulary - Chapter 441: Switchgear, Control Gear and Fuses*
IEC 60050 (551)	*International Electrotechnical Vocabulary - Chapter 551: Power Electronics* 1) Second edition, to be published.
IEC 60050 (601)-1985	*International Electrotechnical Vocabulary - Chapter 601: Generation, Transmission and Distribution of Electricity - General*
IEC 60076	*Power Transformers*
IEC 60146-1-1991	*Semiconductor Convertors. Common Specifications and Line Commutated Convertors - Part 1-1: Specification of Basic Requirements*
IEC 60146-1-2-1991	*Semiconductor Convertors. Common Specifications and Line Commutated Convertors - Part 1-2: Application Guide*
IEC 60146-1-3-1991	Semiconductor Convertors. Common Specifications and Line Commutated Convertors - Part 1-3: Transformers and Reactors
IEC 60204-1-1992	*Electrical Equipment of Industrial Machines - Part 1: General Requirements*
IEC 60529-1989	*Degrees of Protection Provided by Enclosures (IP Code)*
IEC 60664-1-1992	*Insulation Coordination for Equipment within Low-Voltage Systems - Part 1: Principles, Requirements and Tests*
IEC 60721-3-1-1987	*Classification of Environmental Conditions - Part 3: Classification of Groups of Environmental Parameters and their Severities - Storage*
IEC 60721-3-2-1997	*Classification of Environmental Conditions - Part 3: Classification of Groups of Environmental Parameters and their Severities - Transportation*

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IEC 60721-3-3-1994 *Classification of Environmental Conditions - Part 3: Classification of Groups of Environmental Parameters and Their Severities - Stationary Use at Weather Protected Locations*

IEC 61000-2-4-1994 *Electromagnetic Compatibility (EMC) - Part 2: Environment - Section 4: Compatibility Levels in Industrial Plants for Low Frequency Conducted Disturbances*

IEC 61000-4-7-1991 *Electromagnetic Compatibility (EMC) - Part 4: Testing and Measurement Techniques - Section 7: General Guide on Harmonics and Interharmonics Measurements and Instrumentation, for Power Supply Systems and Equipment Connected Thereto*

IEC 61800-3-1996 *Adjustable Speed Electrical Power Drive Systems - Part 3: EMC Product Standard Including Specific Test Method*

IEC 61800-5-1 *Adjustable Speed Electrical Power Drive Systems - Part 5: Safety Requirements - Section 1: Electrical and Thermal*

IEC 61800-5-2 *Adjustable Speed Electrical Power Drive Systems – Part 5: Safety Requirements - Section 2: Functional*

IEC 61800-6 *Adjustable Speed Electrical Power Drive Systems - Part 6: Guide for Determination of Types of Load Duty and Corresponding Current*

IEC Guide 106-1989 *Guide for Specifying Environmental Conditions for Equipment Performance Rating*

1.3 SYMBOLS

Table 1-1 lists symbols defined and/or used in this part of IEC 61800.

Table 1-2 lists symbols and units for motor parameters.

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Table 1-1
SYMBOLS

Parameter	Symbol	Unit	Definition
Rated system voltage	U_{LN}	V	2.4.1
Rated system frequency	f_{LN}	Hz	2.4.2
Line-side converter rated a.c. voltage	U_{VN}	V	2.4.3
Line-side rated a.c. current of the CDM/BDM	I_{LN}	A	2.4.4
Rated input current of the converter	I_{VN}	A	2.4.5
Line-side harmonic content	H_L	V or A	2.4.6
Line-side total harmonic distortion	THD	%	2.4.8
Converter input displacement factor	$\cos \varphi_{V1}$		2.4.9
Line-side displacement factor	$\cos \varphi_{L1}$		2.4.10
Input total power factor	λ_L		2.4.11
Maximum a.c. system, symmetrical short-circuit current	I_{SCM}	A	2.4.12
Short-circuit ratio	R_{SC}		2.4.12
DC current	I_d	A	2.5.1
Rated continuous output current	I_{dN}	A	2.5.2
Overload output current (overload capability)	I_{dM}	A	2.5.3
Rated output voltage	U_{dN}	V	2.5.5
Voltage ripple content	U_{pp}	V	2.5.6
Current ripple content	I_{pp}	A	2.5.6
Efficiency of drive system	η_D	%	2.5.8
Efficiency of CDM	η_C	%	2.5.8
Base speed	N_0	r/min	2.7.3
Maximum operating speed	N_M	r/min	
Minimum operating speed	N_{min}	r/min	
Maximum safe motor speed	N_{smax}	r/min	2.7.4
Torque	M	ft-lbs	
Inertia	J	lb-ft^2	

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Table 1-2
SYMBOLS FOR MOTOR PARAMETERS

Rated output power	P_N	Hp
Rated armature voltage	U_{AN}	V
Rated armature current	I_{AN}	A
Peak load current value	I_p	A
Allowable rate of change of the armature current	dI_A/dt	As^1
Allowable ripple of the armature current	I_{ppM}	A
Armature inductance	L_A	H
Armature resistance	R_A	Ω
Rated hot field voltage	U_{FN}	V
Rated field current	I_{FN}	A
Field current for maximum speed	I_{FNm}	A
Field inductance	L_F	H
Field resistance	R_F	Ω
Base speed	N_0	r/min (note 1)
Maximum speed	N_M	r/min
Maximum safe motor speed	N_{smax}	r/min
Torque (note 2)	M	ft-lbs
Inertia	J	$lb\text{-}ft^2$

NOTE –1 Practically, speed is expressed in RPM as well.
NOTE –2 Torque/speed characteristics. (See Annex A.5.1.).

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2 DEFINITIONS

bandwidth (in a feedback system): The interval separating two frequencies between which both the gain and the phase difference (of sinusoidal output referred to sinusoidal input) remain within specified limits.

closed loop (feedback loop): A signal path which includes a forward path, a feedback path and a summing point and which forms a closed circuit.

control circuit: A circuit containing those parts of a power converter which perform logic functions or which furnish control signals to the power circuit.

Examples of functions encompassed by the control circuit are gating, sequencing, regulation, protection, control interface, and local control. (See Figure 1-2.)

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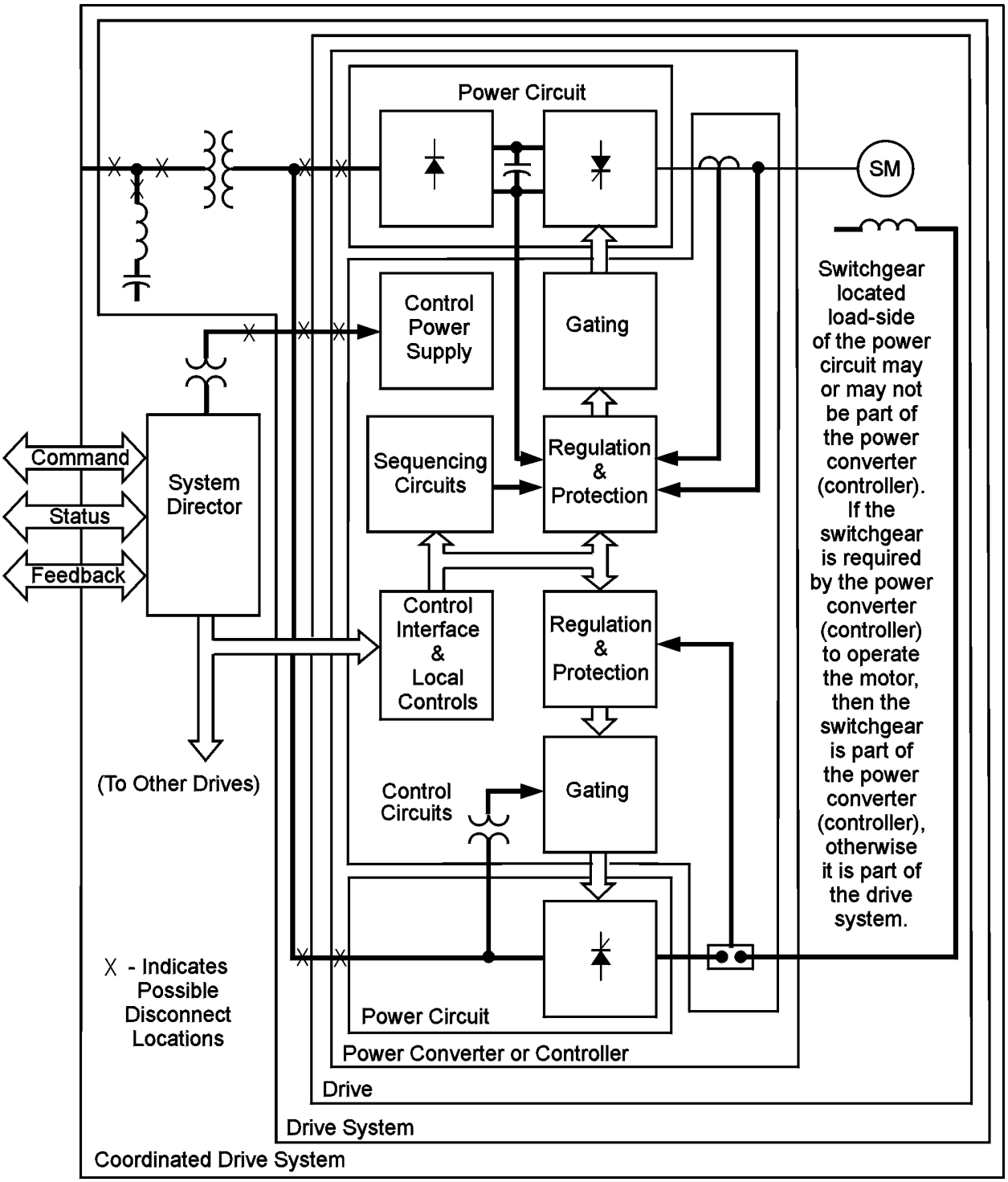


Figure 1-2
BLOCK DIAGRAM OF A TYPICAL COORDINATED DRIVE SYSTEM

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controller: See power converter.

feedback control system: A control system which operates to achieve prescribed relationships between selected system variables by comparing the functions of those variables and using the difference to effect control.

operating deviation band: The total excursion (See Figure 1-8-1.) of the directly controlled variable (unless another variable is specified) as a result of specified operating variables under steady-state conditions and within a specified range of these operating variables.

Operating deviation band is expressed:

a. As a percentage of the maximum rated value of the directly controlled (or other specified) variable

b. For systems which have no readily definable base, such as position or temperature control systems, as absolute numbers

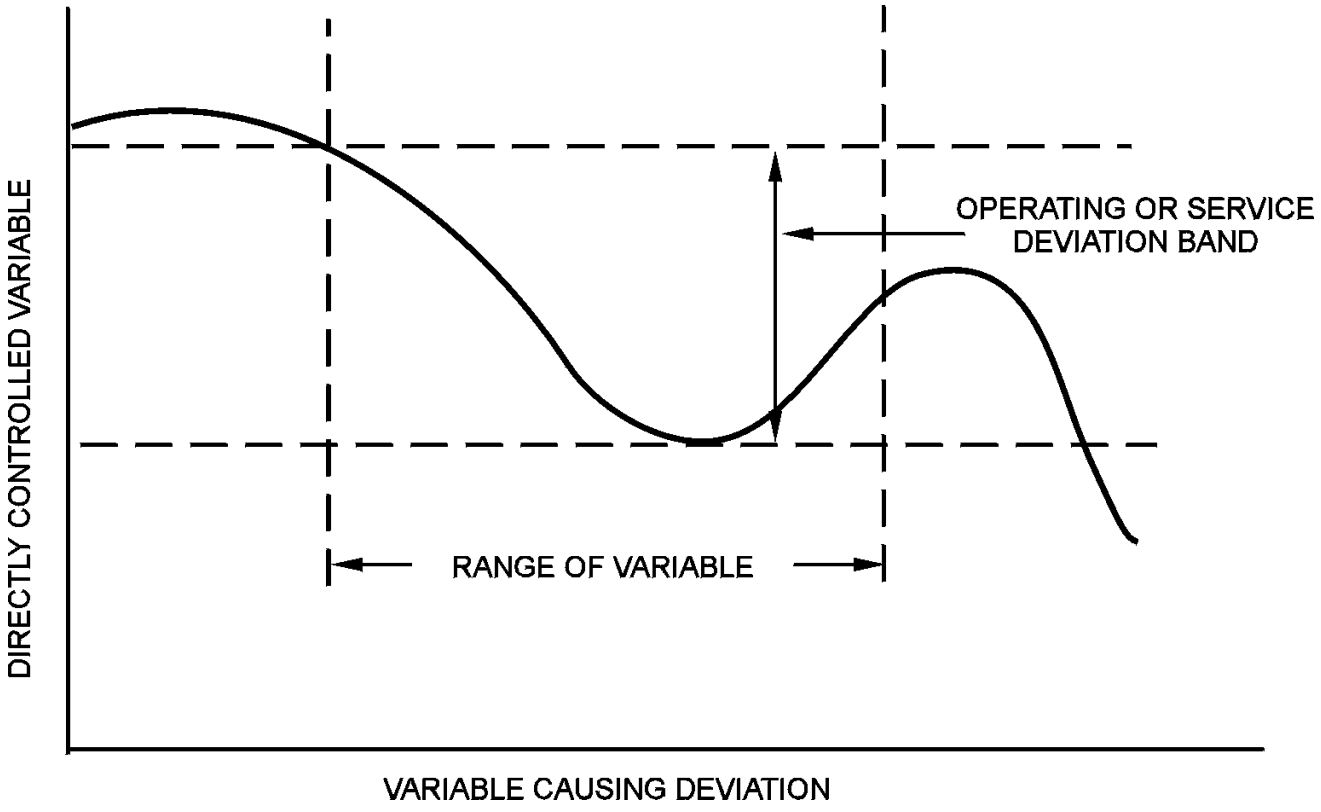


Figure 1-3
OPERATING AND SERVICE DEVIATION BAND

power circuit: Those parts of a power converter employing semiconductors for the transformation of electric power to be supplied to a motor (See Figure 1-2).

power converter: A combination of the power circuit and control circuit included on one chassis.

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The power converter may include a disconnecting means. (See Figure 1-2.)

When used in the context of drive systems, the term “controller” is representative of the same function as denoted by the term “power converter” as used in ICS 7. The term “power converter is the preferred usage in ICS 7.

rectifier: A converter that changes AC power to DC power.

service deviation band: The total excursion (see Figure 1-3 [*needed*]) of the directly controlled variable (unless another variable is specified) as a result of drift and changes in service conditions within specified limits.

A service deviation band is expressed:

a. As a percentage of the maximum rated value of the directly controlled (or other specified) variable

b. For systems which have no readily definable base, such as position or temperature control systems, as absolute numbers

For the purpose of this part of IEC 61800, the following definitions, as well as those given in IEC 60050 (111), IEC 60050 (151), IEC 60050 (441), IEC 60050 (551), IEC 60050 (601), IEC 60146-1-1, IEC 60146-1-2, IEC 60146-1-3, IEC 60147-0, IEC 61136-1 apply.

2.1 SYSTEM

2.1.1 d.c. Power Drive System (PDS) (See Figure 2-1.)

System consisting of power equipment (composed of converter section, d.c. motor and other equipment such as, but not limited to, the feeding section or the field supply), and control equipment (composed of switching control -on/off for example - speed control, current control, firing system, field control, protection, status monitoring, communication, tests, diagnostics, process interface/port, etc.).

NOTE – Figure 2-1 illustrates the main functional elements of a d.c. drive system. It also includes equipment which may be optional on many drive systems. It is intended to encompass a wide variety of d.c. drive configuration possibilities. The converter section does not illustrate or imply a specific topology, or type of switching device, due to the wide variety of both in current use. See annex F.

2.1.2 d.c. Power Drive System - Hardware Configuration

PDS which consists of a complete drive module (CDM) and a motor or motors with sensors which are mechanically coupled to the motor shaft (the driven equipment is not included). See Figure 2-2 for hardware partition of the power drive system.

NOTE – Figure 2-2 illustrates the parts of equipment which can be grouped and supplied as defined and shown.

2.1.2.1 Basic Drive Module (BDM)

Drive module which consists of, a converter section, a control equipment for speed, torque, current or voltage, and a power semiconductor gating system, etc.

2.1.2.2 Complete Drive Module (CDM)

Drive system, without the motor and the sensors which are mechanically coupled to the motor shaft, consisting of, but not limited to, the BDM, and extensions such as feeding section, field supply, and auxiliaries.

2.1.2.3 Installation

Equipment or equipments which include at least both the PDS and the driven equipment.

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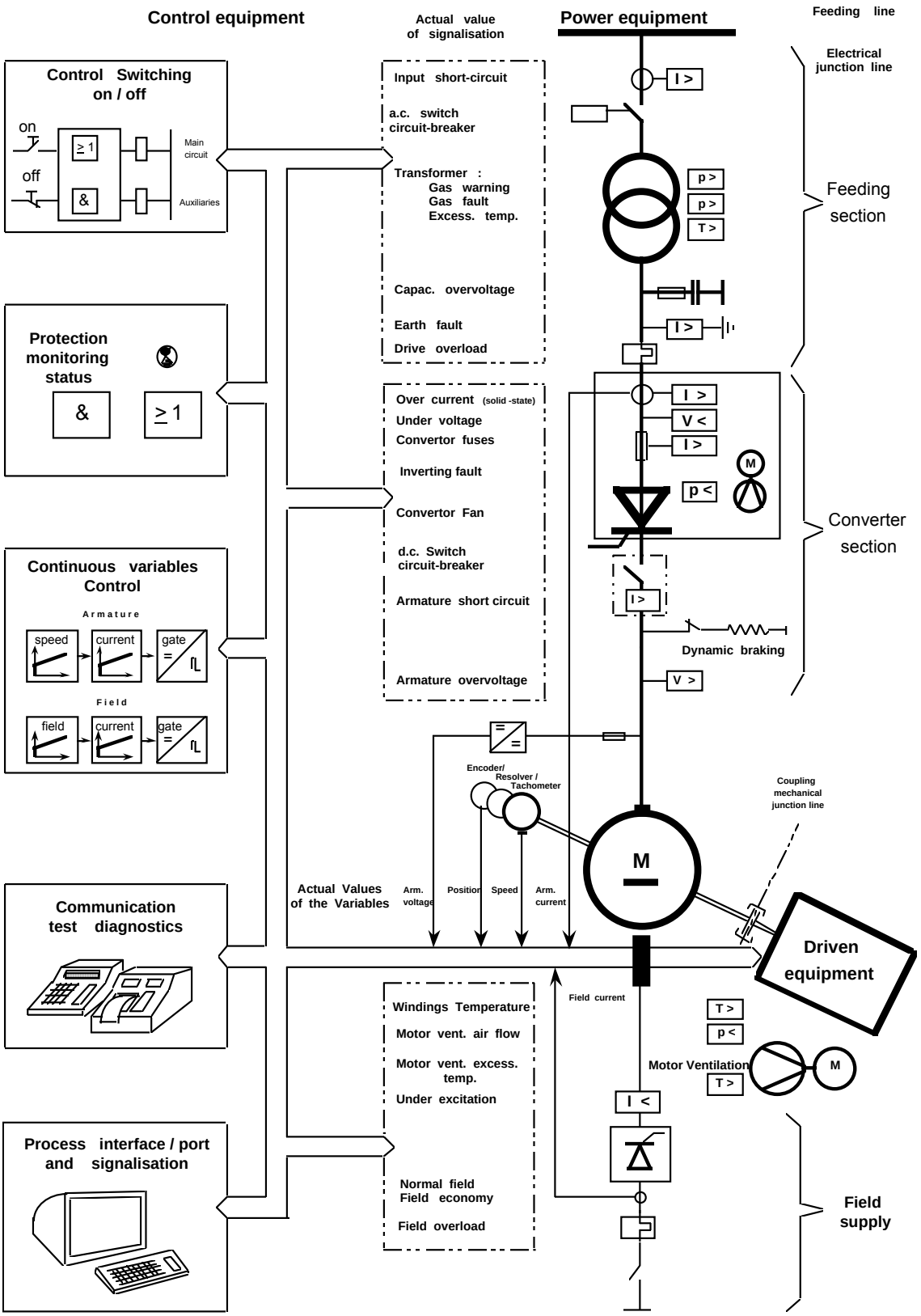


Figure 2-1
FUNCTION DIAGRAM OF A d.c. - DRIVE SYSTEM

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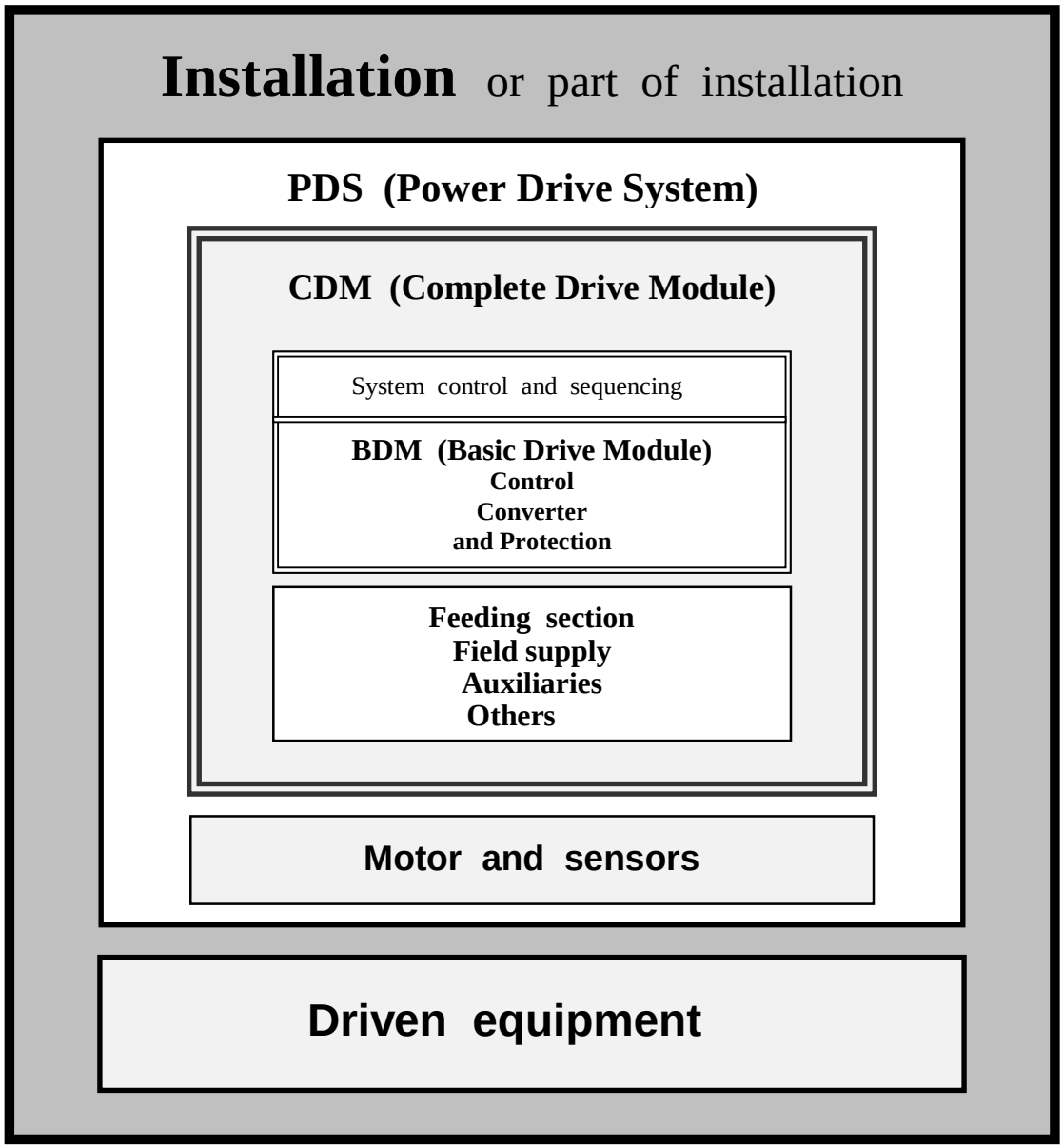


Figure 2-2
PDS HARDWARE CONFIGURATION WITHIN AN INSTALLATION

2.2 CONVERTERS

2.2.1 Converter, General Purpose

Operating unit for electronic power conversion, changing one or more electrical characteristics and comprising one or more electronic switching devices and associated components, such as transformers, filters, commutation aids, controls, protections and auxiliaries, if any.

2.2.2 Rectifying - Rectification

Converter action converting from a.c. to d.c. The rectifier can be uncontrolled or controlled [IEV 551-01-06 modified].

NOTE – For the purpose of this part of IEC 61800, the line-side converter normally operates as a rectifier.

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2.2.3 Inverting - Inversion
Converter action converting from d.c. to a.c. [IEV 551-01-07 modified].

NOTE – For the purpose of this part of IEC 61800, the line-side converter sometimes operates as an inverter.

2.2.4 Converter, d.c. Linked
Converter comprising a rectifier and a chopper with an intermediate d.c. link.

2.2.5 Converter, Line-side Commutated
Converter in which the commutation voltages are supplied by the a.c. input.

2.2.6 Chopper
Converter operating a d.c. conversion (d.c. to d.c.) by means of electronic devices using forced commutation. Its output delivers adjustable d.c. voltage [IEV 551-02-28 modified].

NOTE – In this part of IEC 61800, forced commutation refers to deliberate extinction of semiconductor device before commutation can take place at zero current (natural commutation).

2.2.7 Converter, Voltage Source
Converter which provides an adjustable output voltage supply, essentially unaffected by the value of the load.

NOTE – The term “voltage stiff a.c/d.c. converter” having a similar physical background is used in the second edition of IEV 50(551).

2.3 DRIVE SYSTEM OPERATING CHARACTERISTICS

2.3.1 Two Quadrant Operation
Converter operation of a machine as a motor in one direction of machine rotation and as a generator in the opposite direction of rotation. It involves operation in quadrant I and II of the torque / speed diagram (see figure 2-3).

2.3.2 Four Quadrant Operation
Converter operation of a machine as either a motor or a generator in either direction of machine rotation involves operation in quadrants I, II, III & IV of the torque / speed diagram as shown in figure 3.

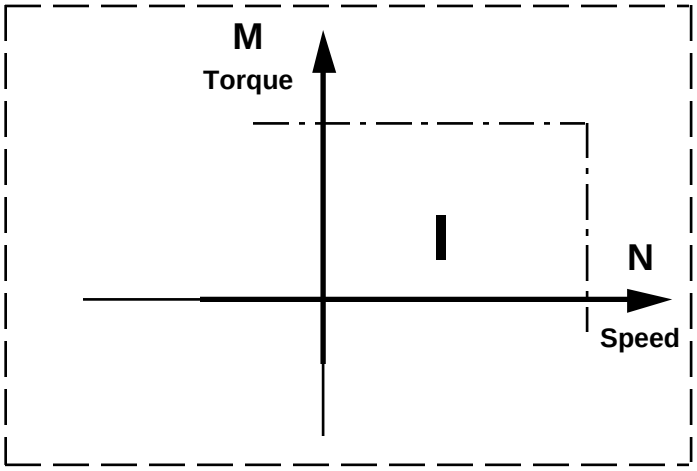
2.3.3 Dynamic Braking
Process of converting the rotational energy of the armature and connected inertial load to electrical energy dissipated in a resistance.

2.3.4 Regeneration
Process of converting the mechanical energy of the system to electrical energy and transferring it to the input supply. The motor is then working as a generator and the ratings of the motor may be different.

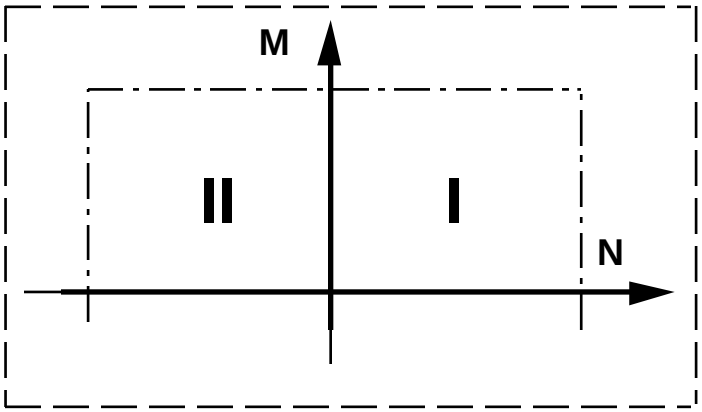
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One quadrant



Two quadrants



Four quadrants

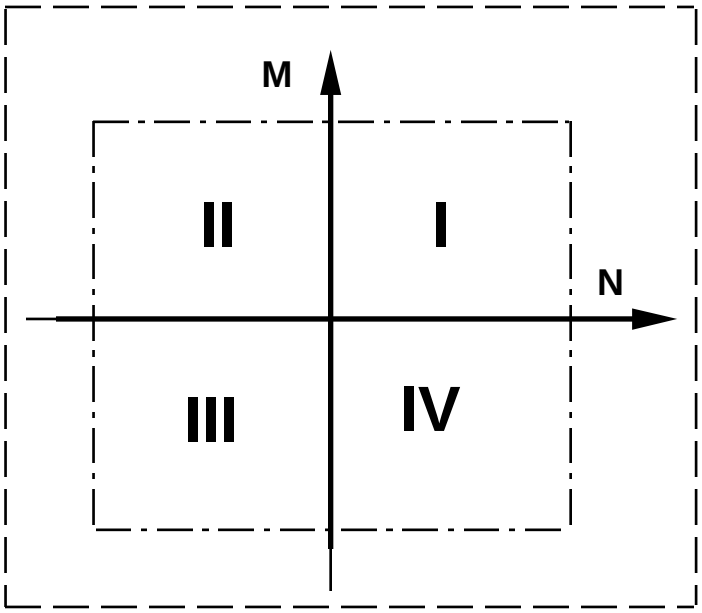


Figure 2-3
OPERATING QUADRANTS

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2.4 CDM, BDM AND CONVERTER INPUT PARAMETERS

Symbols defined in 2.4 are included in Table 1-1.

2.4.1 Rated System Voltage U_{LN}

RMS input line-to-line voltage at the supply terminals of the customers installation to which the PDS will be connected.

2.4.2 Rated System Frequency f_{LN}

Frequency in Hertz of the power input system alternating voltage.

2.4.3 Line-side Rated a.c. Voltage U_{VN}

Rated r.m.s. line-to-line input voltage at the a.c. terminals of the line-side converter, which has been designated as the basis for the converter rating.

NOTE – This voltage may differ from the rated system voltage U_{LN} due to the use of transformers and the effect of impedance. Some drives may have an input transformer with primary voltage higher than 1 000 V. In this case, the transformer and protective devices have to meet this standard and other relevant IEC standards. Capacitively coupled high voltage from primary to secondary winding must be bypassed to earth. (See Annex B.)

2.4.4 Line-side Rated a.c. Current I_{LN}

Maximum r.m.s. value of current on the line-side of the CDM/BDM under rated conditions. It takes into account rated load and the most onerous combination of all other conditions within their specified ranges, for example line voltage and frequency deviations.

NOTE – This current includes currents supplied to the auxiliary circuits of the CDM/BDM. It takes into account the effect of d.c. current ripple and circulating current, if any.

2.4.5 Rated Input Current I_{VN}

Maximum r.m.s. value of current on the valve side of the converter under rated conditions. It takes into account rated load and the most onerous combination of all other conditions within their specified ranges, for example line voltage and frequency deviation.

2.4.6 Line-side Harmonic Content

Quantity obtained by subtracting from an alternating quantity its fundamental component [IEV 551-07-04, applied to the line-side of the system].

NOTE – For example, for voltage (from a practical approach and with interharmonics neglected), the r.m.s. value of The harmonic content is: $$U_{Hn} = \left(\sum_{h=2}^{h=n} U_h^2\right)^{0,5}$$

2.4.7 Characteristic Current Harmonics

Orders of the current harmonics produced by converter equipment in the course of normal operation. For example, in a 6-pulse converter the characteristic current harmonics are the non triple, odd harmonics: h = 6 k ± 1 (k any integer).

NOTE – In addition to power system frequency harmonics, there can be other harmonics resulting from interaction with the converter load. They are called interharmonics.

2.4.8 Harmonic Distortion

According to common practice, harmonic distortion coefficient is relative to the fundamental component of the quantity which is considered. The harmonic factor is relative to the r.m.s. value of the quantity which is considered [see IEV 551-17-05 and IEC 551-17-06].

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THD and THF are defined by:

$$\mathrm{THD} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1} \qquad \text{and} \qquad \mathrm{THF} = \frac{\sqrt{Q^2 - Q_1^2}}{Q}$$

where

Q_1 is the r.m.s. value of the fundamental;

Q is the total r.m.s. value;

h is the harmonic order;

Q_h is the r.m.s. value of harmonic component of order h;

Q can represent either current or voltage.

For the purpose of this standard and for clarity, limits are referred to the corresponding rated value.

Limits for THD and THF are defined by:

$$\mathrm{THD} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_{1N}} \qquad \text{and} \qquad \mathrm{THF} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_N}$$

NOTE 1 – These definitions are in accordance with the second edition of IEV 551and with common practice. Therefore, application of both definitions, total harmonic distortion coefficient THD or total harmonic factor THF, to the voltage provides the same result while the difference is significant when current is considered.

NOTE 2 – It is important to note that these definitions include interharmonics. When interharmonics are present the wave form is no longer periodical, which can produce more complex effects than those produced by harmonics. If interharmonics are negligible, these equations simplify to:

$$\mathrm{THD} = \frac{\sqrt{\sum_{h=2}^{h=40} Q_h^2}}{Q_{1N}} \qquad \text{and} \qquad \mathrm{THF} = \frac{\sqrt{\sum_{h=2}^{h=40} Q_h^2}}{Q_N}$$

where

Q_{1N} is the rated r.m.s. value of the fundamental;

Q_N is the rated total r.m.s. value.

The summation is extended to and includes order 40, according to IEC common practice.

NOTE 3 – For particular use, the highest frequency content of THD (order h from 14 to 40 inclusive) is named partial harmonic distortion coefficient PHD, and the even content (where order h is only even) is named even harmonic distortion coefficient EHD. Applied to current this gives:

$$\mathrm{PHD} = \frac{\sqrt{\sum_{h=14}^{h=40} I_h^2}}{I_{1N}} \qquad \text{and} \qquad \mathrm{EHD} = \frac{\sqrt{\sum_{h=2,\mathrm{even}}^{h=40} I_h^2}}{I_{1N}}$$

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2.4.9 Converter Input Displacement Factor cos φ_{V1}

Cosine of the phase displacement angle between the fundamental phase components of the voltage and current on the input a.c. side of the input power converter.

2.4.10 Line-Side Displacement Factor cosφ_{L1}

Cosine of the phase displacement angle between the fundamental phase components of the voltage and current on the input a.c. side of the CDM.

2.4.11 Input Total Power Factor, λ_L

Ratio of the total power input, to the apparent power, as determined at the connection of the CDM to the supply.

Example: in a three-phase system where the voltage is considered sinusoidal.

$$\lambda_L = (U_L I_{L1} \sqrt{3} \cos \varphi_{L1}) / (U_L I_L \sqrt{3})$$

$$= (I_{L1} / I_L) \times \cos \varphi_{L1}$$

NOTE 1 – The power factor includes the effect of displacement cosφ_1 and of harmonics by means of the deformation factor $\nu = \lambda / \cos\varphi$.

NOTE 2 – The definition applies to the converter input (subscript V) or to the CDM input line-side (subscript L).

2.4.12 Maximum a.c. System, Symmetrical Short-Circuit Current I_{SCM}

Maximum allowable symmetrical short-circuit current (I_{SCM}), as specified on the rating plate can be related to the fundamental component of the line-side rated a.c. current (I_{LN1}) by means of the short-circuit ratio (R_{SC}).

R_{sc} is the ratio of the short-circuit power of the source to the fundamental apparent power on the line-side of the converter(s). (See IEC 60146-1-1.)

$$R_{SC} = S_{SC} / S_{LN1} = I_{SC} / I_{LN1}$$

The maximum allowable symmetrical short-circuit current (I_{SCM}) is of importance in the definition of the protection of the converter. At the point of common coupling (PCC), the relative short-circuit power shall be considered. (See 1.5.35 of IEC 60146-1-1.) This R_{SC} has to be limited to the following R_{SCM}:

$$R_{SCM} = I_{SCM} / I_{LN1}$$

where I_{LN1} is equal to the fundamental content of I_{LN}.

2.5 CDM, BDM AND CONVERTER OUTPUT PARAMETERS

Symbols defined in 2.5 are included in Table 1-1.

2.5.1 d.c. Current I_d

Average value of the current in the d.c. link over one full period of the input power system frequency.

NOTE – DC current I_d can also indicate the current of the intermediate d.c. link in the case of an indirect converter using a chopper. Generally I_A is used to indicate the output current which is also the motor current.

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2.5.2 Rated Continuous Output Current I_{dN}

Output current which can be supplied continuously without exceeding established limits, under prescribed operating conditions.

NOTE – IEC 61800-6 gives different classes of rated current for complex cases of load duty.

2.5.3 Overload Capability I_{dM}

Maximum output current which can be supplied for a specified period of time, without exceeding established limits under prescribed operating conditions.

2.5.4 Continuous Output Rating P_{dN}

Active power which a converter is capable of supplying to a load continuously without exceeding established limits.

2.5.5 Rated Output Voltage U_{dN}

Specified value at rated d.c. current of the direct voltage between d.c. terminals of the CDM/BDM. This value is the available mean value of the d.c. voltage under usual service conditions, as specified in clause 4.

2.5.6 Ripple U_{pp} , I_{pp}

Periodic a.c. voltage/current superimposed on steady direct voltage/current, usually expressed as peak-to-peak value. If the ripple content of the current is given as peak-to-peak value in amperes measured or calculated at rated voltage of the motor, then the symbol is I_{ppN}.

NOTE – Current ripple is also given as a ratio $r = I_{pp} / I_d$, where I_d is the mean value of output current (see B.4.3.2), but $r/2$ is often used in the definition of the motor parameters. It is important to clarify which ratio is used.

2.5.7 Load-side Harmonic Content

Function obtained by subtracting the d.c. component from the non-sinusoidal periodic function on the output side of the converter. For example, the r.m.s. value of the current harmonic content is

$$\mathbf{I_{dHn} = \left(\sum_{h=2}^{h=n} I_h^2\right)^{0,5}}$$

in practice n is limited to 40.

2.5.8 Efficiency Of Power Conversion η_D , η_C

Efficiency η_D of the drive system is the ratio of the power delivered by the motor shaft to the total power drawn from the input power supply (feeding line in Figure 1-1), and is usually expressed as a percentage. Efficiency of the CDM (complete drive module) η_C is the ratio of the total output power delivered by the CDM to armature, field, and auxiliaries (motor ventilation fan, etc.) to the total power drawn from the input power supply (See feeding line in Figure 1-1.), and is usually expressed as percentage.

2.5.9 Maximum Field Supply Current I_{FM}

Maximum continuous mean current of the motor field load that the field converter can supply.

NOTE – If an uncontrolled field converter is used, the converter has to be sized for the maximum field current, with a cold motor.

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2.5.10 Rated Field Supply Voltage U_{FN}
Rated mean voltage of the motor field load to be connected to the field converter.

2.6 CONVERTER CIRCUITRY AND CIRCUIT ELEMENTS

2.6.1 Commutating Capacitor
Capacitor which provides commutating energy for self-commutated thyristors in a self-commutated chopper.

2.6.2 Commutating Inductor
Inductor having one or more windings which modifies or couples the transient current produced during commutation.

2.6.3 a.c. Filter Network
Network designed to reduce the flow of harmonic currents into the associated power system.

2.6.4 Power Factor Correction Network
Network designed to improve the power factor of the associated power system. This network will frequently also reduce the flow of harmonic currents.

2.6.5 d.c. Filter Capacitor
Capacitor connected across the rectifier output within a converter to reduce voltage ripple.

2.7 MOTORS

2.7.1 d.c. Motors Types
DC motors are typically equipped with separate field. (See Figure 1-1.) This type of motor can be compensated or not. The purpose of compensation is to minimize the armature reaction and increase the motor commutating ability.

Note – Other types of motors are: permanent magnet motor, series field, combinations (shunt and series)

2.7.2 Rated Hot Field Voltage
Rated field voltage at operational temperature.

2.7.3 Base Speed N_0
Speed obtained with rated armature voltage, with rated armature current and rated field current, usually the breakpoint speed between constant torque and constant power operation.

2.7.4 Maximum Safe Motor Speed
Maximum designed speed of the motor under which no permanent abnormal mechanical deformation or weakness is introduced. (See Clause 21 of IEC 60034-1.)

NOTE – The maximum safe speed of the driven equipment may be more restrictive.

2.7.5 Torque Pulsation
Cyclic fluctuation of a steady-state motor torque measured as a peak-to-peak variation.

2.8 CONTROL SYSTEMS

2.8.1 Controlled Variable
System variable in the feedback control of adjustable d.c. drives. Some examples of controlled variables are speed, armature voltage, armature and field current.

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2.8.2 Service Variable

Specified variable, usually related to ambient conditions (e.g., temperature), for which the feedback control system is to correct in attempting to maintain the ideal value of the controlled variable.

2.8.3 Operating Variable

Specified variable (e.g., load torque for a speed controlled drive) other than those arising from service conditions and drift for which the feedback control system is to correct in attempting to maintain the ideal value of the controlled variable.

2.8.4 Feedback Control System Variables

Range of service and operating variables covering the total deviations for which the feedback system attempts to correct by means of the controlled variables. The accuracy of this control is then defined as the width of the band of allowable deviation within which the feedback system will regulate the controlled variable.

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3 FUNCTIONAL FEATURES

3.1 OPERATIONAL

The manufacturer shall specify those features included with the CDM. These may include, but are not limited to, one or more of the following features:
- timed acceleration;
- timed deceleration;
- jog;
- adjustable current limit(s);
- dynamic braking;
- reversing;
- regeneration;
- line filtering;
- input/output data processing (analog/digital);
- automatic restart.

3.2 FAULT SUPERVISION

The CDM shall provide specified fault indication. This may consist of a common alarm and/or trip signal provided via dry relay contact(s) or static relay(s). The fault indication is normally activated by one or more of the CDM faults which may include but are not limited to the following:
- external faults;
- fuse(s) blown;
- instantaneous overcurrent;
- overtemperature (converter);
- loss of cooling air;
- motor overload;
- auxiliary power supply fault;
- supply over/undervoltage;
- supply phase loss;
- motor overvoltage;
- overspeed and/or tachometer loss protection;
- field loss protection;
- internal control system fault;
- regulator/power circuit diagnostics.

3.3 MINIMUM STATUS INDICATION REQUIRED

The CDM shall be equipped with status indication signals for "drive on" (whether rotating or at standstill). The CDM may also be equipped with status indication signals for "drive ready for operation."

3.4 I/O DEVICES

Number and nature of I/O shall be stated by the manufacturer. Any modification shall be agreed upon between the manufacturer and user.

NOTE – Inputs and outputs are needed for both variables and parameters. They are provided through analog or digital inputs/outputs using voltage or current. They are communicated through serial or parallel links according to various communication standards. Both analog and digital variables can be manually set by use of a control panel and can be read on displays. Variables and parameters are treated in the same manner.

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4 SERVICE CONDITIONS

4.1 INSTALLATION AND OPERATION

Unless modified, the equipment which is within the scope of this part of IEC 61800 shall be capable of operation under the conditions listed in 2.2 and 2.3 of IEC 60146-1-1, and IEC Guide 106.

4.1.1 Electrical Service Conditions

Unless otherwise specified, the CDM or BDM shall be designed to operate under the service conditions specified below. The values specified include the effect of the drive system being considered.

EMC requirements for power drive systems are stated in IEC 61800-3.

U.S. NOTE – EMC Immunity and Emission requirements of IEC61800-3 are not applicable within the U.S.

NOTE – The limits specified in 4.1.1.1 to 4.1.1.5 link the EMC standards to existing practice given in semiconductor converters given in 2.5.1, 2.5.2 and 2.5.3 of IEC 60146-1-1, and correspond generally to class B.

4.1.1.1 Frequency Variations

Frequency f_{LN} ± 2 % (± 4 % for separated supply network) according to class 3 defined in IEC 61000-2-4.

Rate of change of frequency $\leq$ 2 % f_{LN}/s

(See also 5.2.3.2 of IEC 61800-3.)

4.1.1.2 Voltage Changes

Voltage limits for uninterrupted operation

PDS rated input voltage ± 10 % (at the point of coupling PC), according to class 2 defined in IEC 61000-2-4. (See also 5.2.2.1 and 5.2.2.2 of IEC 61800-3.)

NOTE – Short time voltage variation beyond the levels specified may result in interruption of operation or tripping. If continuous operation is necessary, an agreement is required between the user and the supplier/manufacturer.

Voltage limits for rated performance

Rated converter performance shall be maintained when the steady-state fundamental component of the line a.c. supply voltage is equal to or greater than 100 % and equal to or less than 110 % of the rated value measured at the terminals of the BDM. Rated operation at voltages below 100 % of rated voltage shall be subject to agreement between the user and the supplier/manufacturer.

NOTE – Also refer to 5.2.1.

4.1.1.3 Voltage Unbalance

PDS shall operate with a line voltage unbalance (at the point of coupling PC) up to, but not exceeding 3 % of the fundamental rated input voltage (U_{LN1}). See 5.2.3.1 and Annex B.3 of IEC 61800-3, for definition and calculation.

U.S. NOTE – The accepted definition of voltage unbalance is $((V_{avg} - V_{dev})/V_{avg}) \times 100\%$. V_{avg} is the average of the three RMS phase voltages. V_{dev} is the deviation of the RMS of the phase with the maximum magnitude of deviation from V_{avg}. The manufacturer shall specify the maximum short circuit current at the converter input that can be permitted to be present in combination with the maximum allowable voltage unbalance.

4.1.1.4 Source Impedance

The minimum (R_{SC}) ratio for the PDS to meet rated performance shall be 20 determined at the point of coupling (PC).

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NOTE 1 – A larger source impedance may cause snubbers to have a poor damping ratio resulting in possible failure condition and excessive notch size.

NOTE 2 – See the manufacturer's documentation to determine the maximum design (R_{SC}) ratio.

4.1.1.5 Harmonics and Commutation Notches

Harmonics: Unless otherwise agreed to, the equipment within the scope of this part of IEC 61800 shall be designed to operate with a voltage total harmonic distortion (THD) of 10 % under steady-state conditions (at the point of coupling, PC), and of 15 % during transient periods less than 15 s, according to class 3 defined in IEC 61000-2-4. (See also 5.2.1 of IEC 61800-3.)

NOTE – Compatibility levels for individual harmonic voltages are given in tables 3,4 and 5 of IEC 61000-2-4.

A theoretical example of harmonic distortion illustrates, in Annex B.5, a practical assessment of the relationship between emission and immunity, to take into account the effect of the drive itself as stated in 4.1.

Commutation notches: The equipment shall meet the rated performance with the following notching limits at the line-side terminals of the CDM/BDM. (See 2.5.4.10 of IEC 60146-1-1, immunity class B.)
- Commutation notch depth 40 % of U_{LWM}
- Commutation notch area 250 % x degrees

4.1.1.6 Repetitive and Non-Repetitive Transients

A typical a.c. voltage waveform containing repetitive and non-repetitive transients is shown in Figure 2-1.

The transients are caused by converter commutation, switching on the network and disturbances on the power system.

The BDM shall be designed to operate in an environment with non-repetitive transients caused by transformer switching provided that the supply transformer is sized for no more than five times the apparent power of the drive under consideration. Where transformers are sized for greater capacity, additional transient energy absorption capacity shall be provided external to the BDM.

The energy E (in joules) of the non-repetitive transient caused by switching of the transformer is directly related to the magnetization energy of the transformer feeding the BDM. The energy can be calculated by the equation:

$$E = 400 \times S_N$$

where S_N is expressed in MVA and is equal to:

$$S_N = \sqrt{3} \times U_{LN} \times I_{LN} \times 10^{-6}$$

where
U_{LN} is the rated system voltage;
I_{LN} is the line-side rated a.c. current

The following assumptions are made:
- the magnetization current is 5 %;
- switching occurs at the point of maximum energy release.

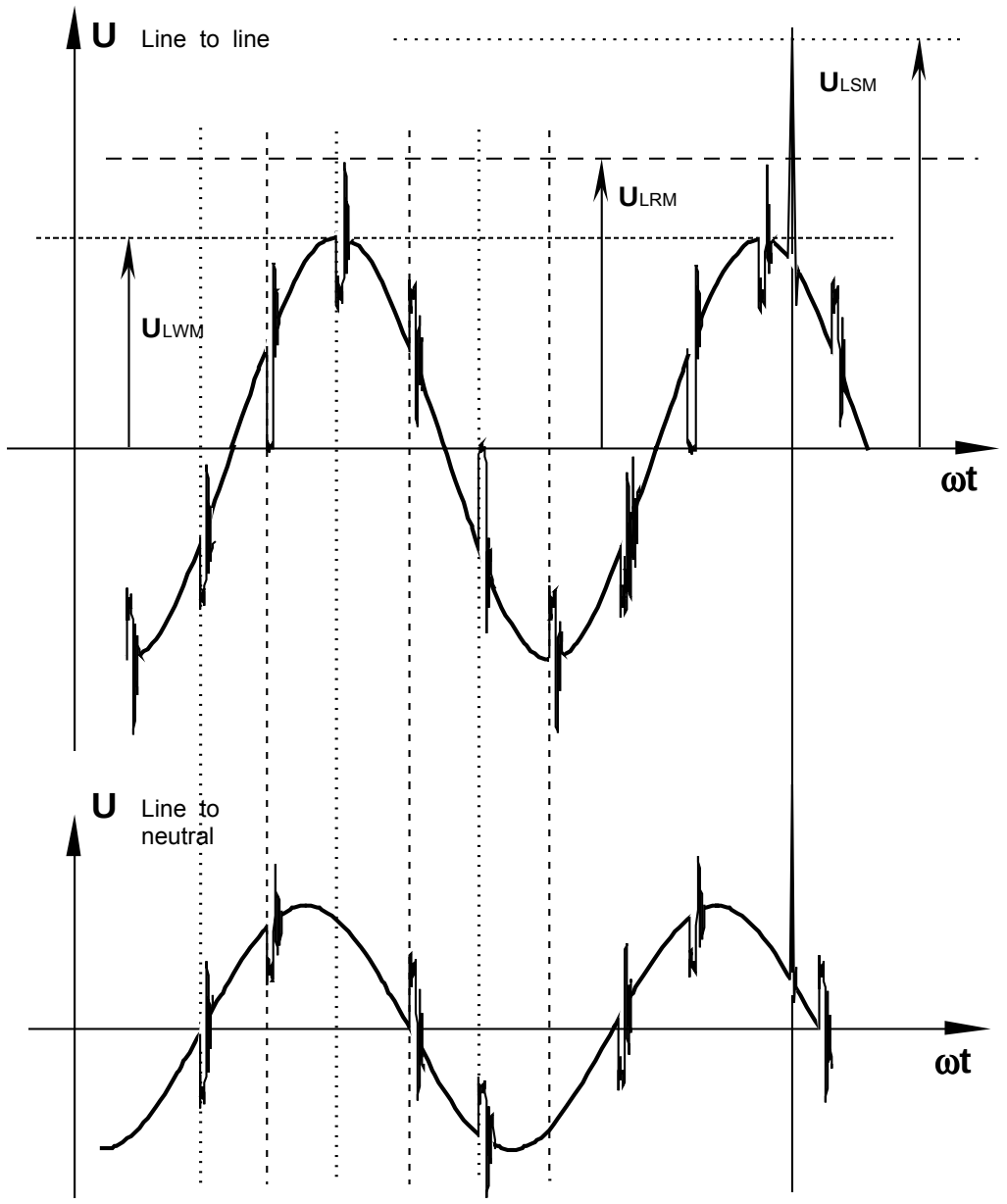
NOTE – If the transformer characteristics are known, a specific calculation can be made.

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4.1.1.7 Unusual Conditions

Particular conditions such as unusual operating duty, unbalanced a.c. system impedance, unusually strong magnetic fields, unusually high levels of radio frequency interference (such as from communication transmitters), and additional impedance outside the CDM or BDM added after the acceptance test shall be communicated where known or specified.



NOTE - Typical range of per unit values are provided for reference only.
The figure assumes there is no impedance between PDS terminals and the converter.
Repetitive transients (U_{LRM} / U_{LWM}): 1,25 to 1,50, depending on the snubber design with respect to di/dt and IRR.
Non repetitive transients (U_{LSM} / U_{LWM}): 1,80 to 2,50, depending on additional protective devices.

Figure 4
TYPICAL a.c. VOLTAGE WAVEFORM AT SIX PULSES CONVERTER TERMINALS

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4.1.2 Environmental Service Conditions

4.1.2.1 Climatic Conditions

The CDM shall operate under environmental conditions specified in IEC 60721-3-3 for class 3K3, and clause 2 of IEC 60146-1-1 for water and oil coolants. This includes the following:

a) coolant temperature

air	0 °C to + 40 °C
water	+ 5 °C to + 30 °C
oil	- 5 °C to + 30 °C

b) ambient temperature

+ 5 °C to + 40 °C

c) relative humidity

5 % to 85 % non-condensing

d) dust and solid particle content

Standard equipment is designed for clean air, refer to 2.5.1 of IEC 60664-1 pollution degree 2; any other condition constitutes "unusual service conditions" and requires specification by the customer; see IEC 60529 for degree of protection of enclosure.

e) off-load periods shall be specified even if the ambient temperature is in the range defined above.

4.1.2.2 Mechanical Installation Conditions

The CDM/BDM shall be installed indoors on a rigid mounting surface in areas or supplementary enclosure, which do not seriously interfere with the ventilation or cooling system. An air-conditioner may be furnished to enhance the reliability of the CDM/BDM.

Other installation circumstances require special consideration and require specification and consultation with the manufacturer.

Vibration shall remain within the limits of IEC 60721-3-3, class 3M1 which is considered normal for stationary equipment.

Table 4-1
INSTALLATION VIBRATION LIMITS

Frequency Hz	Amplitude mm	Acceleration m/s^2
$2 \leq f < 9$	0,3	n.a.
$9 \leq f < 200$	n.a	1

Vibration beyond these limits, or use on non-stationary equipment is considered unusual mechanical conditions.

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4.1.3 Unusual Environmental Service Conditions

The use of power converter equipment, associated drive control, and drive equipment under conditions departing from the usual conditions listed in IEC 60146-1-1 shall be considered unusual. These unusual service conditions shall be specified by the purchaser.

Unusual service conditions, of the kind listed below, may require special optional construction or protective features. The following conditions shall be communicated where known or specified:

a) exposure to damaging fumes;

b) exposure to excessive moisture (relative humidity greater than 85 %);

c) exposure to excessive dust;

d) exposure to abrasive dust;

e) exposure to steam or water condensation;

f) exposure to oil vapor;

g) exposure to explosive mixtures of dust or gases;

h) exposure to salt air;

i) exposure to abnormal vibration, shock or tilting;

j) exposure to weather or dripping water;

k) exposure to unusual transportation or storage conditions;

l) exposure to extreme or sudden changes in temperature;

m) unusual space limitations;

n) cooling water containing acid or impurities which cause excessive scale, sludge, electrolysis or corrosion;

o) unusually high nuclear radiation;

p) altitudes above 1 000 m (3 300 ft);

q) long off-load periods;

r) outdoor equipment.

4.1.4 Installation, Commissioning and Operation

Installation, commissioning, and operation have the same normal and unusual service conditions.

4.2 STORAGE OF EQUIPMENT

The equipment shall be placed under adequate cover immediately upon receipt if packing coverings are not generally suitable for outdoor or unprotected storage.

4.2.1 Climatic Conditions

Equipment shall be capable of storage under environmental conditions as specified in IEC 60721-3-1. This includes the following:

a) ambient temperature class 1K4:- 25 °C to + 55 °C

b) relative humidity class 1K3: 5 % to 95 %

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Modules and panels shall be protected from condensation. If any part of the equipment is not to be installed immediately, it shall be stored in a clean, dry place and protected from variations in temperature, high humidity, and dust. If possible, sudden changes in temperature and humidity should be avoided. If the temperature of the storage room varies to such an extent that the equipment surfaces are exposed to sweating or freezing conditions, the equipment shall be protected by a safe, reliable heating system which will keep the temperature of the equipment slightly above that of the storage room. If the equipment has been exposed to low temperature for an extended period of time it should not be unpacked until it has reached room temperature, otherwise it will sweat. The presence of moisture on certain internal parts can cause electrical failure.

4.2.2 Specific Storage Hazards

The following require particular attention:

a) water - except for equipment specifically designed for outdoor installation, equipment shall be protected from rain, snow, sleet, etc.;

b) altitude - equipment should not be stored above 3000 m above sea level;

c) corrosive materials - equipment shall be protected from salt spray, hazardous gases, corrosive liquids, etc.;

d) time - the above specifications apply to shipping and storage with a total duration of up to six months, longer storage times may require special consideration (i.e. reduced ambient temperature range such as in class 1K3);

e) rodents and fungi - when storage conditions are likely to involve rodent or fungus attack, equipment specifications shall include protective items;

   rodents - materials on the outside of the equipment and the size of apertures for cooling, connection, etc. shall be specified such as to discourage rodent attack or entry;

   fungi - materials shall be specified for a degree of fungus resistance suitable for the storage and operating environments.

4.3 TRANSPORTATION

4.3.1 Climatic Conditions

Equipment shall be capable of transportation in the supplier's standard package, under environmental conditions as specified in class 2K3 of IEC 60721-3-2. This includes the following.

a) ambient temperature: -25 °C to +70 °C

NOTE – Temperature limits refer to the ambient temperature immediate surrounding the equipment (example inside a container).

b) relative humidity: 95 % at +40 °C

NOTE – Some combinations of temperature and humidity may cause condensation.

4.3.2 Unusual Climatic Conditions

Where transportation temperature below -25 °C are anticipated, the use of heated transport or the removal of selected low temperature sensitive components is required.

4.3.3 Mechanical Conditions

Equipment shall be capable of transportation, in the supplier's standard package, within the limits prescribed in class 2M1 of IEC 60721-3-2.

This includes vibrations and shocks. (See Tables 4-1 and 4-2.)

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Table 4-2
TRANSPORTATION VIBRATION LIMITS

Frequency Hz	Amplitude mm	Acceleration m/s^2
$2 \leq f < 9$	3,5	n.a.
$9 \leq f < 200$	n.a.	10
$200 \leq f < 500$	n.a.	15

Table 4-3
TRANSPORTATION SHOCK LIMITS

Mass kg	Height of free fall m
$M < 20$	0,25
$20 \leq M < 100$	0,25
$100 \leq M$	0,10

NOTE 1 – If a shock and vibration environment beyond those limits is anticipated, special packaging or transport is required.

NOTE 2 – If a less damaging environment is known to exist, packaging may reflect reduced requirements by agreement between manufacturer/supplier, user, and carrier.

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5 RATINGS

5.1 BDM INPUT RATINGS

5.1.1 Input Voltages

The BDM input ratings shall be stated by the manufacturer. Preferred values are:

a) 100, 110, 200, 220, 230*****, 240, 380, 400*****, 415, 440, 500, 660, 690***** V at 50 Hz;

b) 100, 115, 120, 200, 208, 220, 230, 240, 400, 440, 460, 480, 575, 600 V at 60 Hz.

***** Standard voltages as specified in IEC 60038.

5.1.2 Input Currents

There are two input currents:
- converter alone: I_{VN};
  this value shall be stated by the manufacturer at the minimum a.c. line impedance;
- CDM or BDM: I_{LN};
  this value includes current required by auxiliaries I_{XN}.

5.2 BDM OUTPUT RATINGS

5.2.1 Continuous Output Ratings

Continuous output ratings shall be stated by the manufacturer and shall be in terms of voltage (U_{dN}) and current (I_{dN}).

A rated output power (either or both Hp or kW) can also be given as a general guide to assist the user in motor selection.

NOTE 1 – Rating in term of U_{dN} and I_{dN} allows use of direct measurement techniques and adequately addresses conductor current capacity.

NOTE 2 – When CDM and motor are not provided by the same manufacturer/supplier, information is to be exchanged to define proper performance and compatibility of CDM and motor.

5.2.2 Overload Capability

PDS shall be rated for one of the following overload capabilities, unless otherwise specified. The overload capability applies to the rated speed range (see also note 3).

a) Following continuous operation at rated output current, 150 % of rated output current (I_{dN}) for 45 s, followed by a period of load current less than rated current and of such duration that the r.m.s. output current over the duty cycle does not exceed rated output current (I_{dN}).

Example: if the duty cycle requires 150 % of rated current for 30 s in every 5 min, the remaining 4,5 min must be at approximately 92 % of rated current or less to maintain an r.m.s. value ≤ 100 %. If the requirement is 30 s out of 30 min, the remaining 29,5 min must be at approximately 98 % of rated current or less.

NOTE 1 – The overload is coordinated with occasional excess current of the motor see 18.3 of IEC 60034-1
45 s for machine output rating ≤ 1 kW per 1 r/min,
30 s for machine output rating > 1 kW per 1 r/min.

There is an alternative rating in common use: following continuous operation at rated output current, 150 % of rated output current (I_{dN}) for 1 min, followed by a period of load current less than rated current and of such duration that the r.m.s. output current over the duty cycle does not exceed rated output current (I_{dN}).

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Example: if the duty cycle requires 150 % of rated current for 1 min in every 10 min, the remaining 9 min must be at approximately 92 % of rated current or less to maintain an r.m.s. value ≤ 100 %. If the requirement is 1 min out of 60 min, the remaining 59 min must be at approximately 98 % of rated current or less.

b) Following continuous operation at rated output current, 125 % of rated output current (I_{dN}) for 1 min, followed by a period of load current less than rated and of such duration that the r.m.s. output current over the duty cycle does not exceed rated output current (I_{dN}).

Example: if the duty cycle requires 125 % of rated current for 1 min in every 10 min, the remaining 9 min must be at approximately 96 % of rated current or less to maintain an r.m.s. value ≤ 100 %. If the requirement is 1 min out of 60 min, the remaining 59 min must be at approximately 99 % of rated current or less.

c) Following continuous operation at rated output current, 110 % of rated output current (I_{dN}) for 1 min, followed by a period of load current less than rated and of such duration that the r.m.s. output current over the duty cycle does not exceed rated output current (I_{dN}).

Example: if the duty cycle requires 110 % of rated current for 1 min in every 10 min, the remaining 9 min must be at approximately 98 % of rated current or less to maintain an r.m.s. value ≤ 100 %. If the requirement is 1 min out of 60 min, the remaining 59 min must be at approximately 99 % of rated current or less.

NOTE 2 – The relationship between the overload currents specified and the torque developed by the motor is not covered by the above.

NOTE 3 – Special overload conditions can be specified between the user and the supplier/manufacturer. For example, overload magnitude and duration may be the subject of such specification, examples of duty classes are given in table 3 of IEC 60146-1-1. See also 2.5.2 where it is reminded that complex cases can be covered by IEC 61800-6.

5.2.3 Speed Range

The speed shall be capable of being adjusted over a range of not less than eight to one by armature voltage control. This speed range may be extended by motor field weakening to a maximum speed depending on the motor rating. (See Figure A-1.)

NOTE – Operation below base speed

Drives are capable of operation at any speed within the rated speed range. When drives are operated continuously at rated torque at speeds below the rated base speed, the temperature rise of the motor may exceed the rated full load value. To meet the specified duty cycle and torque requirements of the load for a given application, the drive system design should assure adequate torque capability at reduced speed with a safe motor temperature rise.

5.2.4 Existing d.c. Voltage Ratings

Inverting operation may require reduction of armature voltage.

A three-phase line commutated converter can fail in the inverting mode due to excessive d.c./a.c. ratio. This ratio can have its large value due to a low a.c. line or to a large motor terminal voltage.

The low a.c. line may be due to a large motor starting on the power system causing a line dip, or to a properly placed commutation notch from another converter.

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The excessive motor terminal voltage can be due to a large motor counter EMF or a high rate of decreasing motor current (the armature current rate times the motor inductance results in an increased motor terminal voltage).

Usual d.c./a.c. ratio for typical industrial conditions is about 1,01 or 1,02 (this d.c./a.c. ratio is motor counter (EMF + L_A dI/dt) divided by a.c. nominal line voltage).

The d.c. voltage rating of the packaged drive system motor shall be as shown in Table 5-4-1.

5.3 Efficiency and Losses

The equipment included in the determination of the overall efficiency shall be stated.

The losses or efficiency of the PDS or of the CDM/BDM (see 2.5.8) shall be given by the manufacturer at rated load and base speed.

NOTE – The ventilation losses of the forced ventilated motor are included in the PDS losses, as those of a self ventilated motor, and in both cases they are not included in the CDM losses.

An example of variation of efficiency and losses versus speed is given in Figure 5-1.

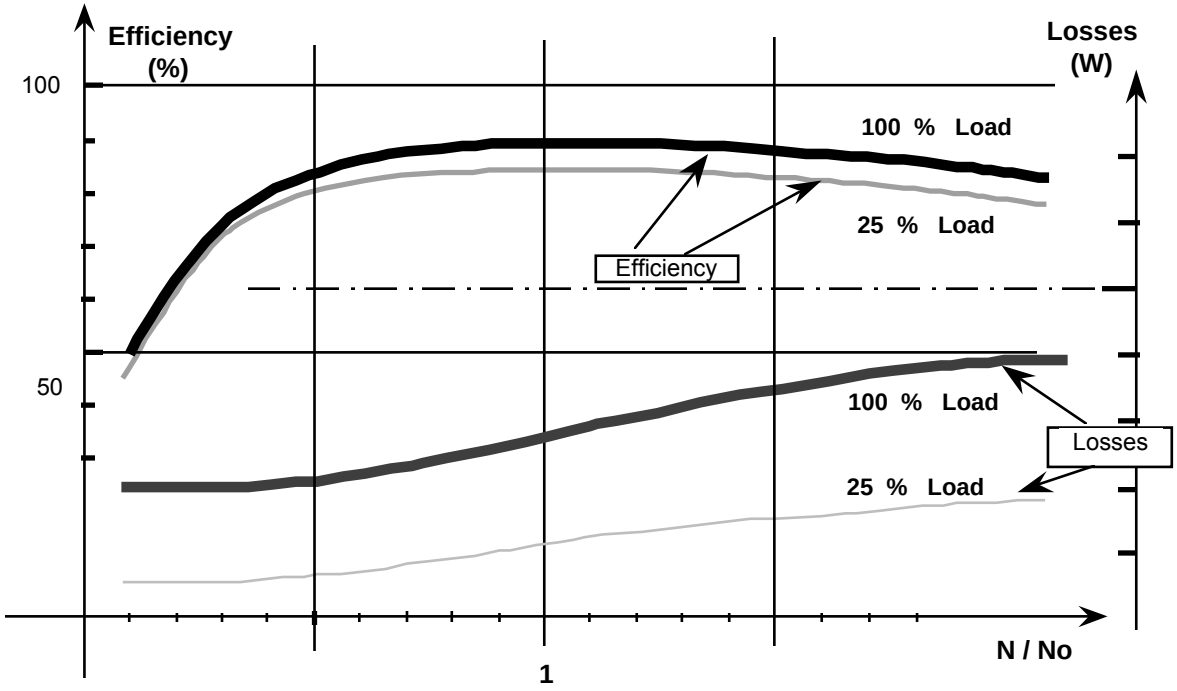


Figure 5-1
TYPICAL CURVES FOR EFFICIENCY AND LOSSES OF A PDS

5.4 RIPPLE

The ripple content of the converter is designated by the type of conversion, as indicated below. (See Figure F-1).

Type A Direct current generator
- battery,
- polyphase rectifier having no less than 12 pulses per cycle and maximum 15 % phase control.
- any power supply that provides sufficient series inductance to obtain 6 % peak-to-peak, or less, armature current ripple.

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Type B — Three-phase full wave power supply having 12 controlled pulses per cycle, without free-wheeling diode and without series inductance added in the motor armature circuit.

Type C — Three-phase full wave power supply having six controlled pulses per cycle, without free-wheeling diode and without series inductance added in the motor armature circuit.

Type D — Three-phase semibridge power supply having three controlled pulses per cycle, with free-wheeling diode and without series inductance added in the motor armature circuit.

Type E — Three phase single way power supply having three controlled pulses per cycle, without free-wheeling diode and series inductance, added in the motor armature circuit.

Type K — Single phase full wave power supply having two total pulses and two controlled pulses per cycle, with free-wheeling diode and without series inductance added in the motor armature circuit.

Type L — Single phase full wave power supply having two controlled pulses per cycle, without free-wheeling diode and without series inductance added in the motor armature circuit.

NOTE 1 – The magnitude of ripple increases with the increase in the letter designation. Therefore a motor designated for use on any type controller may be used on any controller designated by a lower letter.

NOTE 2 – General definition of ripple content (I_{pp}) is given in 2.5.6.

5.5 TRANSFORMERS AND REACTORS

Transformers and reactors shall comply with IEC 60146-1-3.

Additional information is provided in Annex C.

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6 PERFORMANCE REQUIREMENTS

6.1 STEADY-STATE PERFORMANCE

Steady-state performance for drive variables such as output speed, torque etc. shall be specified in accordance with 6.1.1 to 6.1.4. (See Annex D.)

6.1.1 Deviation Band (See Figure 6-1)

The deviation band is the total excursion of the directly controlled variable (unless another variable is specified) under steady-state conditions as a result of changes in the service or operating conditions within their specified ranges. It is expressed:

a) as a percentage of the ideal maximum value of the directly controlled (or other specified) variable, see example in 6.1.2;

b) as an absolute number for systems which have no readily definable base, such as position or air temperature control systems.

6.1.2 Selection of Deviation Bands (Steady-State)

The steady-state performance of a feedback control system shall be described by two numbers, selected from table 6 (other levels may be defined by agreement).

The range of variables to which the operating and service deviation bands apply shall be specified. (See Figure 6-1).

The first number, representing the operating deviation band, shall correspond to the maximum deviation band due to the operating variable(s), and the second number, representing the service deviation band, shall correspond to the maximum deviation band due to service conditions.

While the total deviation may be equal to the sum of the above deviations, it is unlikely that this extreme will be reached in practice.

Table 6
MAXIMUM DEVIATION BANDS (%)

± 20	± 10	± 5	± 2	± 1	± 0,5	± 0,2	± 0,1	± 0,05	± 0,02	± 0,01

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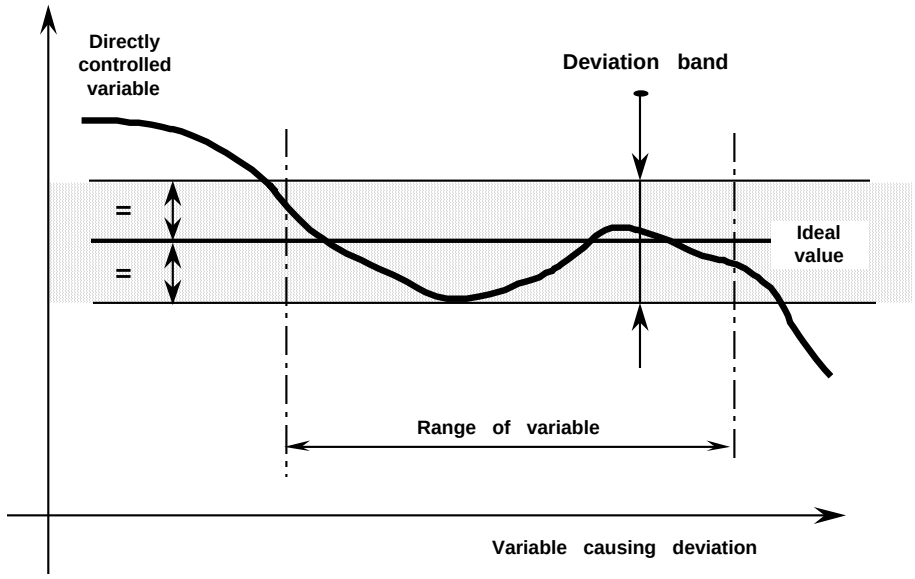


Figure 6-1
DEVIATION BAND

Example 1: "Operating deviation band 0,1 %, service deviation band 0,2 %" designates a system with ± 0,1 % maximum deviation band due to the operating variables and ± 0,2 % maximum deviation band due to service conditions.

Example 2: The deviation band is measured relatively to the ideal maximum value in ± percent. With a six to one field weakening system (See figure A.1.) and a 1 % tachometer feedback system, the following results are calculated:

1 800	$r \times min^{-1}$	Ideal maximum value
± 18	$r \times min^{-1}$	Deviation
180	$r \times min^{-1}$	1/10 of the maximum value
± 18	$r \times min^{-1}$	Deviation
300	$r \times min^{-1}$	Base speed
± 18	$r \times min^{-1}$	Deviation

NOTE – Speed control deviation with motor armature voltage feedback is usually in the range of ± 20 % to ± 2 %.

6.1.3 Service deviation band-limits

The specified service deviation band (selected from table 6) shall not be exceeded under any combination of applicable service conditions at any time during any 1 hour interval following a warm-up period as specified by the manufacturer, with the operating variables held constant during the observation.

6.1.4 Operating deviation band-limits

The operating deviation band of the directly controlled variable (selected from table 6) shall not be exceeded for the range of the operating variable indicated. The service conditions shall be held constant during the observation.

NOTE – When required by the application, the performance information should also include data on the steady-state relationship of the directly controlled variable to the reference. This aspect of performance is not included in the above discussion of operating or service deviation bands.

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6.1.5 Resolution

The resolution represents the minimum obtainable variation of the controlled variable. It may be represented by an absolute value or by a percentage of the maximum value.

6.2 DYNAMIC PERFORMANCE

If dynamic performance is important, the required dynamic responses to specific disturbances shall be specified. (See Annex D.)

Such disturbances might include those to the reference, those to the power source, and those reacting upon the controlled variable.

6.3 DYNAMIC BRAKING AND DYNAMIC SLOWDOWN

Dynamic braking refers to the addition of dissipative elements (resistors) to allow faster electrical braking of the machine.

Dynamic braking here is considered to apply only to the use of a resistor across the direct current output of a d.c. drive.

Dynamic braking and dynamic slowdown are functions, characteristics of which should be agreed upon between the user and the manufacturer/supplier. The following subclauses may be subject to modification by negotiation.

6.3.1 Dynamic braking

When dynamic braking (stop) is provided:

a) The converter shall be capable of braking a load at a current of 110%, 125% or 150% of rated current, depending on converter rating;

b) The dynamic braking resistor shall be capable of absorbing two times the stored rotational energy of the motor at maximum speed (with the resistor initially at ambient temperature);

c) Drive systems with large variable inertia of the driven equipment (such as winders) shall be capable of braking the maximum stored energy; the dynamic braking resistor is initially at ambient temperature, the energy rating shall be adequate to allow stopping the drive system once from any operating speed; the maximum dynamic braking armature current at top speed is 150%; in this case inertia of the driven equipment shall be provided by the user.

NOTE – The figure of current 150 % is typical and can be chosen differently according to other overload conditions (e.g., 110 % for fans).

6.3.2 Dynamic slowdown

For single quadrant converter.

When dynamic braking (slowdown) is provided, the resistors shall be capable of absorbing the total stored rotational energy of the armature and the driven equipment under two consecutive braking sequences from maximum to minimum speed, with the resistor initially at ambient temperature.

NOTE – The maximum total inertia of the driven equipment is considered to be one time that of the d.c. motor.

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6.4 OTHER PERFORMANCE REQUIREMENTS

Other performance requirements are to be quantified by the purchaser or by the manufacturer together with the purchaser, for example using the following items.

6.4.1 Use of the Drive in the Application

- audible noise
- operating quadrants: (See Figure 2-3.) The usual combinations are quadrants I, I and II, or all quadrants.
- torque as a function of speed (See Figure A-1.)
- special mechanical conditions (See Figure D-4.)

6.4.2 Use of the Drive in its Connection to Supply

- earthing (See B-2.)
- displacement factor at rated conditions (See 2.4.9.)
- line-side harmonic content (See 4.1.1.5 and B-3.)
- maximum symmetrical fault current, short circuit.

6.4.3 Ratings

- rated continuous output current (See 2.5.2 and 5.2.1.)
- rated output voltage (See 2.5.4 and 5.2.1.)

6.4.4 Protective Devices

6.4.4.1 Overcurrent Protection Devices

The current setting of overcurrent protection devices shall not exceed the service limit output current rating of the BDM.

6.4.4.2 Acceleration Control

Drives shall be provided with either current limit or timed acceleration.

6.4.4.3 DC Motor Field Control

When the field control of the motor could cause detrimental generated voltage and/or current in the armature circuit, means shall be provided to automatically prevent such a possibility.

6.4.4.4 Field Loss Protection

Should be provided, if it is not covered by other means.

6.4.4.5 Overspeed and Speed Feedback Loss Protection

Shall be provided, if speed feedback is used and maximum safe speed can be exceeded.

6.4.4.6 Fan Loss Protection

Drive systems supplied with fans shall have fan loss protection.

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7 TESTS

7.1 CLASSIFICATION OF TESTS

7.1.1 Type Test
Test of one or more devices made to a certain design to show that the design meets certain specifications [IEV 151-04-15].

7.1.2 Routine Test
Test to which each individual device is subjected during or after manufacture to ascertain whether it complies with certain criteria [IEV 151-04-16].

7.1.3 Sampling Test
Test on a number of devices taken at random from a batch [IEV 151-04-17].

7.1.4 Special Test
Test additional to type and routine tests, made either at the discretion of the manufacturer or according to an agreement between the manufacturer and the customer or his representative.

7.1.5 Workshop Test
Test on a device or equipment carried out in the factory or laboratory of the manufacturer to validate the design.

7.1.6 Acceptance Test
Contractual test to prove to the customer that the device meets certain conditions of its specification [IEV 151-04-20].

7.1.7 Commissioning Test
Test on a device or equipment carried out on site, to prove the correctness of installation and operation [IEV 151-04-21].

7.1.8 Witness Test
Any of the above tests performed in the presence of the customer, the user, or his representative.

7.2 PERFORMANCE OF TESTS

7.2.1 General Conditions

It is advisable to restrict the performance of costly tests to those which are necessary. This recommendation is therefore outlined so that testing can normally be limited to the tests in manufacturer's works on the separate components in accordance with 7.3. Special tests, as shown in 7.4 are only carried out, if specified in the contract. When the user or his representative desires to witness factory tests, it shall be specified in the order. When agreed upon before order, the supplier shall provide certified test results of type or routine tests. Tests shall be performed by the manufacturer prior to shipment unless otherwise agreed.

7.2.2 Earthing Conditions

The manufacturer shall state the acceptable earthing systems for the CDM/BDM. Type tests shall be performed to verify complete CDM/BDM performance with the acceptable earthing systems. These may include:

- neutral to earth;
- line to earth;

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- neutral to earth through high impedance;
- isolated (not earthed).

The unacceptable systems shall be indicated as:
- forbidden; or
- with modification of performance, which shall be quantified through type tests.

7.3 ITEMS OF SEPARATE DEVICE TESTS

7.3.1 Standard Tests for PDS

Table 7-1
SEPARATE TESTS

Separate device	IEC standard
Transformer	Clause 5 of IEC 60146-1-3
Motor	IEC 60034-1, IEC 60034-2
BDM	Table 8
CDM	Table 8

NOTE 1 – All tests for power transformers specified in IEC 60076 should also apply to CDM transformers, if not in contradiction with the tests specified in the above clause. The tests specified in clause 5 of IEC 60146-1-3 are to be regarded as special tests applicable to the CDM transformer.

NOTE 2 – The motor test, according to IEC 60034, does not guarantee drive behavior. Ripple and harmonic content delivered by the converter should also be considered.

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7.3.2 Standard Tests for CDM/BDM

Table 7-2
STANDARD TESTS FOR CDM/BDM

Tests	Type test	Routine test	Special test	Specification
Insulation (see note)	**X**	**X**		4.2.1 of IEC 60146-1-1
Light load and functional	**X**	**X**		4.2.2 of IEC 60146-1-1
Rated current	**X**			4.2.3 of IEC 60146-1-1
Overcurrent capability			**X**	4.2.12 of IEC 60146-1-1
Measurement of ripple voltage and current			**X**	4.2.15 of IEC 60146-1-1
Power loss determination	**X**			4.2.4 of IEC 60146-1-1
Temperature rise	**X**			4.2.5 of IEC 60146-1-1
Power factor measurement			**X**	4.2.6 of IEC 60146-1-1
Measurement of inherent voltage regulation			X	4.2.8 of IEC 60146-1-1
Checking of auxiliary devices	X	X		4.2.7 of IEC 60146-1-1
Checking the properties of the control equipment	X	X		7.3.3
Checking the protective devices	X	X		4.2.10 of IEC 60146-1-1
EM Immunity*	X			clause 5 of IEC 61800-3
EM Emission*	X			clause 6 of IEC 61800-3
Audible noise			X	4.2.14 of IEC 60146-1-1
Additional tests			X	4.2.16 of IEC 60146-1-1

NOTE – If components connected to earth are required for correct operation of the PDS/CDM, they are to be disconnected during the insulation test. (Coordination with other standards is under consideration).

*****U.S. NOTE – EM Immunity and Emission requirements of IEC61800-3 are not applicable within the U.S.

7.3.3 Checking The Properties of The Control Equipment of CDM/BDM

It is not possible to verify the properties of the control equipment under all load conditions which may prevail in the user application. However, the equipment shall be checked with a motor preferably of similar rated power. If this cannot be done as a workshop test (See 7.1.5), it may be performed using a lower power motor with appropriate scaling of feedback quantities.

If specified by the manufacturer, routine test for the checking of the control equipment may be accomplished with an unloaded motor check using multiple steady state speed conditions, i.e. at minimum and maximum speed. The dynamic performances shall be checked during the transition from one speed to another. It may be useful to add inertial loads to the motor so that the CDM/BDM operates in current limit (if supplied) during the acceleration. The checking of the deceleration shall be compatible with the design of the equipment.

The satisfactory operation of the equipment shall also be verified for the whole range of supply voltage for which it is designed, if this has not yet been done in another test (e.g. checking the protective devices). For the routine test, the CDM/BDM is connected to rated input voltage, or voltages if multi-rated. For the type test, the function of the equipment is also tested at maximum and minimum values of each input voltage range.

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7.4 ITEMS OF POWER DRIVE SYSTEM TESTS

Items for PDS tests are shown in Table 7-3. These are special tests. (See 7.1.4.)

Table 7-3
CLASSIFICATION OF SPECIAL PDS TESTS

Rating Tests	Subclause of 7.4.2
Light load	7.4.2.1
Load	7.4.2.2
Load duty	7.4.2.3
Allowable FLC (full load current) versus speed	7.4.2.4
Temperature rise	7.4.2.5
Efficiency	7.4.2.6
Line-side current harmonic content	7.4.2.7
Power factor	7.4.2.8
Current sharing	7.4.2.9
Voltage division	7.4.2.10
Checking of auxiliary devices	7.4.2.11
Checking coordination of protective devices	7.4.2.12
Checking properties under unusual service conditions	7.4.2.13
Shaft current / bearing insulation	7.4.2.14
Audible noise	7.4.2.15
Motor vibration	7.4.2.16
EMC tests	7.4.2.17
Harmonic content of the CDM output current	7.4.2.18
Dynamic tests	**Subclause**
Current limit and current loop	7.4.3.1
Speed loop	7.4.3.2
Torque pulsation	7.4.3.3
Automatic restart	7.4.3.4
Flux loop	7.4.3.5

7.4.1 Test Set-up

Regarding measuring circuit, see Figure 7-1. In this figure physical variables are directly measured or calculated from indirect measurements.

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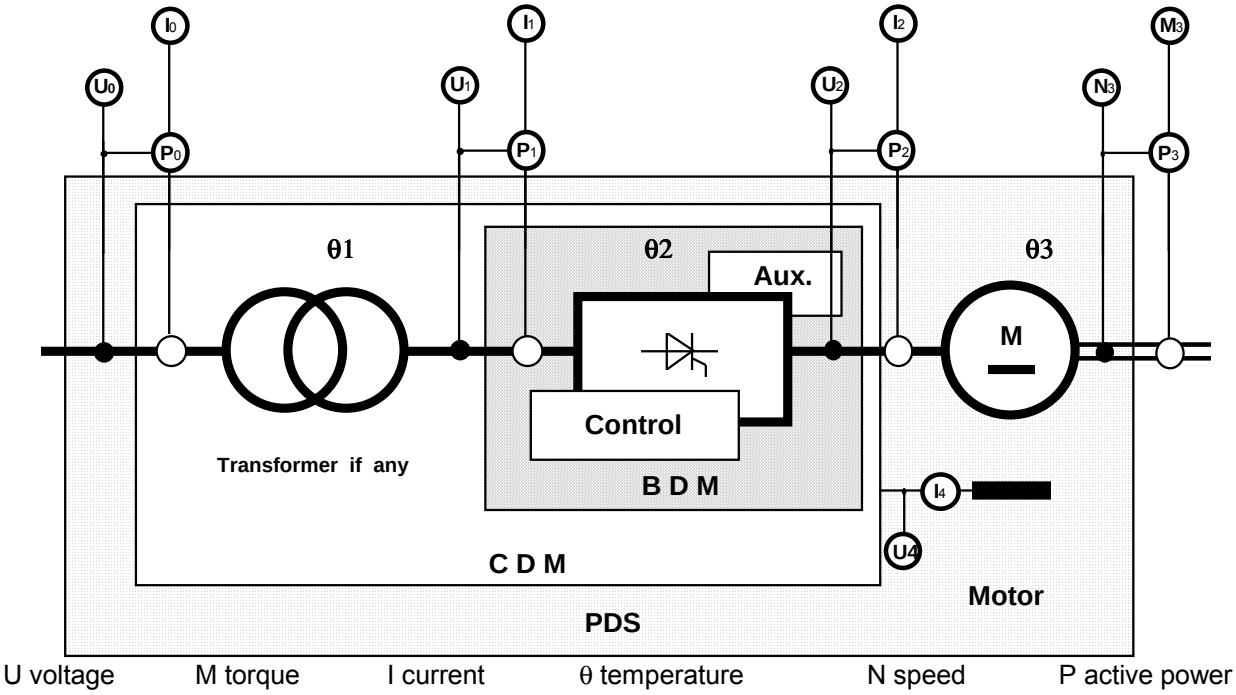


Figure 7-1
MEASURING CIRCUIT OF PDS

7.4.2 Definitions of Rating Tests

7.4.2.1 Light Load

The shaft of the motor is coupled to a load (see note), which is able to provide conditions to the tested drive such that the correct function of the control system can be proven. If agreed between the manufacturer and the user, a no load test can be used. The motor should be selected to require adequate current to prove correct CDM/BDM functions.

NOTE – The load is the driven equipment or, for test purposes, a simulation of the driven equipment.

7.4.2.2 Load

The shaft of the motor is coupled to a load (see note), which is suitably designed to provide the needed r.m.s. values of voltage, current, etc. and to run the drive system under specified steady-state conditions.

The manufacturer and the user have to agree if this test is done in a workshop test or in a commissioning test.

NOTE – The load is the driven equipment or, for test purposes, a simulation of the driven equipment.

7.4.2.3 Load Duty

The shaft of the motor is coupled to a load (see note), which is capable of providing the agreed upon load duty profile over a long-term run, to verify that the temperature rise in the equipment reaches stable conditions within ratings.

Manufacturer and user have to agree if this test is done in a workshop test or in a commissioning test.

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NOTE – The load is the driven equipment or, for test purposes, a simulation of the driven equipment.

7.4.2.4 Allowable FLC (Full Load Current) Versus Speed

The range of speed over which the drive system can operate continuously with the converter delivering rated full load current, without exceeding the thermal rating of any equipment, will be determined by appropriate temperature measurements conducted at stabilized temperatures for each speed examined.

The shaft of the motor is coupled to a load. The load is to provide full load or appropriate overload.

NOTE – This test is typically a workshop test but may in certain cases be accomplished during a commissioning test by agreement between manufacturer and customer. If a workshop test, the shaft of the motor is coupled to a load. The load is adjusted to provide FLC or specified overload at appropriate points within the speed range. If a commissioning test, the load is provided by the process and conditions shall be specified.

7.4.2.4.1 Motor Commutation Versus Speed

The test of motor commutation versus speed consists of the quotation of the commutation of the motor under the following conditions. This is a workshop or a commissioning test, at base speed, under overload conditions defined by the ratings of the drive, with both forward and reverse running (if needed), at maximum speed, under overload conditions defined by the ratings of the drive, with both forward and reverse running (if needed).

Under agreement, this method can be replaced by a quotation of commutation on dynamic conditions allowing a test without load (the shaft of the motor is free). Dynamic conditions are defined by acceleration (for both rotations, forward and reverse if needed) under maximum (limitation) current (corresponding to overload of FLC):
- firstly from 0 to base speed;
- secondly from base speed to maximum speed;
- and third from maximum speed to 0.

Classification of the commutation shall take place at the end of the acceleration.

Classification of commutation is made by visual observation according to table 10 below.

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Table 10
CLASSIFICATION OF COMMUTATION MADE BY VISUAL OBSERVATION

Sparks Code		Sparks Size			Nature of Sparks						Result
					Incandescent Point			Fusing			
Code	% of length	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	
1											Excellent
1-1/4	< 20 %	■			■			■			Good
	20 to < 50 %	■			■			■			
	50 to 100 %	■			■			■			
1-1/2	< 20 %		■		■			■	■		Fair
	20 to < 50 %		■		■			■	■		
	50 to 100 %		■		■			■	■		
1-3/4	< 20 %			■	■			■	■		Poor
	20 to < 50 %			■	■			■	■		
	50 to 100 %			■	■			■	■		
2	< 20 %			■		■			■	■	Rather bad
	20 to < 50 %			■		■			■	■	
	50 to 100 %			■		■			■	■	
2-1/2	< 20 %			■			■			■	Bad
	20 to < 50 %			■			■			■	
	50 to 100 %			■			■			■	

7.4.2.4.2 Motor Temperature Rise Versus Speed

The test of temperature rise of the motor is not needed if the motor has a separated cooling supply.

In case of permanent use of a motor with shaft mounted fan at low speed and high torque, the manufacturer of the motor shall provide a diagram of permanent allowable FLC versus speed.

NOTE – The field circuit of a shaft mounted fan motor at low speed may be overheated even in no load conditions.

By agreement between the user and the manufacturer of the drive a temperature rise test can be made using standard measurements of temperature (see clauses 15 and 16 of IEC 60034-1). In this case speed has to be chosen at 3 %, 10 % or 30 % of base speed according to the nature of driven equipment. The test is then carried out with a load corresponding to the allowable FLC curve.

7.4.2.5 Temperature Rise

The temperature rise tests are carried out at minimum speed, base speed and maximum speed with the maximum required load. The temperature rise tests are continued until all temperatures are stabilized.

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7.4.2.6 Efficiency

Mechanical power (P_3) is measured by the brake tests, dynamometer tests or back to back test according to 9.2 of IEC 60034-2, or calorimetric test. Then, overall system efficiency = (P_3 / P_0) x 100 (%). If the accurate measurement of the PDS output is not possible, the efficiency can be approximated by calculations in conjunction with system tests.

7.4.2.7 Line-Side Current Harmonic Content

This measurement is performed using instrumentation and techniques in accordance with IEC 61000-4-7, under rated operating conditions.

7.4.2.8 Power Factor

Power factor measurements shall be made under rated operating conditions, (see 2.4.10 and 2.4.11). This measurement can be made while performing rating test 2 (load test, see 7.4.2.2).

7.4.2.9 Current Sharing

If parallel connected power devices are used in the power drive system, the current sharing shall be checked. This test shall be performed at rated output current.

Examples of parallel configurations are:

- a converter section made up by more than one converter bridge;
- a converter section made up by more than one semiconductor valve per arm;
- a motor section with motor windings in parallel.

The balance shall be adequate to insure that no device is stressed beyond design values under worst case conditions.

7.4.2.10 Voltage Division

If two or more, BDM and/or motors, are connected in series, voltage division shall be checked so that no overvoltage occurs to BDM and/or motors. The voltage division shall be adequate to insure that no device is stressed beyond design values under worst case conditions.

7.4.2.11 Checking of Auxiliary Devices

The function of all auxiliary devices, that are not completely tested in the CDM/BDM or motor tests, shall be checked. Examples of such devices are: motor fans, lubricating oil pumps fed from the CDM, external circuit breakers and d.c. breakers.

If convenient, this can be done while performing light load test, see 7.4.2.1.

7.4.2.12 Checking Co-Ordination of Protective Devices

Checking of the protective devices shall be done, as far as possible, without stressing the components of the equipment above their rated values.

The emergency stop function, if supplied, shall be verified. The proper operation of all protective devices, that are not completely tested in the CDM/BDM or motor tests, shall be verified.

Due to the wide variety of protective devices and their combinations, it is not possible to state any general rules for the checking of these devices.

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Examples of protective devices to be checked during the power drive system test are: motor overspeed, motor overvoltage, motor overload, loss of speed feedback, mains undervoltage, earth fault, etc.

Reduced settings are recommended to verify the protection functions, without stressing the components of the system.

When the converter has earth fault protection, this earth fault test is carried out at the motor terminals in order to verify that the earth fault protection operates as specified.

7.4.2.12a Short-Circuit Withstand Capability

The converter shall meet the test requirements of UL 508C as to short-circuit withstand capability ratings expressed in terms of available rms symmetrical amperes, rated system voltage and the type and ratings of short-circuit protective device(s) stated by the manufacturer.

7.4.2.13 Checking Properties Under Unusual Service Conditions

Unusual climatic conditions may require special coating on electronic assemblies and/or cabinet. In extreme temperature conditions, an air conditioner or heater may be provided. The unusual condition shall be specified by the purchaser and the corrective measure and test shall be agreed upon by the equipment manufacturer and the purchaser.

7.4.2.14 Shaft Current Bearing Insulation

Shaft currents may result due to voltage and current ripple which are superimposed on the d.c. quantities during converter operation. While these currents are small in magnitude, they may cause damage to either anti-friction or sleeve bearings. Testing methods for their presence are to be agreed upon by the manufacturer and the purchaser of the equipment.

7.4.2.15 Audible Noise

Power drive systems may be required to be tested for audible noise. The test should be done over the operating speed range and load range (see note). Acceptable audible noise levels shall be agreed upon between manufacturer and user. See also IEC 60034-9.

NOTE – The load is the driven equipment, or for test purposes, a simulation of the driven equipment.

7.4.2.16 Motor Vibration

This test is carried out at various speeds and loads to identify any converter effects on motor vibration.

7.4.2.17 EMC Test

EMC tests are defined in IEC 61800-3.

U.S. NOTE – EMC Immunity and Emission requirements of IEC61800-3 are not applicable within the U.S.

7.4.2.18 Harmonic Content of CDM Output

Harmonic content is in terms of current. Ripple shall be measured as peak-to-peak value in amperes.

Conditions of measurement shall be agreed upon between the user and the manufacturer:
- voltage of the motor, corresponding to the speeds chosen;
- significant load (between 50% FLC and 100 % FLC).

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7.4.3 Definitions of Dynamic Tests

7.4.3.1 Current Limit and Current Loop

These tests characterize the dynamic performance of the CDM or of the PDS independently from the driven equipment.

Three items can be tested.

a) Current limit

An incremental load change is provided to require the CDM to reach its preset current limit point. (As an alternative, an incremental step speed change into adequate rotational inertia can provide a transient load causing the CDM to reach the current limit set point.) The rise time of current, overshoot magnitude and duration and damping characteristics may then be analyzed.

b) Current loop bandwidth

Current loop bandwidth can be established by using harmonic analysis of the response between current reference and current measurement (feedback). Amplitude and phase shift have to be checked. This test, when performed, shall be carried out within a linear or quasi-linear area.

c) Step response to current reference

This test can include non linear area.

These tests shall be carried out at different speeds to be chosen near 0, 50% base speed, 100% base speed, and maximum field weakened speed (N_M).

NOTE - It is usually necessary to adjust the speed by using a machine coupled to the shaft of the drive system under test (which is itself adjusting the torque by means of current following the reference).

7.4.3.2 Speed Loop

A step in speed reference is provided and correctly selected to accommodate the following tests. This test can be carried out under no load or light load conditions.

- The current limitation value is reached and checked.
- The drive output speed response is measured without reaching any limits (normally done within 50% base speed, at 100 % base speed, and at maximum field weakening speed (N_M)). Time response following a step in speed reference is illustrated in annex D.

A step in load may be provided to allow measurement of the consequent speed response. This may be carried out while performing rating test 7.4.2.2 (load test). The load step shall be chosen so that no limitations are reached.

Measurement shall be performed in accordance with the description given in annex D.

7.4.3.3 Torque Pulsation

Relative levels of air-gap torque pulsation may be measured under no load conditions using speed changes, provided that adequately sensitive speed measurement devices are coupled to the shaft. Ideally, air-gap torque pulsation arising within a specific PDS should be measured with a known load inertia, proper load/PDS mechanical coupling and shaft mounted torque sensing equipment.

NOTE – Torque pulsation may be estimated from the armature current waveform, for constant field systems.

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7.4.3.4 Automatic Restart

If automatic restart is provided, it shall be verified for the specified power outage duration. This function shall be coordinated with emergency stop and inhibited if required.

7.4.3.5 Flux Loop

DC voltage control: this test is only applicable for drives with controlled excitation, and is particularly important for drives with extended speed range by field weakening.

The motor terminal voltage or EMF shall be checked by a suitable recording instrument over the complete speed range, at a low speed increase from minimum to maximum operating speed. A dynamic test shall also be performed when the motor speed is increased and decreased following the fastest allowed speed ramp. It shall be verified that the recorded values are within the specified range.

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8 PRODUCT INFORMATION

8.1 MARKING

The following information shall be supplied on the rating plate of the CDM or BDM.

a) The manufacturer's name.

b) Equipment identification (model number, serial number, and year of manufacture).

c) Input ratings:

- voltage;
- rated current on the line-side I_{LN} or rated input current of the converter I_{VN} and auxiliaries input current I_{XN} according to the constitution of the CDM or BDM, these values are to be used in the definition of the incoming supply;
- frequency;
- number of phases;
- minimum source impedance or maximum prospective short-circuit current and maximum source impedance.

d) Output ratings:

- rated output voltage;
- rated continuous current;
- overload capability (see 5.2.2);
- rated power (optional).

e) Output rating-field:

- rated output voltage;
- rated continuous current.

NOTE – Size limitation may require that some elements be provided in instruction manuals.

8.2 INFORMATION TO BE SUPPLIED WITH THE PDS OR CDM/BDM

8.2.1 The following information shall be supplied with the furnished equipment:

- information necessary for calibrating components, devices and subassemblies which are intended to be adjusted by the user;
- information to allow for the proper selection of the input and output protection and earthing;
- operating instructions, including all information necessary to operate the furnished equipment;
- EMC information according to IEC 61800-3;

U.S. NOTE – EMC information requirements of IEC 61800-3 are not applicable within the U.S.

- warning notices where safety considerations exist;
- input phase sequence and output polarity.

8.2.2 The Following Information Shall be Supplied or Made Available:

- maintenance and service instructions, including information for locating and replacing faulty components or sub-assemblies; the language shall be appropriate to the country of origin or as agreed upon by the supplier/manufacturer and the customer;
- energy absorption rating of the dynamic braking slowdown and dynamic braking stop circuits.

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8.2.3 Speed Information Shall be Supplied With the Power Drive System, Including:

- base speed;
- maximum speed;
- maximum safe speed;
- field current at base and maximum speed.

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9 SAFETY AND WARNING LABELS

9.1 WARNING LABELS

Safety and warning labels shall be provided by the manufacturer and located as required by the codes and standards in the location of the equipment use (if known) and according to IEC 60204-1. They shall be in the appropriate language(s) for the location of use.

If the user location is not known, the warning labels will be provided and located in accordance with the prevailing codes and standards of the country of origin and IEC 60204-1. They shall be in the language(s) of the country of origin.

All safety and warning labels shall be duplicated in the instruction manual.

NOTE - Some principal areas for consideration are:

- A warning label should be provided adjacent to the operating handle of the main power disconnect if this disconnect does not de-energize all exposed live parts when it is in the "OFF" position.

- Where a control circuit disconnecting device may be confused with the power circuit disconnecting device, due to size or location, a warning label should be provided adjacent to the operating handle of the control circuit disconnecting device stating that it does not disconnect all power from the equipment.

- When the time required for draining stored charges to 50 V is more than 1 min, a warning shall be provided.

- If a portion of the equipment carries more than 50 V and can be moved into a position outside the volume occupied by the closed enclosure or into an aisle, the assembly shall include guarding for circuits above 50 V except where the short-circuit current for these voltages is limited to less than 5 mA.

- In those cases where it is possible for the user to wire circuits into the enclosure that are not disconnected by the disconnecting device supplied by the manufacturer, a warning label shall be supplied.

- If a part of the equipment is a FELV circuit (extra-low voltage for functional reasons only according to IEC 60364-4-41), this information shall be given on a warning label.

9.2 SAFETY AND NATURE OF A PDS

The PDS is coupled to a driven equipment which has to comply with safety standards and rules. All protection systems of the driven equipment, including the shaft of the motor, are defined by the user. The user shall provide to the manufacturer of the PDS all the necessary specifications which are consequences of machinery safety and have to be included in the control of the PDS. (See Annex E.)

The PDS is mainly an electrical equipment and the safety risk is mainly electrical. The safety risk is predominantly electrical for the CDM/BDM.

For these reasons PDS shall comply with IEC 60204-1.

Compliance with this standard does not, in itself, ensure compliance with all safety requirements. Detailed requirements are defined in other standards. (See Annex E.)

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Annex A
(Informative)
MOTOR CONSIDERATIONS

A.1 GENERAL

The CDM/BDMs covered by this part of IEC 61800, are all intended to be used with d.c. motors (one or more).

The purpose of this annex is to help the user select the proper motor for the application, and to be aware of the possible effects on motor performance which arise from its use with a converter. The intent of this annex is advisory or tutorial in nature.

The motor enclosures include all recognized types (open drip proof, totally enclosed, explosion proof, etc.).

Standards for d.c. motors are defined in IEC 60034.

A.2 COOLING CONSIDERATIONS

Generally, there are three typical methods of motor cooling. They are coded in IEC 60034-6 and are identified as an IC code. The code consists of five characters, the first two being IC and the balance according to the following:

- Circuit arrangement (0 to 9)
  Free circulation 0
  Use of pipes 1, 2, 3
  Use of heat exchange (including the motor frame) 4, 5, 6, 7, 8, 9

- Primary coolant, the most frequently used being air (A) and water (W)
- Method of movement of primary coolant
  Free convection 0
  Self circulation 1
  Motor mounted independent component 6
- Secondary coolant with same codification as for primary coolant.
- Method of movement of secondary coolant with same codification as for method of movement of primary coolant.

The three typical ways of motor cooling are described and coded as follows:

a) Shaft-mounted fans
   Cooling is in this case a function of motor speed and is also called "self-ventilation with internal fan"; this method would be coded IC0A1

b) Separate cooling supply (often supplied with filters)
   - Air supply from a blower directly mounted to the motor IC0A6
   - Air supply from a separate duct IC1A7

It is possible that at reduced speeds, the shaft-mounted fan of the motor may not be sufficient to maintain a normal temperature rise, due to the diminishing effectiveness of internal air circulation.

This is of primary concern for loads which require close to 1 p.u. torque at speeds below approximately 0.5 p.u. Loads which require reduced torques below this speed rarely constitute a problem (e.g. centrifugal type fans and pumps).

The maximum allowable temperature of the winding insulation and motor frame (explosion proof) usually limits the speed range of variable speed drives.

The temperature rise depends on:

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- the speed range desired;
- the load torque versus speed profile;
- the type of motor load (static/dynamic);
- the type of motor enclosure;
- the motor frame size selected;
- the motor cooling system.

All of the above will determine whether the motor fan cooling is adequate.

A.3 WAVEFORM HARMONIC CONSIDERATIONS

The harmonic content of the voltage/current waveform applied to the motor(s) produces deleterious heating and motor torques (braking, plugging and oscillatory), axial forces and additional acoustical noise.

These effects are complex and depend on:

- minimum operating speed;
- the magnitude and number of the harmonics produced;
- the connected driven equipment;
- the motor parameters.

Generally these are relatively high-frequency phenomena, which are of little importance in d.c. motors.

A.3.1 Converter Topologies

All the converters to which this standard is applicable (see annex F) contain harmonics in the output current and voltage. The harmonic distribution and magnitude depend upon the type of converter and the motor parameters. The motor nameplate requires the inclusion of allowable type of converter.

The motor is to be used with the proper converter type to avoid motor failure problems. (See Figure F-1.**)**

A.3.2 Potentials to Earth

The output voltage harmonics and voltage offset to earth also have an effect on motor insulation systems in the following areas:

- peak voltage between terminals;
- rate of change of voltage (dv/dt);
- voltage from terminals to frame/earth.

A.4 TORSIONAL CONSIDERATIONS

Motors designed to be used at constant speed may have mechanical resonances which will be excited at speeds other than design speed.

The motor vibration should be checked over the operating speed range to assure trouble free operation in the adjustable speed range. (See D.5.3.1, D.5.3.2 and Figures D-9 and D-10.)

A.4.1 Torsional Analysis

The existence of the above conditions can be determined by a comprehensive torsional analysis, if necessary.

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A.4.2 Remedies to Torsional Problems (Rare with d.c. Drives)

The object of the torsional analysis is to determine the stress levels in the mechanical parts and ensure endurance limits are not exceeded by the oscillating stress and that the yield limit is not exceeded by the average stress.

If the analysis indicates that the mechanical system is overstressed, there are several remedies that can be employed in the system design.

These remedies include:

- change of shaft material or dimension to move resonant frequencies beyond the operating range;
- use of energy absorbing couplings;
- use of phase multiplication converters to reduce the torque pulsations;
- selective electronic damping.

A.4.3 Torque Pulsation

The knowledge of the relative harmonic content of motor voltages and/or currents is also important in determining the repetitive pulsating torques excited by harmonics.

It is noticeable that these torque pulsations occur at relatively high frequencies (harmonics of supply frequency). They are well filtered by the mechanism itself. Effects may occur mainly with single-phase converters.

A.5 OPERATIONAL MODES

The drive system may be designed to operate in one or more of the operating modes below:

a) variable torque changing as a function of speed, for example speed squared (as may be found in pump, fan and compressor applications);
b) constant torque over a specific speed range;
c) constant power over a specific speed range where the torque decreases when speed increases;
d) regenerative operation where the drive systems convert mechanical torque from the motor shaft to electrical power back into the plant power system.; regenerative operation may be in any of the three modes defined above - variable torque, constant torque or constant power;
e) dynamic braking where the drive system functions to convert torque from the motor shaft to electrical power fed to a resistor, or a similar element to be dissipated as heat.

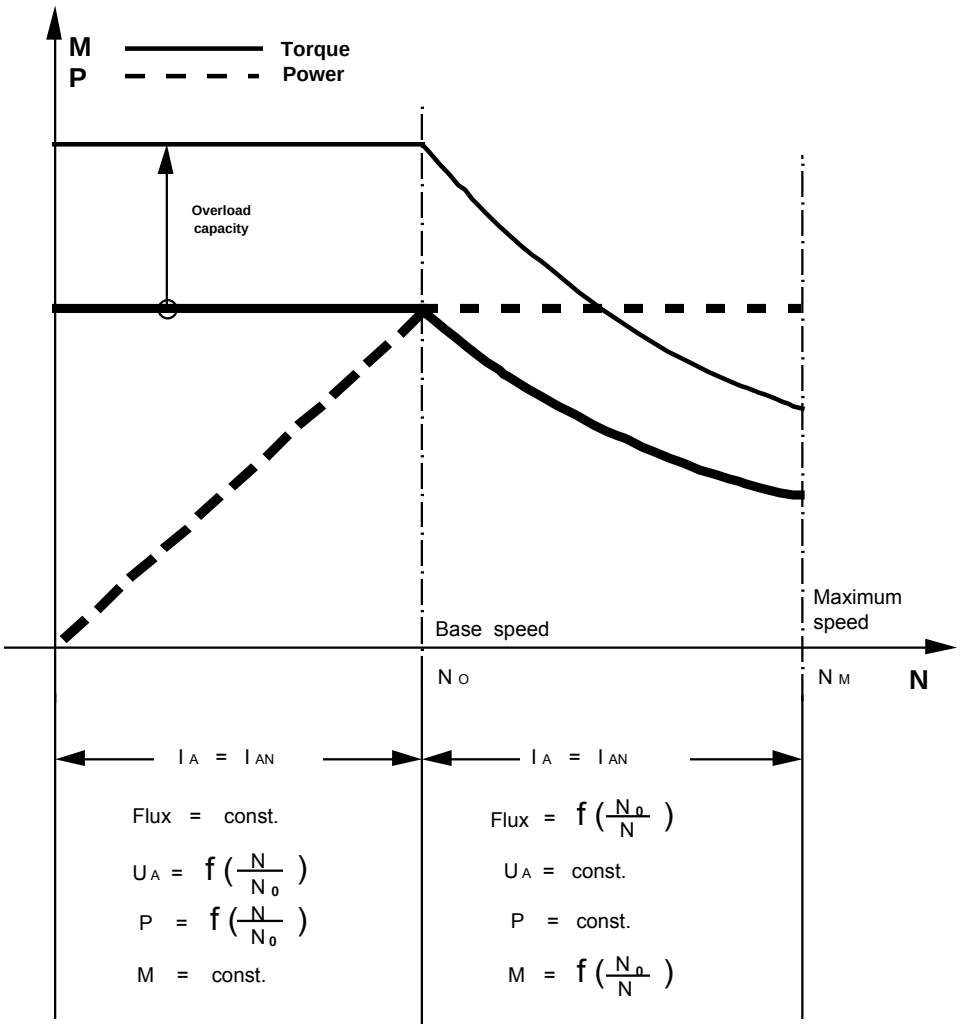
The operational mode(s) specified for the drive system should be compatible with the motor capabilities for the torque and speed range of operation. (See Figure A-1.)

A.5.1 Torque/Speed Characteristics

The torque/speed characteristics can be defined for the drive system, for example as shown in Figure A-1.

For a self-ventilated motor powered by a CDM/BDM, the torque which can be transmitted is reduced by the reduction of ventilation with reduction in speed.

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NOTES
1 - Reducing overload capacity may be necessary for speed range over the base speed.
2 - Operation below the base speed may necessitate the use of a blower for correct cooling of the motor.
3 - This figure may be extended to four quadrant operation .
4 - Reducing load capacity may be necessary for operation above base speed.

Figure A-1
TORQUE AND POWER OUTPUT OF A d.c. MOTOR

A.5.2 Considerations of Drive Regeneration

Some adjustable speed drives, covered by this part of IEC 61800, can be operated continuously in the regenerative mode, the mode in which the motor converts mechanical energy from the driven equipment into electrical energy, which the CDM/BDM then returns to the a.c. input supply.

The mechanical output of the motor can be described in terms of torque and angular velocity (speed). These variables can, in general, have two polarities. Therefore there are four possible modes of operation. (See 2.3.) Power is the product of torque and angular velocity.

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Power flow from converter to motor is termed motoring whereas power flow from the motor into the converter is termed regeneration.

Generally, the motor nameplate indicates rated voltage during motoring operation. It might be necessary to reduce this value during regeneration in order to avoid inverting failures.

A.6 ACOUSTIC NOISE

DC motors operated on rectified power produce a characteristic noise, best described as a "hum," which has its origin in the a.c. ripple voltage inherent in this power source.

These a.c. ripple voltages produce corresponding a.c. ripple currents in the motor armature circuit, and these periodic currents interact with motor field fluxes to produce periodic forces which can excite vibration of various parts of the motor structure.

These ripple currents are more properly termed harmonic currents and their magnitude and number is dependent upon several factors including power supply type, armature circuit inductance and thyristors conduction angle.

The noise which results from these current harmonic excitation forces may not exceed legal or specific limits. It can be annoying, however, because of its high pure tone content, especially in case of using d.c. chokes with choppers.

A.7 SERVICE LIFE OF THE MOTOR INSULATION SYSTEM

The insulation system of the motor is subjected to higher dielectric stresses when converter fed than in the case of supply with pure d.c. voltages and currents.

If a current source chopper is used, a high rate of voltage change in the motor occurs during the commutating period, which subjects the main insulation to stresses.

The voltage gradients, dv/dt, which stress the interturn insulation, particularly that of the armature are of importance in the case of supply from pulse width modulated choppers.

Knowledge substantiated by practical experience on the quantitative influence of the two above-mentioned factors on the service life of the insulation system is not in evidence. It is however widely accepted that no considerable reduction of the service life arises from chopper operation if the following limit values are observed:

$$V_{peak} \leq 2 \text{ x rated voltage;}$$

$$dv/dt \leq 500 \text{ V/}\mu\text{s}$$

A.8 SHAFT VOLTAGES

Shaft voltages may result from operation on a converter.

Experience shows that shaft voltages higher than approximately 500 mV (peak) may necessitate insulation of antifriction bearings.

As motors are practically never fitted with bearing insulation, it is advisable to carry out a measurement of the shaft voltage during converter operation. Methods of correction include bypassing the current from the bearings by use of an earthed brush on the shaft or the use of insulated bearings.

A.9 NEW DRIVE SYSTEMS

A feasibility study of a new drive system performance may be required from the manufacturer.

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- mechanical characteristics (torque versus speed, inertia, elasticity, backlash) at the motor shaft;
- required speed range;
- supply voltage with tolerances (voltage/frequency);
- available continuous power and short-circuit capacity;
- operating conditions (continuous, transient, cyclical);
- particular specifications for the installation site;
- a.c. supply harmonics, commutation notches, voltage overshoot.

NOTE- See D.3 for additional information.

A.10 MOTOR REFERENCE DOCUMENTS

IEC 60034, *Rotating Electrical Machines*

IEC 60034-5:1991, *Rotating Electrical Machines - Part 5: Classification of Degrees of Protection Provided by Enclosures of Rotating Electrical Machines (IP Code)*

IEC 60034-6: 1991, *Rotating Electrical Machines - Part 6: Method of Cooling (IC Code)*

IEC 60034-7: 1992, *Rotating Electrical Machines - Part 7: Classification of Types of Constructions and Mounting Arrangements (IM Code)*

IEC 60079, *Electrical Apparatus for Explosive Gas Atmospheres*

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Annex B
(Informative)
LINE-SIDE CONSIDERATIONS

B.1 INTRODUCTION

The connection of a CDM/BDM to the supply (line-side) results in an impact at the point of connection which is also reflected further up the supply network. Other loads, of course, produce similar effects at points of common coupling (PCC). In addition the converter constitutes a non-linear type load, for example the waveforms of the line-side voltage and current are dissimilar.

The connection of the converter then produces distortion of the line-side voltage waveform. This is in addition to any existing distortion of the waveform at PCC prior to the connection of the converter and due to the utility and other connected loads on the network.

The non-linear aspect of the converter means that harmonic currents flow into the converter in addition to the useful fundamental (sinusoidal) current. Since these harmonic currents do not aid in transmission of power and contribute to the loading of the distribution system, minimizing the magnitudes of these harmonic line currents is desirable. IEEE 519 discusses in detail the effects of harmonic currents and establishes acceptable limits as to the effects of harmonic currents. The user should specify the degree of harmonic control required.

The converters are also capable of generating a voltage transient on the a.c. input lines known as a line notch. The line notch transient is described in IEEE 597. Acceptable limits for notch and methods of reducing the notch area are given in IEEE 519 and IEC 60146-1-1. Since the severity of the line notch transients also depends on the configuration of the input power converter, the user should consider this fact in applying converters. The converter manufacturer can be consulted to determine the type of input power converter utilized and to recommend methods to reduce line notching transients.

Finally, the switching of the semi-conductors in the line-side converter takes place at very high speeds (microseconds) and this adds high frequency transients to the line-side which can cause concerns over electromagnetic compatibility (EMC).

The drive effect on the power system and equipment at the PCC is the subject of Annexes B and C of IEC 61800-3.

B.2 AC POWER SOURCE EARTHING

AC power system grounding is a critical consideration. Five earthing situations are possible in a three-phase a.c. power system: isolated, solidly earthed neutral, solidly earthed line, low resistance earthed neutral, and high resistance earthed neutral. The high resistance earthed neutral is the preferred system for drives used in processes where continuous operation is of importance. For example, the solidly earthed line or center tapped delta earthed line may cause the drive to perform improperly, the reason is mainly the voltage from regulator common to earth. The manufacturer's instruction book is to be consulted for guidance on permissible a.c. power system earth configurations. Section 12 of IEEE 597, contains a more rigorous discussion on earthing methods. Table 6 of Section 12 of IEEE 597 the above reference summarizes characteristics of the types of system earthing under three major categories: solid, high resistance, and isolated.

NOTE – The mode of earthing of the power supply network, and the mode of earthing of the housing of the equipments is explained and coded in IEC 60364-3.

B.3 INTRODUCTION TO HARMONICS AND INTERHARMONICS

The theoretical study of power converters and their use has modeled a converter as a source of harmonic currents.

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NOTE 1 – Some new converters can be considered as source of harmonic voltages. Therefore connection to the PC through an impedance converts them into harmonic current sources.

NOTE 2 – PCC: point of common coupling on a public network;
IPC: in-plant point of coupling on a private network;
PC: point of coupling (for either of the cases quoted above).

The installer, and utility can define the harmonic impedance of the system at the point of coupling (PC).

This value can be used to refine the harmonic model of the power drive system (PDS).

The harmonic nuisance on an equipment results from harmonic voltage effects.

$$U_h = Z_h \times I_h$$

Then the question is how to estimate the harmonic risk (or interharmonic when order h is not an integer).

There are two basic types of converters connected to the a.c. line:

- Type 1: those thyristor converters with large inductance in the d.c. load, where the current harmonics are determined from the short-circuit a.c. fundamental current ripple, (See Figure B-4.) converter pulse number and firing angle and from the R_{SC} ratio. The voltage harmonics are mainly due to the R_{SC} ratio and converter pulse number, as shown in Table B-1;

- Type 2: those diode converters with small inductance (or no inductance at all) and large capacitance in the d.c. load, where the current harmonics are a function of inductances on the line-side. (See Figure B-5.)

An example of evaluation of the harmonic risk (harmonic voltage) is given in 3.6.3 of IEC 60146-1-2.

This example is limited to type 1 converters connected to a network without capacitor banks or long supply lines (cables). Table B-1 shows, for a given voltage harmonic distortion, the minimum R_{SC} requirement at different pulse numbers, the notch area, and the amplitude of the first harmonic rank.

Table B-1
MINIMUM R_{SC} REQUIREMENTS FOR LOW VOLTAGE SYSTEMS

THD	p = 6			p = 12			p = 18			p = 24		
p.u.	R_{SC}	A_E	U_5 p.u.	R_{SC}	A_E	U_{11} p.u.	R_{SC}	A_E	U_{17} p.u.	R_{SC}	A_E	U_{23} p.u.
0,01	231	0,25	0,0041	150	0,19	0,0043	106	0,18	0,0055	99	0,14	0,0054
0,015	154	0,40	0,0062	100	0,29	0,0065	71	0,27	0,0081	66	0,22	0,0081
0,03	77	0,74	0,0123	50	0,57	0,0130	35	0,55	0,0165	33	0,43	0,0163
0,05	46	1,24	0,0206	30	0,93	0,0217	21	0,91	0,0275	20	0,72	0,0268
0,08	29	1,98	0,0327	19	1,51	0,0342	13	1,47	0,0444	12	1,19	0,0447
0,1	23	2,48	0,0409	15	1,89	0,0428	10	1,84	0,0555	9	1,49	0,0559

THD: Total harmonic distortion A_E : notch area in p.u. x degrees

NOTE 1 – For medium voltage systems use $R_{SCmin} = 3 \times R_{SC}$ as minimum requirement (resonance allowance).
NOTE 2 – For high voltage systems use $R_{SCmin} = 2 \times R_{SC}$ as minimum requirement (resonance allowance).
NOTE 3 – Not to be used for systems with directly connected capacitor banks or filters.
NOTE 4 – Interpolation: THD x R_{SC} = constant for a given p.
NOTE 5 – The total harmonic distortion is given as the contribution of the converter to the existing distortion.
NOTE 6 – The notch area is given for one single notch, without multiple commutation.
NOTE 7 – Use S_{1LN} for distortion corresponding to rated apparent power.

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It is also advisable to note that:

- on a group of PDS, the interharmonics have little chance to combine, it results in a calculation by arithmetic summation;
- on the other hand, it is usual to use a quadratic summation for the harmonics of non synchronized PDSs, with controlled input converter;
- if the PDSs have uncontrolled input rectifiers the harmonics add arithmetically.

The phase relationship of the harmonic current generated by a converter to the converter source voltage is determined by the phase angle at which the commutation starts and the harmonic order. The harmonic currents generated by converters belonging to different consumers connected to the same section of the feeder circuit will add up vectorially. Addition of harmonics is conceptually simple, but rigorous addition of harmonics is practically impossible and virtually meaningless because of the statistical nature of the harmonic current generation and the prohibitive amount of the detailed data required.

For voltage source converters with diode input rectifiers, the following simple and conservative method of approximation by addition is recommended; namely, solve the circuit for each harmonic source separately to determine the branch currents and node voltages caused by the harmonic source, and then arithmetically total them. Coincidence factors of the converter loads can be used to refine the addition if such data is readily available. More information is provided in annex B.2 of IEC 61800-3.

The user should periodically perform harmonic measurements, at selected points where a high level of harmonic distortion is suspected, to determine the system behavior and confirm that:

- utility capacitors, filters, cables and transformers are not being overstressed by excessive harmonics;
- a harmful degree of series or parallel resonance is not occurring;
- the level of harmonics at selected points of interface are within the limits.

The harmonic analysis, based on the coincidence factors of converter loads, should be made to validate response measurement results, and to allow extrapolation of those (response) results for the assessment of the impact of proposed or planned new converter installations. Sole reliance on an extensive analytical addition of harmonics is not recommended.

B.4 RESULTS FOR TYPICAL CONVERTERS; PHASE CONTROL

The power converter can be considered to be a generator of harmonic currents into the electrical system of the plant. The harmonic order is a function of the converter pulse number, i.e. 6 or 12 for the majority of converters. The harmonic orders are (kp ± 1) where k is an integer number and p is the converter pulse number. Table B-2 illustrates an ideal case of harmonic orders for 6-pulse converters, when the d.c. current is perfectly filtered (without ripple).

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Table B-2
HARMONIC CURRENT
6-PULSE CONVERSION

Harmonic order	Harmonic current in percent of fundamental (FLA)			
	X_c = 0 %	X_c = 8 % α = 10 °	X_c = 8 % α = 30 °	X_c = 8 % α = 90 °
5 (note 2)	20	18,7	19,6	19,8
7 (note 2)	14,3	12,4	13,7	14,1
11	9,1	6,4	8,2	8,7
13	7,7	4,6	6,6	7,3
17 (note 2)	5,9	2,3	4,5	5,3
19 (note 2)	5,3	1,5	3,8	4,6
23	4,3	0,6	2,7	3,6
25	4,0	0,5	2,2	3,2
29 (note 2)	3,4	0,6	1,5	2,5
31 (note 2)	3,2	0,7	1,2	2,3
35	2,9	0,6	0,7	2,3
37	2,7	0,5	0,5	1,6
41 (note 2)	2,4	0,4	0,2	1,3
43 (note 2)	2,3	0,3	0,1	1,1
47	2,1	0,1	0,1	0,9
49	2,0	0,1	0,2	0,7

NOTE 1 – X_c is the commutating (line) reactance in percent.
α is the delay angle of converter.
NOTE 2 – The magnitude of these harmonic currents in 12-pulse converters is normally taken to be 10 % of the 6-pulse values.

The magnitude of the harmonic currents is a function of the magnitude of the fundamental current, the commutating reactance X_c and the delay angle of the converter.

The exact harmonic current magnitude can be calculated at any given operating condition as defined by the magnitude of the fundamental current, the delay angle of the converter and the commutating reactance. In general, the harmonic magnitude will increase with decreasing d.c./a.c. ratio (angle approaching 90 °), and decreasing commutating reactance.

Different approximations of harmonic current calculation have been given for this basic three-phase bridge converter. (See Figure B-1.)

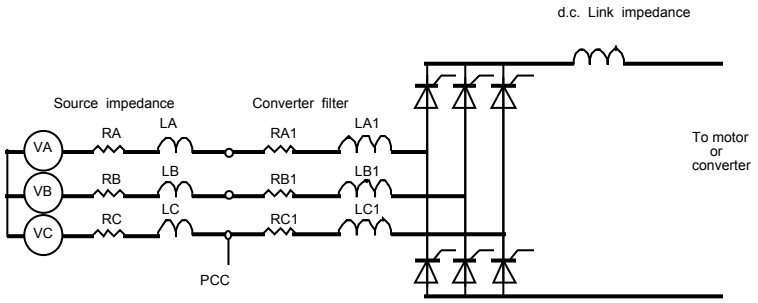


Figure B-1
THYRISTOR CONVERTER WITH A LARGE D.C. INDUCTANCE

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B.4.1 Square Wave Line Current

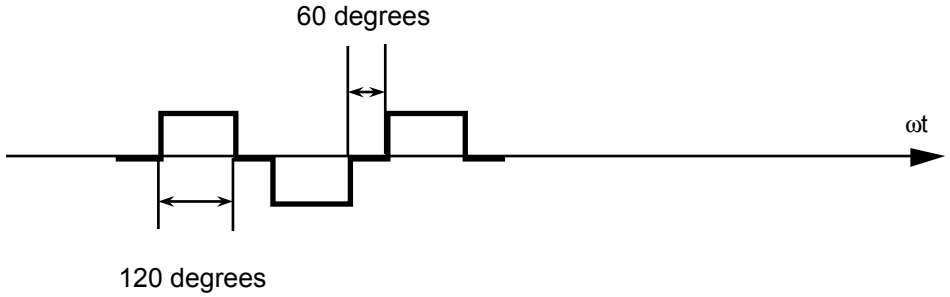


Figure B-2
SQUARE WAVE LINE CURRENT

B.4.2 Trapezoidal Line Current

References: IEC 60146-1-2, IEC 61000-2-1

a) First approximation (see 3.6.2.1 of IEC 60146-1-2)
For typical impedance of distribution network (result independent of R_{SC})

$$\frac{\mathbf{I_h}}{\mathbf{I_1}} = \frac{1}{\left(\mathbf{h} - \frac{5}{\mathbf{h}}\right)^{1,2}}$$

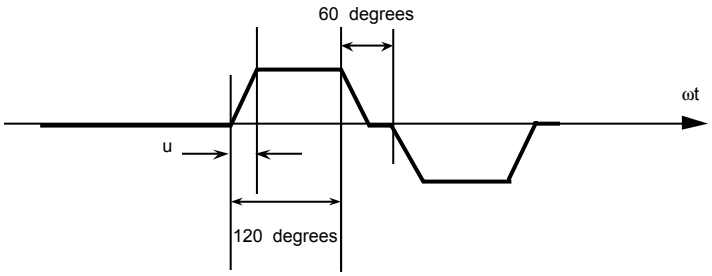


Figure B-3
TRAPEZOIDAL LINE CURRENT

b) Alternate method of approximation (result independent of firing angle but dependant of R_{SC})

$$\frac{\mathbf{I_h}}{\mathbf{I_1}} = \frac{3}{\mathbf{k}} \cdot \frac{\left|\sin\left(\frac{\mathbf{hu}}{2}\right)\right|}{\left(\frac{\mathbf{hu}}{2}\right)} \cdot \frac{1}{\mathbf{h}}$$

where commutation angle u is given by

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$$\cos\alpha - \cos(\alpha + u) = 2dx = \frac{2X_c I_d}{\sqrt{2}U_{vo}}$$

and remember that $x_c = \frac{X_c}{Z_n}$ and $R_{sc} = \frac{1}{kx_c}$

$$k = \frac{I_{dm}}{I_{dN}}$$

(the ratio between maximum and rated current).

c) Final approximation (see 3.6.4 of IEC 60146-1-2) gives a mathematical formula with graphic representation. The result is depending on firing angle α and commutation angle u.

Table B-2 is based on this approximation.

B.4.3 Current Harmonic with d.c. Current Ripple

These three preceding approximations are assuming the d.c. current is without ripple. This is not necessarily true, particularly for drives where line-side diode rectifiers are used without a reactor.

B.4.3.1 Square Wave Line Current with Ideal d.c. Ripple

The idealized d.c. current ripple consists of parts of sine wave.

$$r = \frac{I_{pp}}{I_d}$$

$$I_1 = I_d\left(\frac{3}{\pi}\cdot\sqrt{\frac{2}{3}} + 0{,}014r\right)$$

harmonic orders h = 6 k ± 1 = 6k + ε

$$\frac{I_h}{I_1} = (-1)^{\varepsilon}\left(\frac{1}{h} + \frac{6{,}46r}{h-1} - \frac{7{,}13r}{h}\right)$$

This result is graphically presented in Figure B-4, and generally gives a practical approximation, particularly for drives with large inductance in the d.c. circuit.

NOTE – High ripple, harmonic currents of order 7 and 13 are phase shifted, which are shown as negative values in Figure B-4.

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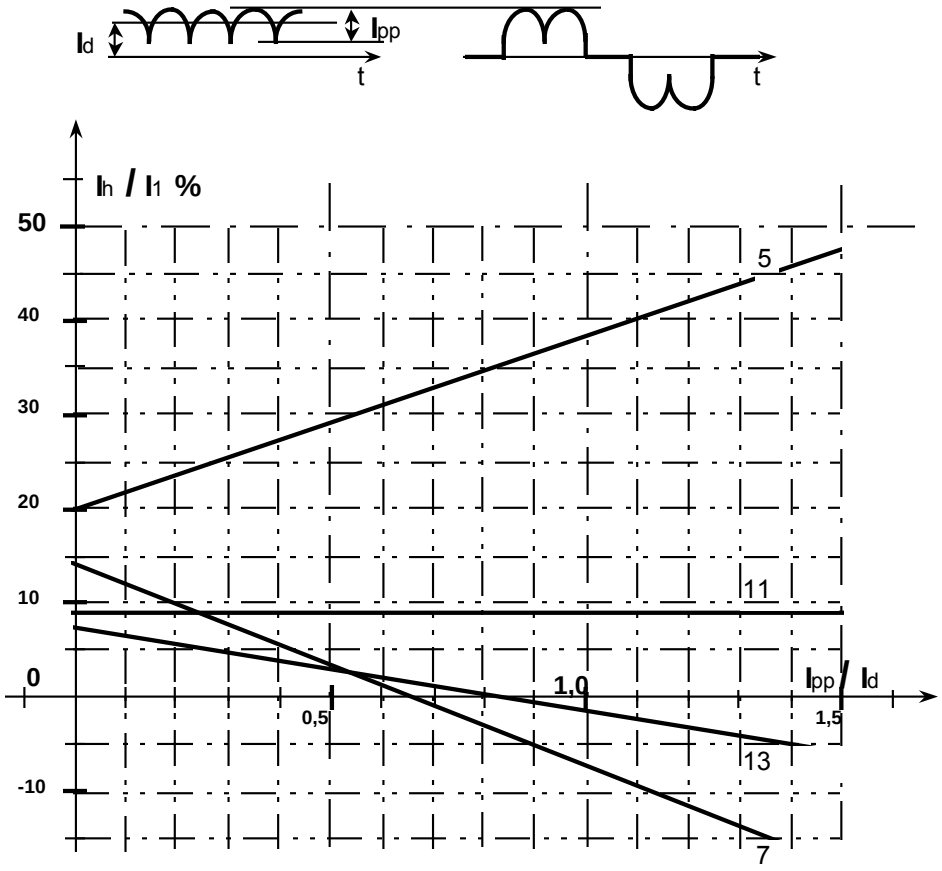


Figure B-4
MAJOR HARMONIC COMPONENTS OF SUPPLY CURRENT
CONSIDERING SQUARE WAVE LINE CURRENT WITH IDEALIZED d.c. RIPPLE

B.4.3.2 Trapezoidal Line Current with Ideal d.c. Ripple

An extension of the above case, taking into account the commutation angle has also been described and leads to more complex representations (IEEE Transactions on Industry Applications No. 1 Jan/Feb. 83).

B.4.4 Diode Rectifiers

Another configuration is that of a diode rectifier as the line-side converter of the PDS. In the most common case of the three-phase bridge, the resulting harmonic content of the current is largely dependant on the conduction time of the diodes, i.e., dependant upon the total equivalent reactance X_L.

Figure B-5 shows a power converter with a diode converter on the line-side. The converter is shown with a three-phase line impedance, a converter filter (impedance) and a d.c. link impedance. Converter impedance can be defined as two times the converter filter impedance summed with the d.c. link impedance, since the impedances are in series for any given conduction path. Figure B-6 shows input voltage and current waveforms of the above converter configuration, for a 2 % source impedance and 6 % line impedance.

The line-side voltage distortion factor is improved with the increased converter impedance and degraded with increased source impedance. Figure B-7 shows the line-side voltage and current distortion factors as a function of source impedance and total converter impedance respectively.

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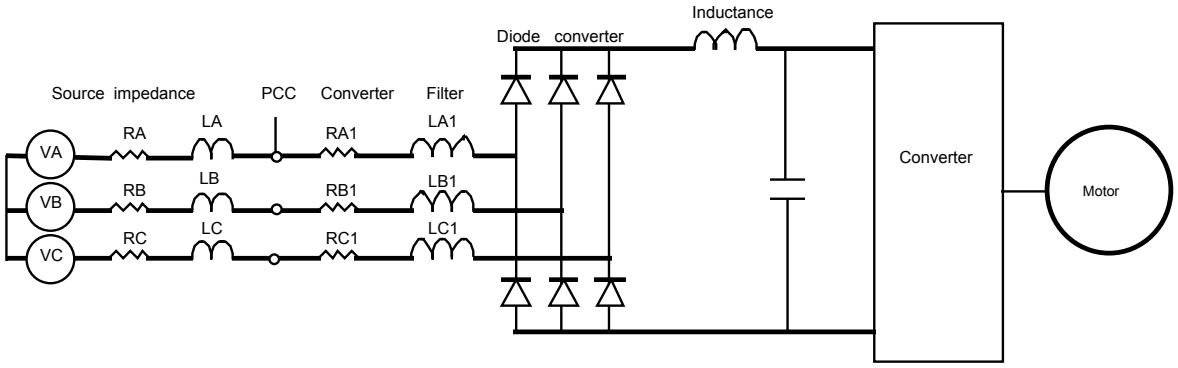
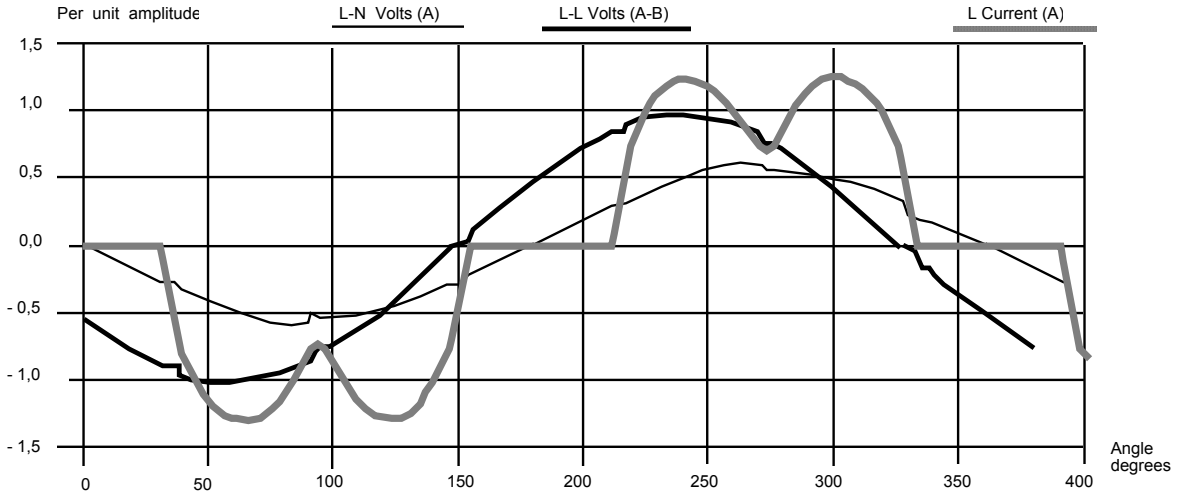


Figure B-5
POWER CONVERTER WITH A DIODE CONVERTER ON THE LINE-SIDE AND A PWM INVERTER OR A D.C. CHOPPER



NOTE - Source impedance = 2 %, converter impedance = 6 %

Figure B-6
POWER CONVERTER WITH A DIODE CONVERTER ON THE LINE-SIDE AND A PWM INVERTER OR A D.C. CHOPPER

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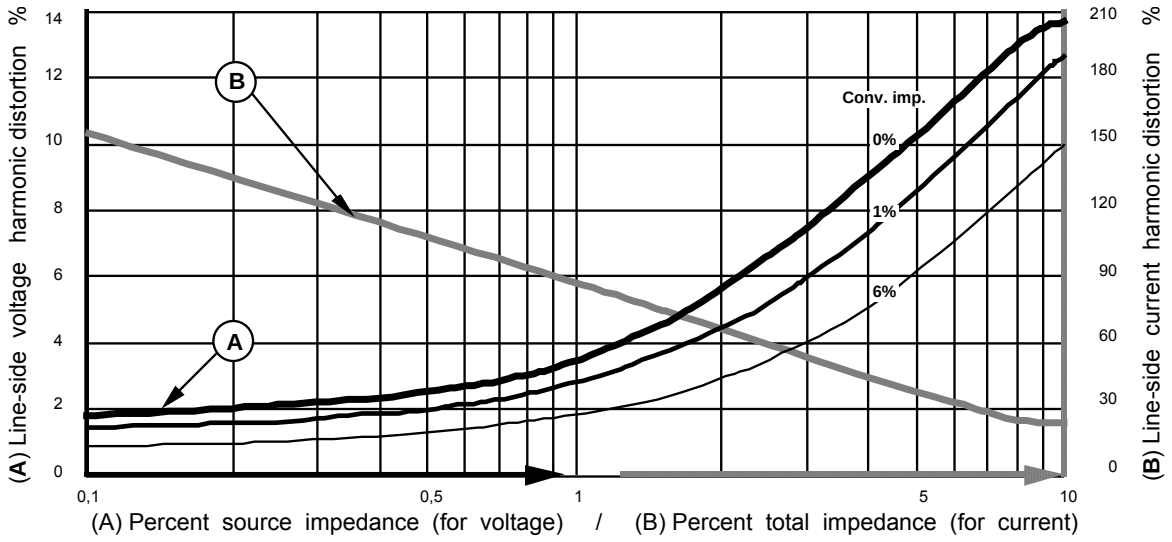


Figure B-7
POWER CONVERTER WITH LINE-SIDE RECTIFIER

B.4.5 Diode Rectifiers without d.c. Link Inductance

A particular case arises with converters which have no inductance in the d.c. link (low power BDM).

The line-side current distortion is inversely related to the total (input) impedance which consists of the sum of the converter impedance and the source impedance. (See Figure B-8.)

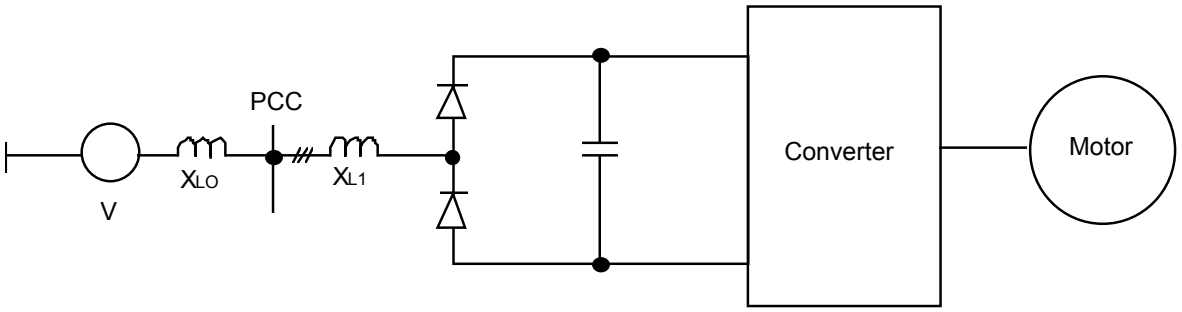


Figure B-8
DIODE RECTIFIER WITHOUT D.C. LINK INDUCTANCE

The p.u. value of x_L is:

$$\mathbf{x_L} = \frac{\mathbf{X_L I_d}}{\frac{\mathbf{U_{vo}}}{\sqrt{3}}}$$

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where I_d is the actual value and not the rated value.

$$x_c = \frac{X_L I_{VN}}{\frac{U_{vo}}{\sqrt{3}}} \quad X_L = \frac{X_C \cdot I_d}{I_{VN}}$$

NOTE - This is a different definition from x_C in p.u.

Results are given on the following figures, in terms of current distortion. For individual harmonic currents see Figure B-9; and for current distortion factors, see Figure B-10.

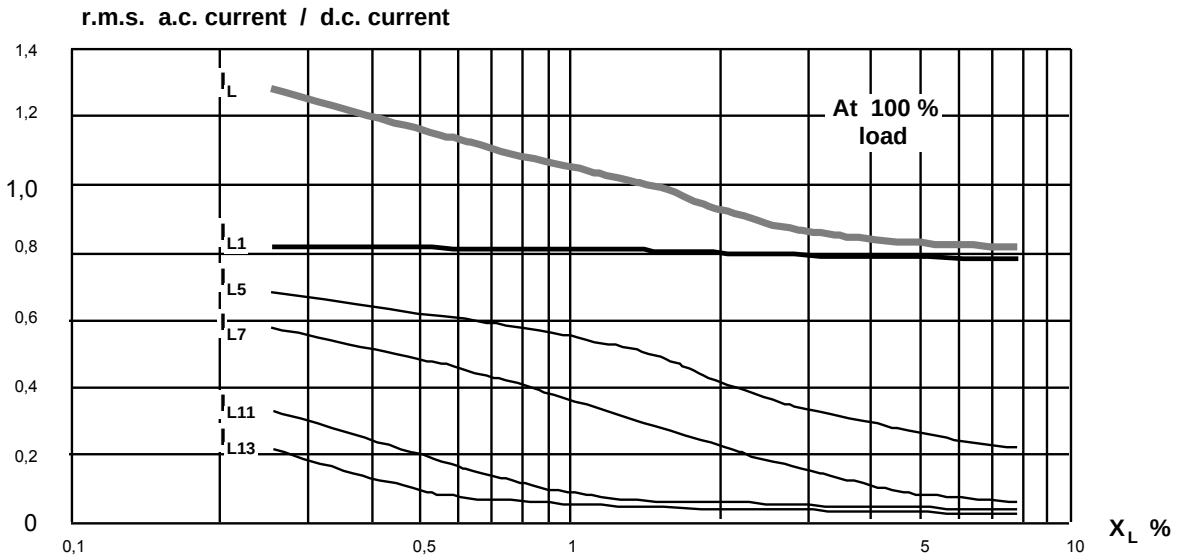


Figure B-9
INPUT HARMONIC CURRENT

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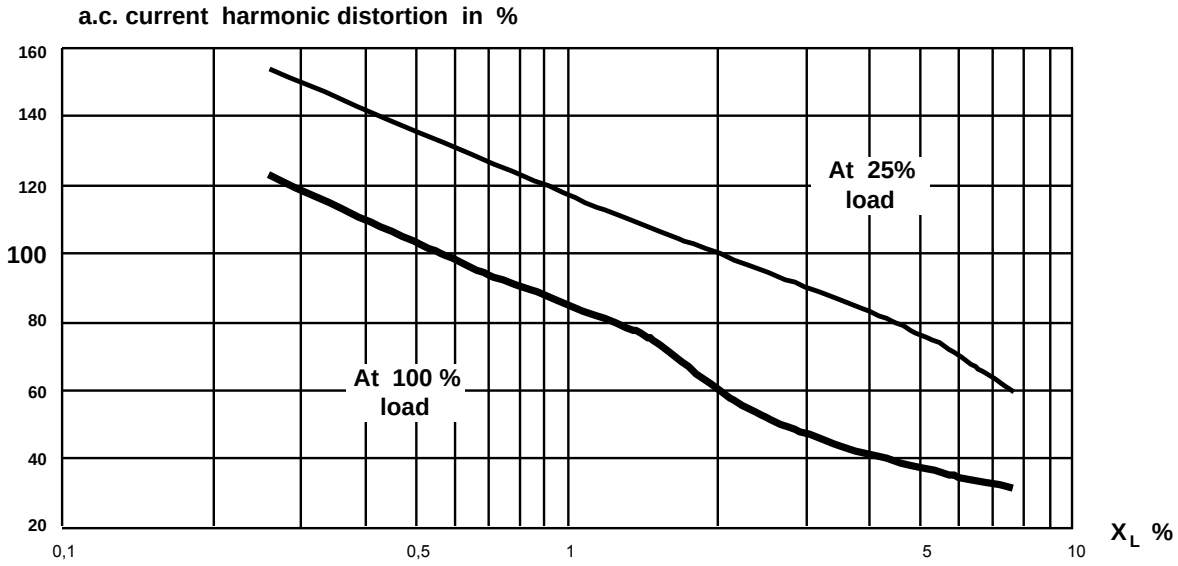


Figure B-10
INPUT CURRENT DISTORTION

B.4.6 General

All these approximations provide information on the regular order of harmonics. They consider an ideal equipment without technological deviation. Since no equipment can be ideal, this results in differences between ideal value and actual value of firing or extinction angle of power components. As a result, non regular orders (or irregular orders) of harmonics can be produced such as even harmonics or triple harmonics.

B.5 EXAMPLE OF ASSESSMENT OF HARMONIC EFFECT OF A PDS

A theoretical example of harmonic distortion (limited for simplicity to order 25) illustrates a practical assessment of the relationship between emission and immunity, to take into account the effect of the drive itself as mentioned in 4.1.

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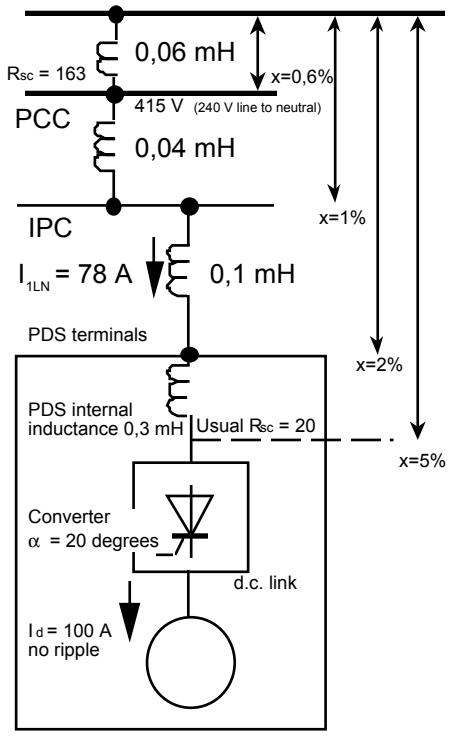


Figure B-11
EXAMPLE OF SIMPLE STRUCTURE

A 6 pulse thyristor converter, included in a power drive system, is connected to a distribution system (PCC) through its internal inductance of 0,3 mH, a line inductance of 0,1 mH from the PDS to the IPC, and an inductance of 0,04 mH representing the in-plant network (from the IPC to the PCC).

The inherent inductance of the distribution network at PCC is 0,06 mH. The rated line-to-line voltage is 415 V at 50 Hz (240 V line-to-neutral).

For simplicity of the example, the d.c. current is without any ripple and I_d = 100 A. The resulting I_{LN1} = 78 A. This corresponds to R_{SC} = 163 at PCC. Harmonic currents are assessed with figure 7 of IEC 60146-1-2, with the assumption of a firing angle α = 20° (d_x = 2,55 %, commutation angle u = 7,3°).

Table B.3. shows the contribution of the converter in harmonic voltages phase to neutral (unit is volt).

Table B-3
HARMONIC RESULTS FOR THE DRIVE CONTRIBUTION

h	5	7	11	13	17	19	23	25	THD %
I_h (A)	15,4	10,8	6,4	5,3	3,7	3,2	2,3	1,9	27 %
U_h (V) phase to neutral at PCC	1,44	1,42	1,33	1,31	1,20	1,13	1,00	0,90	1,5 %
U_h (V) phase to neutral at (PC) IPC	2,41	2,37	2,22	2,18	2,00	1,89	1,66	1,50	2,4 %
U_h (V) phase to neutral at PDS terminals	4,8	4,8	4,5	4,4	4,0	3,8	3,4	3,0	4,8 %
U_h (V) phase to neutral at converter terminals	12,1	11,9	11,1	10,9	10,0	9,5	8,3	7,5	12,1 %

Summation of this individual effect with the pre-existing voltage distortion at IPC or PCC is a rather complex matter. However, the simplified approach given in B.2.3.3 of IEC 61800-3 can be applied to obtain a rough assessment of the resulting distortion.

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B.6 ATTENUATION OF EMISSION OF HARMONICS

Power factor compensation and harmonic attenuation are two intimately linked problems.

In addition, local and therefore multiple compensation greatly increases the risk of resonance on the system. Consequently, it is preferable to adopt a global compensation strategy for the entire installation.

Most often, it will involve the installation of filters tuned to the most disruptive harmonic orders. This is the general way to solve the problem.

Drive harmonics can be cancelled by the addition of phase shifting transformers (change of converter pulse number). Obtaining power from a transformer with a delta and wye secondaries results in characteristic current harmonics in the transformer primary of 12 k ± 1. Typically the fifth and seventh current harmonic is reduced to 10 % of the 6-pulse value. For type 1 converters, equal converter delay angles are required. Figures B-4 and B-6 for 12-pulse operation would need to be recalculated.

For multiple type 1 or type 2 drives fed from phase shifted transformers, some reduction of the total harmonic current content will result.

B.7 COMMUTATION NOTCHES

A particular time based analysis can be used for commutation notches, which represent a part of the harmonic emission of a converter. (See 3.5 of IEC 60146-1-2.) They are the result of transient line-to-line short circuits on feeders at each commutation of a line commutated converter.

A general three-phase bridge converter consists of six semiconductor switches arranged as shown in Figure B-12. The transfer of current from one switch to another in the same row (an upper row of three or a lower row of three) is called commutation. During commutation, two (or three) semiconductors conduct simultaneously in the same row and cause a brief short-circuit between phases. The line-to-line voltage collapses to zero at the bridge terminals, and notches appear in the line-to-line voltage (Figure B.13).

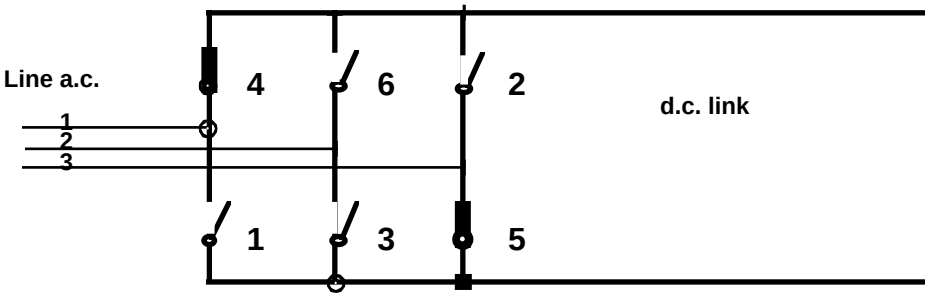


Figure B-12
3-PHASE, 6-PULSE BRIDGE CONVERTER

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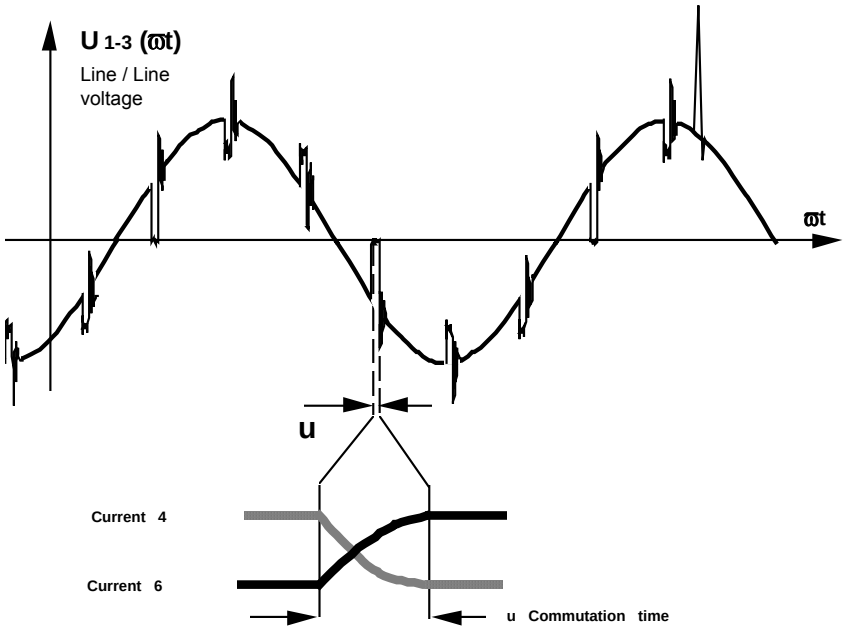


Figure B-13
COMMUTATION NOTCHES WITH A 3-PHASE, 6-PULSE BRIDGE CONVERTER

Commutation notches on the power line from another converter will discharge thyristor RC snubbers and a.c. line RC circuits. The extra discharge of the snubber capacitor over the self-generated notches may cause the capacitor series resistor, to overheat and fail. The commutation notch may also be capacitively coupled to the converter regulator, through the power supply transformer, causing regulator failure or drive stability problems.

The maximum commutation notch occurs during current limit mode of operation.

Notch related short-circuit may be total, if the converter is connected to the mains without use of decoupling devices. (for example the notch may reach a 100% depth). The short circuit may also be limited (for example has an impedance) when the converter is connected to the PCC through reactances (See Figure B-14.) for the equivalent circuit. The notch depth then depends on the impedance decoupling as follows:

$$\mathbf{d} \leq 100 \times \frac{\mathbf{Z}_{cc}}{\mathbf{Z}_{cc} + \mathbf{Z}_{d}}$$

where d is the notch depth in percent.

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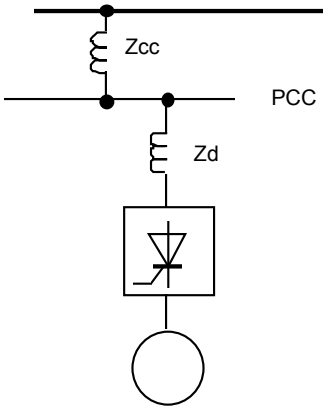


Figure B-14
EQUIVALENT CIRCUIT FOR ASSESSMENT
OF COMMUTATION NOTCH MITIGATION

It implies that the notch depth can be reduced, by reducing Z_{cc} and increasing Z_d.

Z_d can be increased by installing isolation transformers or reactors. When isolation transformers or reactors are installed, they should be placed as close as possible to the converter bridge so that they also prevent the commutation transients from interfering with the communication and control circuits.

The notch depth can be reduced by rewiring and moving the PC closer to the source. It effectively reduces the common impedance Z_{cc} while keeping (Z_{cc} + Z_d) the same (Z_d increases due to cable length as Z_{cc} decreases).

However, the notch area seen at the PC is independent of the value of the decoupling reactance. Keeping everything else constant, increasing decoupling reactance makes the notch depth decrease but notch width increase. Their product thus yields a constant area.

B.8 PROTECTION AGAINST VOLTAGE DIPS AND SHORT INTERRUPTIONS

The equipment which is within the scope of this part of IEC 61800 might be sensitive to voltage dips and short duration power supply interruptions. During such disturbances, the motor torque capability decreases significantly, the motor tends towards standstill. The driven equipment generally continues to run during the period of power supply recovery. As the converter is no longer synchronized with the motor, a random restart can lead to prohibitive overcurrents (with the risk of equipment damage), resulting in protection circuits tripping and system's shutdown. To avoid such phenomena, many drives cease operation when supply loss is sensed. For applications requiring a continuous operation, a precise specification is to be established between the user and the supplier/manufacturer.

Several solutions are possible.

Uninterruptible power supply (UPS)

Undisturbed operation can be provided with such a solution. The power rating of the drive system and the maximum duration of the disturbances to be accommodated determine the rating of the UPS.

Voltage dip compensation (ridethrough sequence)

This solution allows continuous operation of the driven equipment during significant three-phase voltage dips of larger amplitudes, if speed decreases are acceptable. The maximum amplitude of the three-phase voltage dip, the maximum duration of the disturbance, the speed decrease permitted in the driven equipment of process and the load characteristic are necessary considerations in the accurate sizing of the voltage dip compensation.

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Flying restart after short supply interruption

During three-phase voltage dips and short supply interruptions, not supported by the drive system and without back-up power supply, it is not possible to achieve continuous operation for long duration disturbances. The speed decrease depends on the load torque, the inertia of the driven equipment and the motor, friction loading and the disturbance duration. It is even possible that the motor may stop completely. However, it is frequently possible to perform a flying restart following recovery of the power supply while the driven equipment is still running. This solution may often require a speed sensor. The design parameters include the maximum disturbance duration to be supported, the duration between the power supply recovery and the return of the machine to its initial speed. Without any flying restart, it is usually necessary to stop the driven equipment and/or process.

B.9 REFERENCE DOCUMENTS

IEC 60364-3-1993 *Electrical Installation of Buildings – Part 3: Assessment of General Characteristics*

IEC 61000-2-1-1990 *Electromagnetic Compatibility (EMC) - Part 2: Environment - Section 1: Description of The Environment - Electromagnetic Environment for Low-Frequency Conducted Disturbances and Signaling in Public Power Supply Systems*

IEEE 519 -1992 *Recommended Practices and Requirements for Harmonic Control in Electric Power Systems*

IEEE 597-1983 *Practices and Requirements for General Purpose Thyristor d.c. Drives*

IEEE *Transactions on Industry Applications No. 1 Jan / Feb 83*

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Annex C
(Informative)
AUXILIARY EQUIPMENT

C.1 GENERAL

Various electrical equipment, well identified, may be exposed to unusual conditions when used with adjustable speed drive systems (PDSs). For example, transformers and reactors may operate at various harmonic currents and winding impulse loading, etc. This annex is intended to assist in identifying such areas for this type of auxiliary equipment.

C.2 TRANSFORMERS

Transformers (isolation and autotransformers) can be used on the input of BDMs.

Such transformers are not normally essential for converter operation but are intended to satisfy one or more of the following requirements to:

- establish voltage levels;
- meet codes and regulations;
- provide isolation (galvanic);
- establish earthing requirements;
- provide transient suppression;
- reduce short-circuit levels;
- increase pulse number;
- reduce harmonic content.

The design of snubbers, dv/dt, di/dt, or reactor networks in the converter is based on assumptions of the source impedance. Transformers may be used to adjust the impedance.

NOTE – The transformers are subjected to waveforms with harmonic content.

C.2.1 Voltage

When the line voltage is other than the rated converter input voltage, a step-up or step-down transformer or auto-transformer on the converter input may be used. The required voltage transformation may be accomplished by using feeder transformers supplying mixed loads. In the case of larger converters, separate dedicated transformers may be supplied for single converters or groups of converters.

C.2.2 Codes

Local or plant codes may specify electrical isolation, which could require the use of input transformers.

C.2.3 Provide Continuity of Service for Installations Prone to Nuisance Grounding

For certain applications, engineering practice may dictate the use of ungrounded or impedance grounded branch circuits on CDM/BDM and motors. Such applications are usually found in continuous process industries such as pulp and paper, food processing, chemical, cement mixing, mining, or metals.

Nuisance grounding of branch circuit conductors is common in these industries due to the effects of moisture or environmental conditions on the branch circuit and motor insulation systems. To maintain continuity of service in a nuisance ground environment, an isolation transformer is used to galvanically

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isolate the CDM/BDM branch circuit from the overall distribution system. In this manner, continued CDM/BDM branch circuit operation is possible with a single nuisance ground. To provide continued protection, the user should clear the nuisance ground at the earliest opportunity.

The use of a transformer to provide continuity of service under nuisance ground conditions should not be confused with the converter ground fault protection. Converter ground fault protection will protect the converter under ground fault conditions specified by the manufacturer but may not provide the continuity of service desired.

C.2.4 Line Voltage Unbalance

Unbalanced voltage greater than 3 % between phases of the incoming line may cause larger than rated line currents to be drawn from the a.c. line. An isolation transformer equipped with taps may be used to compensate the voltage unbalance at all rated load conditions.

C.2.5 Reduction of Converter Input Harmonic Currents

The CDM/BDM input currents are generally non-sinusoidal. These non-sinusoidal currents are composed of a sinusoidal component of current at line frequency (known as the fundamental current) and additional sinusoidal components of current (known as harmonic currents) at frequencies other than the line frequency.

Since the harmonic currents do not aid in the transmission of power and contribute to the volt-ampere loading of the distribution system, minimizing the magnitudes of these harmonic line currents is desirable.

For certain types of CDM/BDM, the harmonic content of the input line current may be varied by inserting impedance between the converter input and the distribution system. Transformers are convenient devices for modifying the feeder impedance characteristics.

See Annex B for additional information on feeder impedance modification and minimization of line voltage notching.

C.2.6 Reduction of Prospective Short-Circuit Current at Converter Input

When the prospective short-circuit current at the point of coupling (PC) of the converter is greater than the maximum short-circuit capacity of the converter stated by the manufacturer, input transformers may be inserted between the power distribution system and the converter to reduce the prospective current.

C.2.7 Pulse Number p

In some cases, transformers or auto-transformers are used in order to increase the pulse number and hence reduce the voltage harmonic distortion.

C.3 REACTORS

Line reactors can also be used in place of transformers to accomplish line voltage unbalance compensation, feeder impedance modification, minimization line notching and reducing of prospective short-circuit current.

Reactors (both iron and air cored) are also used in PDS converter topologies as filters, commutating elements, series smoothing, current balancing elements, etc.

Their design is special and relates to the particular converter topology used.

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C.4 SWITCHGEAR

Switchgear (disconnectors, circuit breakers, combination starters, contactors, etc.) may be used on the input of PDSs.

Such switchgear is not essential for converter operation but is intended to satisfy one or more of the following requirements:

- meet local codes;
- effect isolation (safety);
- protection.

C.5 REFERENCE DOCUMENTS

IEC 60289-1988	*Reactors*
IEC 60364-4-46-1981	*Electrical Installations of Buildings – Part 4: Protection for Safety - Chapter 46: Isolation and Switching*
IEC 60364-5-537-1981	*Electrical Installations of Buildings – Part 5: Selection and Erection of Electrical Equipment - Chapter 53: Switchgear and Controlgear - Section 537: Devices for Isolation and Switching*
UL 508	*Industrial Controllers*
UL 508C	*Power Conversion Equipment*
NEMA ICS 1.1	*Safety Guidelines for the Application, Installation and Maintenance for Solid State Control*
NEMA ICS 1-11A	*Surge Testing*
NEMA ICS 7	*Industrial Control and Systems, Adjustable Speed Drives*
NEMA ICS 7.1	*Safety Standards for Construction and Guide for Selection, Installation and Operation of Adjustable-Speed Drive Systems*
IEC 62103	*Electronic Equipment for Use in Power Installations*
IEEE 519-1992	*Recommended Practices and Requirements for Harmonic Control in Electric Power Systems*
IEEE 597-1983	*Practices and Requirements for General Purpose Thyristor d.c. Drives*
IEEE P936-1987	*Guide for Self Commutated Converters*
IEEE P995-1987	*Recommended Practice for Efficiency Determination of Alternating-Current Adjustable-Speed Drives*

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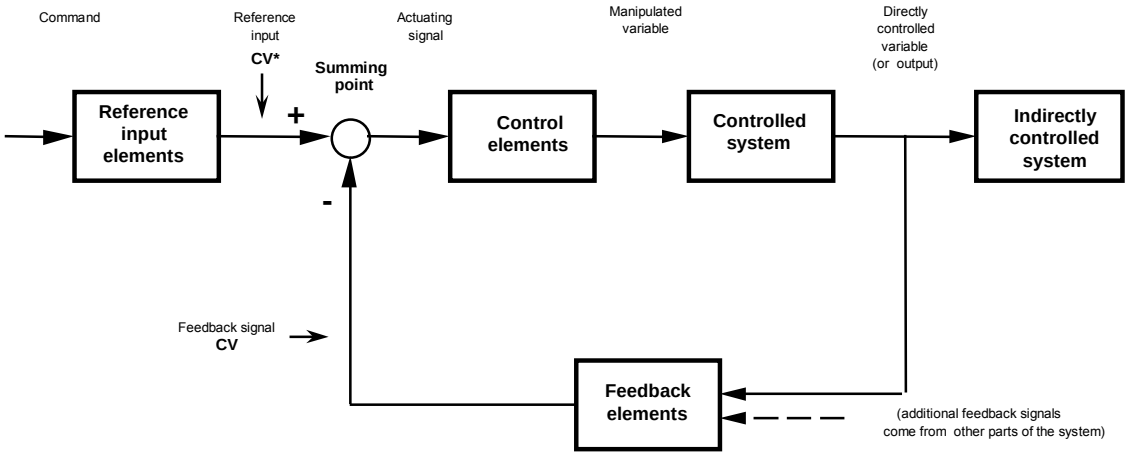
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Annex D
(Informative)
CONTROL STRATEGIES

There are many types of control strategies which are used in order to achieve the best compromise between such desirable aspects as good performance at all speeds, speed and torque responses, high efficiency, low harmonic content, high input power factor, and so on.

D.1 CONTROL CONFIGURATIONS

The ultimate scope of an adjustable speed d.c. drive system is to control a variable of a process. (See Figure D-1.) The variable may be a linear speed, a position, a tension or some other physical quantity.



Note - CV is the controlled variable, it appears in the diagram as :

- reference noted CV*;
- measurement of actual value noted CV.

Figure D-1
BLOCK DIAGRAM OF FEEDBACK CONTROL SYSTEM CONTAINING ALL BASIC ELEMENTS

In the overall feedback control system, a master controller and a d.c. motor control system can, in general, be distinguished.

The master controller compares the actual value of the process variable with the reference value and gives an output that is the command for the d.c. motor control system. The function of the d.c. motor control system is to regulate the value of a specified parameter of the d.c. motor to the value requested by the master controller.

The configuration and performance of the master controller are outside the scope of this part of IEC 61800.

This annex deals with the configuration of d.c. motor control systems.

D.1.1 Basic Structure

The basic structure of a motor control system depends on the requirements of the application.

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The most important of these are listed below:

a) the parameter of the motor, that is sensed to provide the primary feedback signal, may be the speed of revolution (speed control with speed feedback signal), the d.c. voltage (speed control with d.c. voltage feedback signal) or the torque producing current (armature current and field current control);

b) operation with or without field weakening;

c) operation with or without armature current reversal, or field current reversal;

d) armature current reversal, if any, with or without circulating current.

Table D-1 shows how, considering these variants and their relative possible combinations, nine basic structures (from A to I) of d.c. motor control system configurations may be defined.

Current control is not considered as a specific variant taking into account that quite often the configurations listed in Table D-1 are provided with a current controller.

Table D-1
TYPICAL CONTROL CONFIGURATIONS

		Control configurations								
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
V	**Feedback device**	Tachometer						d.c. voltage transducer		
a	**Without / with field weakening**	Without			With			Without *		
r	**Without / with armature current reversal**	With-out	With		With-out	With		With-out	With	
i	**Armature current reversal without / with circulating current**		With-out	With		With-out	With		With-out	With
a	**Without / with field current reversal**	A1 without A2 with			D1 without D2 with			G1 without G2 with		
n										
t										
s										

* When a d.c. voltage transducer is applied for feedback, field weakening operation is possible by sending the "speed" reference to the field current controller via a function generator giving the proper relationship between field current and speed at constant d.c. armature voltage. This is an old method.

The configurations A and G are the simplest. They correspond to operation without field weakening and armature current reversal, using respectively a tachometer or a d.c. voltage transductor as a feedback device. All other configurations may be obtained by additional specific blocks.

Figure D-2 shows a block diagram containing most of the control configurations. With reference to this figure, in Table D-2 each control configuration is split into its constitutive blocks.

In some drive systems a control system is employed which utilizes parallel speed and current control loops as an alternative to the classical series regulator configuration.

D.1.2 Optional Facilities

Besides the basic structure, a d.c. motor control system has some optional facilities. The most relevant are listed in Table D-2. They are also shown in the block diagram (Figure D-2).

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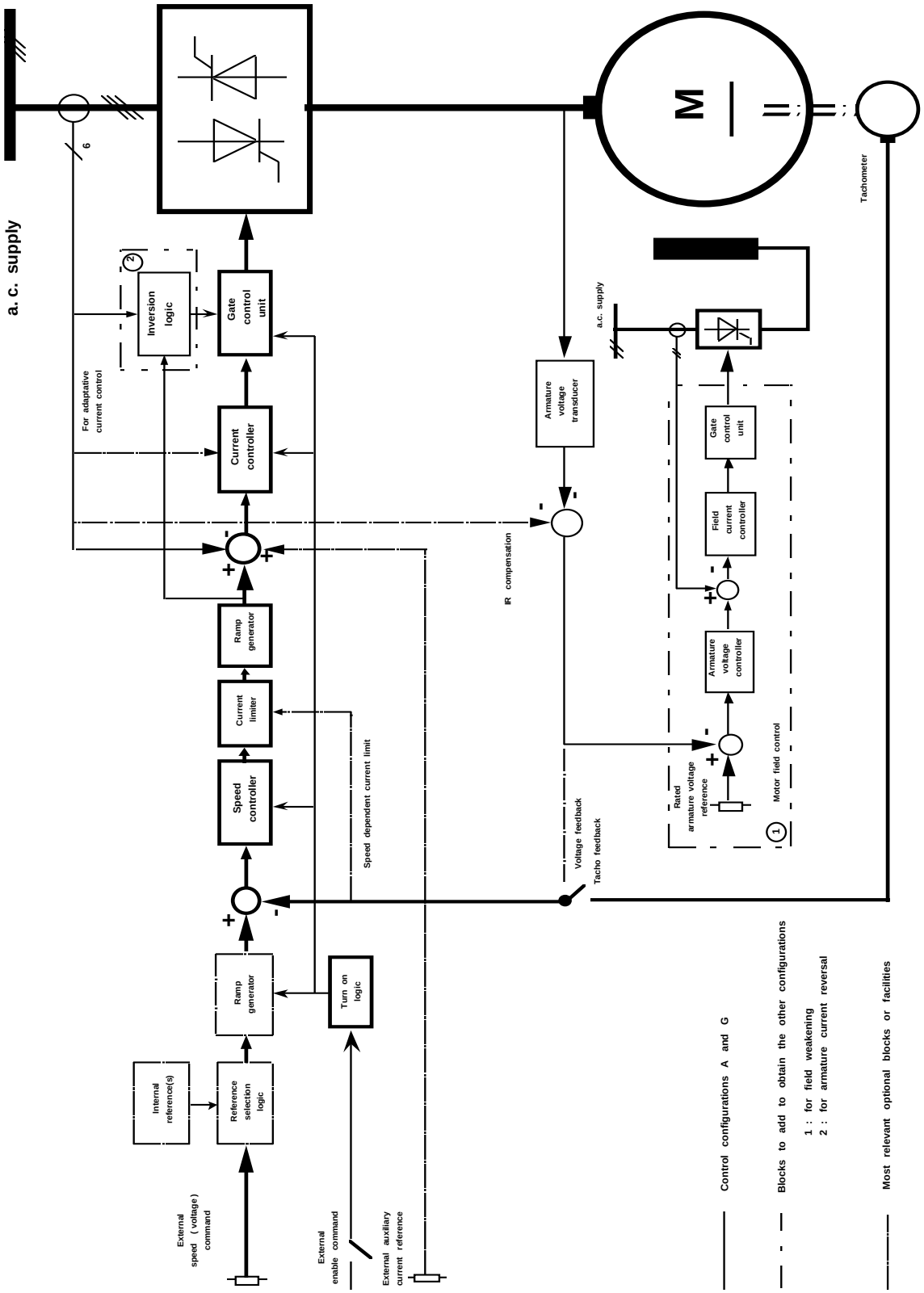


Figure D-2
BLOCK DIAGRAM

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Table D-2
COMPOSITION OF THE TYPICAL CONTROL CONFIGURATIONS

		Control Configurations								
		A	B	C	D	E	F	G	H	I
Basic blocks	Tachometer	⊗	⊗	⊗	⊗	⊗	⊗	≠	≠	≠
	DC armature voltage	≠	≠	≠	⊗	⊗	⊗	⊗	⊗	⊗
	Speed controller	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	Current limiter	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	Current controller	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	Gate control unit	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	Turn on logic	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
	Motor field control	≠	≠	≠	⊗	⊗	⊗	≠	≠	≠
	Inversion logic	≠	⊗	≠	≠	⊗	≠	≠	⊗	≠
Option	Internal references	o	o	o	o	o	o	o	o	o
	Reference selection logic	o	o	o	o	o	o	o	o	o
	Ramp generator	o	o	o	o	o	o	o	o	o
	Speed dependant current limit	o	o	o	o	o	o	o	o	o
	IR compensation	≠	≠	≠	o	o	o	o	o	o
	External auxiliary current reference	o	o	o	o	o	o	o	o	o
	Adaptative current controller	o	o	o	o	o	o	o	o	o
	Circulating circuit regulator	≠	≠	⊗	≠	≠	⊗	≠	≠	⊗
	Speed controller gain correction during field weakening	≠	≠	≠	o	o	o	≠	≠	≠
	Minimum and full field limit	≠	≠	≠	o	o	o	≠	≠	≠

⊗ The block is always present in the configuration.
≠ The block is never present in the configuration.
o The block is optionally present in the configuration.

D.1.3 Digital And Analog Control

The drive control can be made by analog or digital techniques.

When digital techniques are used, the system has one or several sampling times provided by the clock.

Sampling time is a period in which measures for calculation are constant, calculations are performed, and resulting controller outputs are constant.

The sampling time is chosen in relation to the time constants of the controlled process and with the response time required by the process.

The same consideration is made for transport time, required for the transmission of information between different digital systems.

D.2 CONTROL MODES

D.2.1 Operating Modes

Two operating modes are exemplified which relate the user's need to the performance of the equipment. These are:

a) torque control mode;

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b) speed control mode.

It is important to distinguish between:

- electromagnetic torque produced by the electrical machine;

- mechanical torque on the shaft.

This last variable involves the complete mechanical system because of the load reaction Unless otherwise specified, it is conventionally assumed that “torque” is the electromagnetic torque without considering load reaction and loss.

D.2.2 Loop Control

As no comparison is meaningful without first defining the loop control, three types of feedback loops are considered.

a) open loop control, without feedback;

b) closed loop control, with indirect (calculated) feedback. This calculation is made from electrical variables such as voltage, flux, current, firing pulses of the converter, etc. The manufacturer should indicate how this feedback was calculated; i.e. using stated variables, d.c., a.c. and so on;

c) closed loop control, with direct (sensor) feedback. The manufacturer has also to specify the performance requirements for the sensor: accuracy, bandwidth and so on.

D.2.3 Accuracy and Performance

Table D-3 illustrated below shows one suggested generalized format intended to help the user analyze the way a drive is controlled and hence evaluate its expected performance.

This table requires the manufacturer to identify the control performances both for steady-state conditions and in terms of dynamic response. The manufacturer is to indicate the typical guaranteed accuracy with steady state conditions, for each operating mode at:

- low speed;

- medium speed (50 % of base speed);

- base speed;

- maximum speed.

Table D-3

DRIVE SYSTEM CONTROL STRATEGIES

Operating mode	Feedback type	**Static Behavior** (accuracy / deviation band)				**Dynamic Behavior** (settling time to a reference step)
		Low speed	Medium speed	Base speed	Maximum speed	
Torque control mode	**Without feedback**					
	With indirect feedback (calculated)					
	With direct feedback (sensor)					
Speed control mode	**Without feedback**					
	With indirect feedback (calculated)					
	With direct feedback (sensor)					

NOTE 1 – The service deviation band and the operating deviation band are related to the maximum rated values (see 6.1).
NOTE 2 – Between base speed and maximum speed, the CDM provides excitation to the motor which results in less than rated flux. In this condition, the motor works in an underexcited mode and the drive provides constant electrical power.

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D.3 STEADY STATE AND TRANSIENT PERFORMANCE

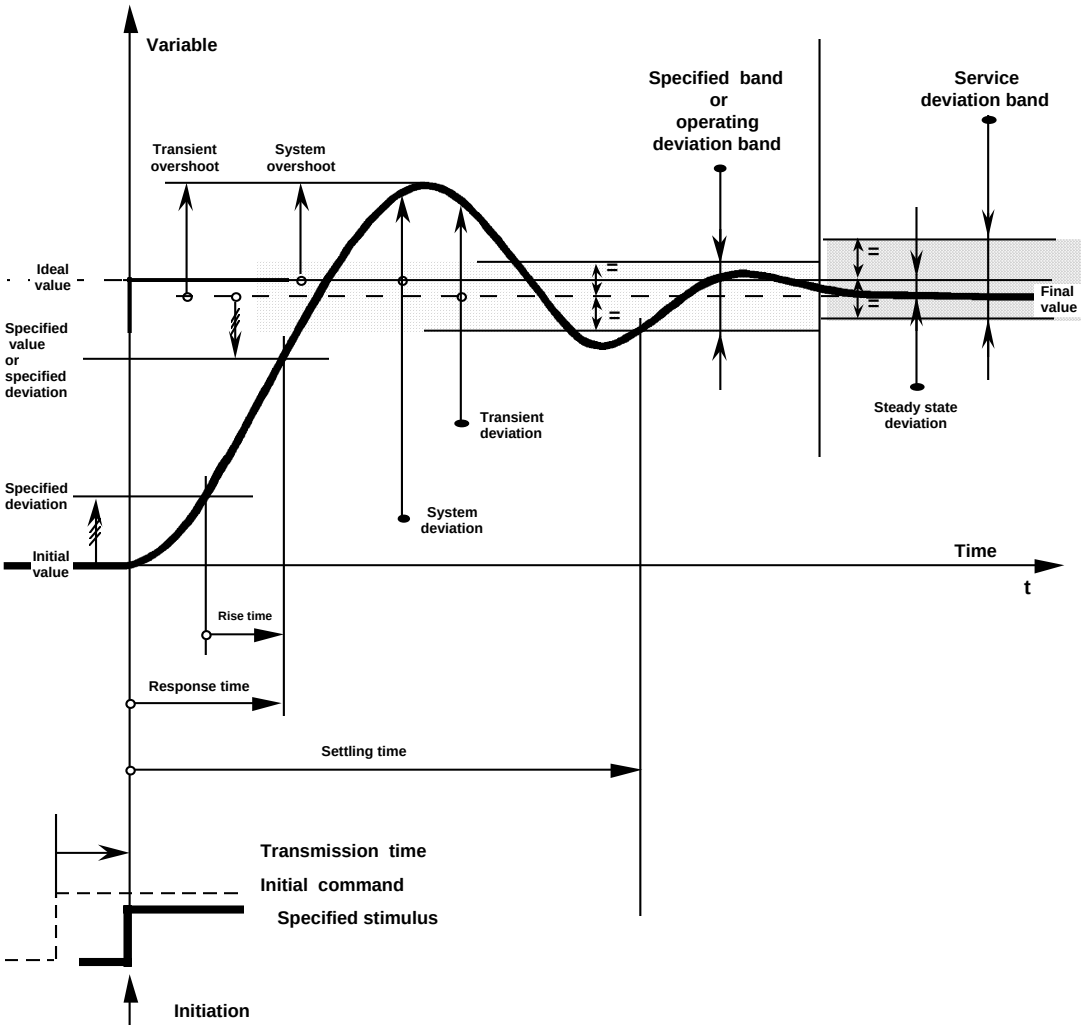
D.3.1 Time Response

Time response represents the output versus time curve resulting from the application of a specified input under specified operating conditions. Reference input elements are those elements which operate in response to the command to produce a suitable reference-input signal and transmit it to the summing point. (See Figure D.1) Referring to Figure D-1, the ideal value is reached when the feedback signal equals the reference input.

D.3.1.1 Response Time

Response time is the time required, following the initiation of a specified stimulus to a system, for an output going in the direction of the necessary corrective action to first reach a specified value. (See Figures D-3, D-4, D-5.)

NOTE - Specified value is often taken as an error value referred to an ideal value in percent.



NOTE 1 – The specified value is often as an error value referred to the final value.
NOTE 2 – Settling time: if the band is not specified, it should be assumed to be the operating deviation band but centered on the final value.
NOTE 3 – Response time: if the deviation is not specified, it may be assumed to be the minus or plus value of the operating deviation band.
NOTE 4 – Rise time: if the deviations are not specified, they may be assumed to be the plus or minus values of the operating deviation band. (Typically, rise time is defined as the time between 10% and 90% of steady-state value).

Figure D-3
TIME RESPONSE FOLLOWING A STEP CHANGE OF REFERENCE INPUT — NO LOAD CHANGE

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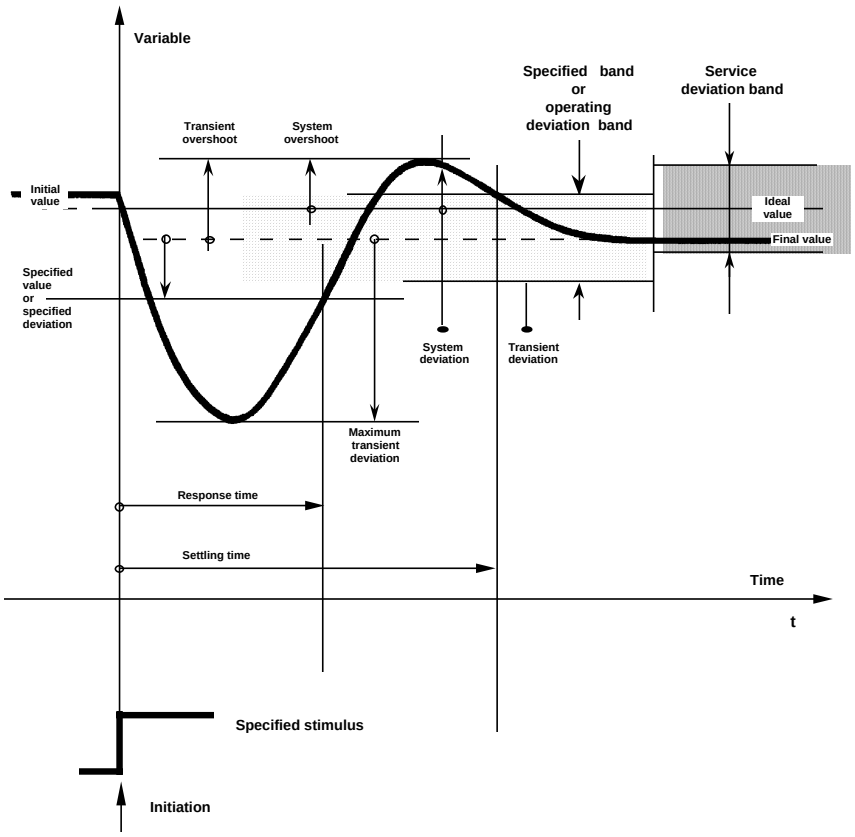


Figure D-4
TIME RESPONSE FOLLOWING A STEP INCREASE IN LOAD — NO REFERENCE CHANGE

D.3.1.2 Rise Time

Rise time is the time required, in the case of steady-state increment, for the output of a feedback system (other than first order) to make the change from a small specified value near the initial value to a specified value near the ideal value. The specified values are often 5% to 10% and 95% to 90% of the increment before overshoot, if any. (See Figure D-3.)

If the term "rise time" is unqualified, response to a step change is understood. Otherwise the pattern and magnitude of the stimulus should be specified.

D.3.1.3 Settling time

Settling time is the time required, following the initiation of a specified stimulus to a system, for a specified variable to enter and remain within a specified narrow band centered on its final value. (See Figures D-3, D-4.)

NOTE – If the band is not specified, it should be assumed that it is the operating deviation band.

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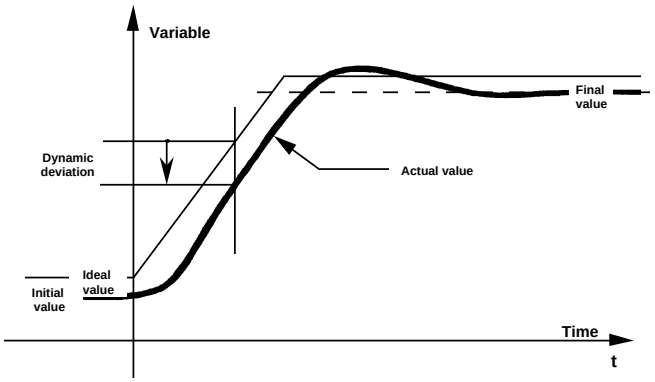


Figure D-5
TIME RESPONSE FOLLOWING A REFERENCE CHANGE AT SPECIFIED RATE

D.3.2 Performances of Particular Functions

Additional information may be requested about particular functions.

D.3.2.1 Speed Ratio Control

Speed ratio control is a control which operates two drives at a preset ratio of speeds. The adjustment range of a speed ratio control, when direct proportionality exists between the two drives as shown in figure D.6, is usually expressed as plus or minus percentage with respect to the master drive speed.

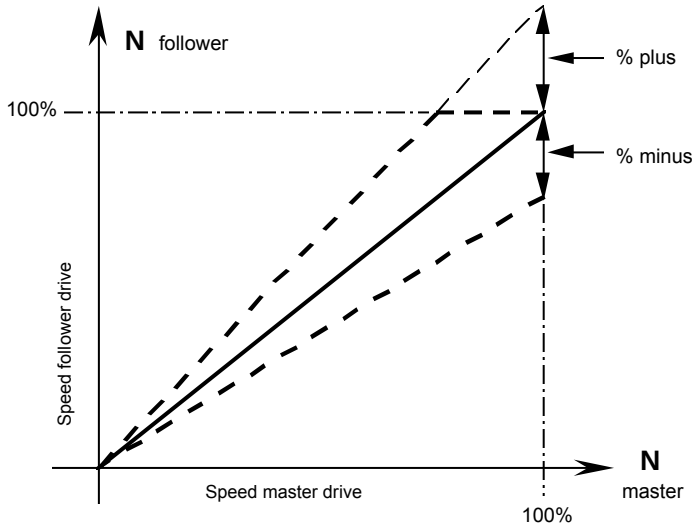


Figure D-6
MASTER / FOLLOWER DRIVE SYSTEM

D.3.2.2 Speed Ramp Generator

The performance of the ramp generator, if provided, is defined by the range of acceleration or deceleration rate that may be set. In addition, the application of fast deceleration for emergency stopping should be considered.

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D.3.2.3 Current Limiter - Torque Limiter

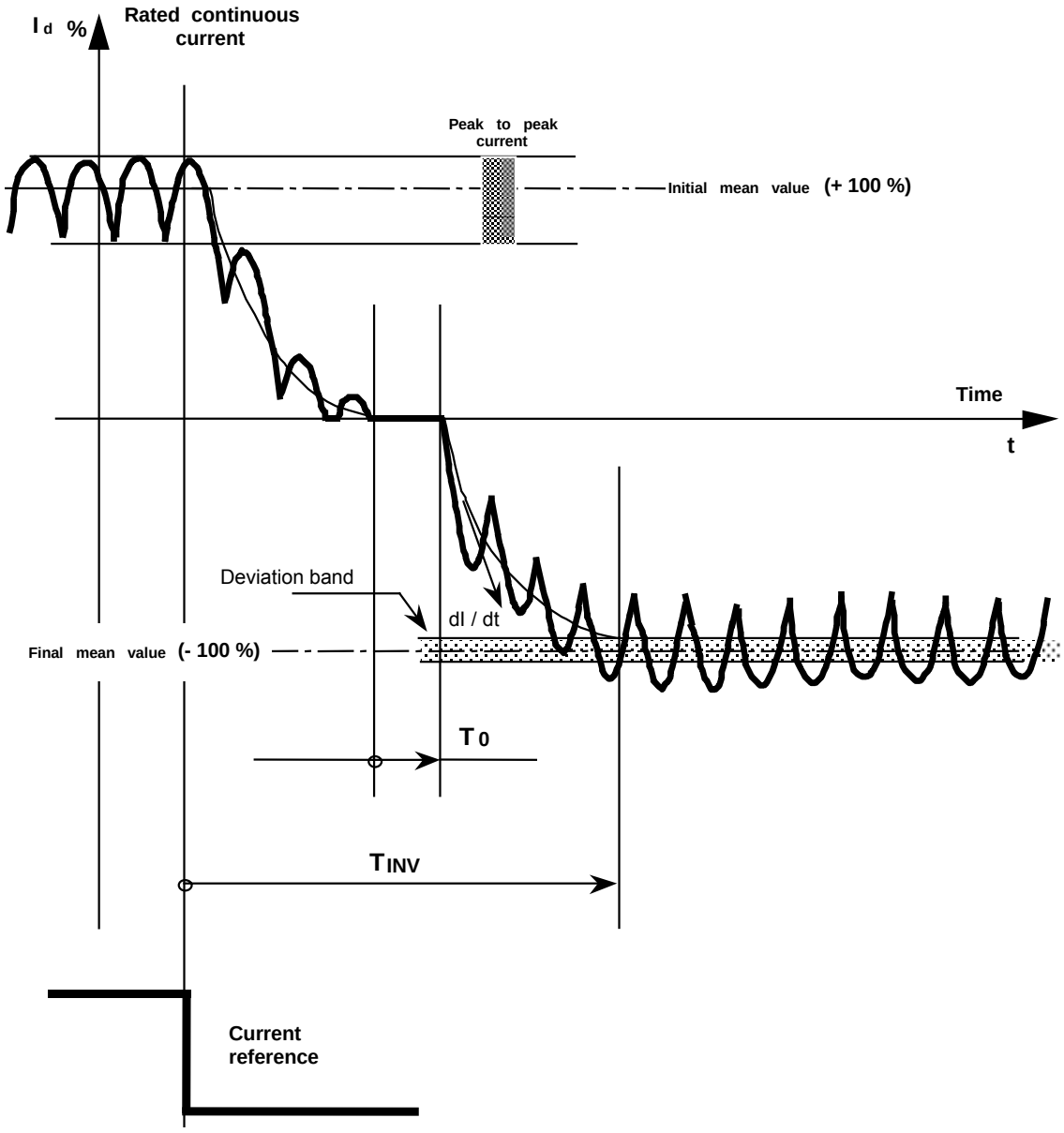
The characteristics of the current/torque limiter are defined by the range in which the current limit may be set.

D.3.2.4 Armature Current Reversing Time

For drives with armature current reversing without circulating current, there is an interval during current reversion in which the current is zero. In Figure D-7 the method of measurement of reversing time is demonstrated. The test conditions are: speed is zero, no field is applied, motor shaft is locked, rated current step applied and reverse current demanded. Measurement is made and recorded.

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T 0 **Zero current inversion time.**

T INV **Inversion time: It starts with the initial step signal, and lasts until the mean value of the current remains in its operating deviation band. The rate of change of current influences, of course, the inversion time.**

Figure D-7
ZERO CURRENT INVERSION TIME

D.4 LIST OF RELEVANT CONTROL PARAMETERS

D.4.1 CDM/BDM Control Parameters

According to Figure D-2 the basic CDM/BDM parameters are:

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- acceleration time for direct speed reference;
- deceleration time for direct speed reference;
- acceleration time for reverse speed reference;
- deceleration time for reverse speed reference;
- gain of speed controller if any;
- constant time of speed controller if any;
- direct current reference limitation;
- reverse current reference limitation;
- di/dt limitations;
- gain of current controller;
- constant time of current controller;
- firing angle limitations (rectifying and regenerating);
- d.c. voltage limitation;
- gain of flux controller;
- constant time of flux controller, etc.

D.4.2 Motor Parameters

Motor parameters include:
- armature resistance;
- armature inductance;
- field circuit resistance;
- field circuit inductance.

D.4.3 Mechanical Parameters

Mechanical parameters include:
- inertia (including the part of the rotor of the motor);
- elasticity;
- backlash;
- others.

D.4.4 Supply Parameters

Supply parameters include:
- R_{SC} short circuit ratio;
- harmonic impedance;
- line impedance (fundamental) or continuous current capacity.

D.5 STRUCTURES

D.5.1 Functional Structures

Variables involved in a drive are speed and torque.

Reference is made to Figure D-8.

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The motor is an energy converter (electrical to mechanical). Electromagnetically it is a torque producer which can be electronically controlled.

The converter is a power electronic unit which requires a firing system (converter control and gating interface). The combination of the converter and the converter control constitutes the controlled converter.

The actuator control achieves the command of torque production, controlling the electromagnetic behavior of the motor, through the controlled converter.

The combination of the motor, the controlled converter and the actuator control constitutes the actuator. The system control transmits the references, the command and the system sequencing to the actuator.

The combination of the system control, the actuator and the driven equipment constitutes the installation, or part of the installation.

D.5.2 Hardware Structures

The hardware structures, specifically the limits of the different components of the drive system, do not correspond to the functional structure definitions.

This is technologically driven. Different suppliers may be responsible for various elements due to their specific technical expertise in that area. For example, driven equipment is not included in the drive system.

It is of use to define the complete drive module (CDM), which is the drive system, without the motor (and its associated sensors). As seen in Clause 2, Figure 2-3 and in Figure D-8, the CDM can be divided in a basic drive module (BDM) and its extensions. This BDM may or may not include the speed controller.

Stand alone products are basic or complete drive modules (CDM or BDM). When connected to a motor, they become a drive system (PDS).

D.5.3 Important Drive Performances Issues

The performance which is specific to the CDM/BDM, only concerns the torque producing motor current.

Speed performance depends on the CDM/BDM, the motor, and the driven equipment. They are not specific to the CDM/BDM alone. In fact, some mechanical characteristics such as torsional elasticity and backlash, can limit the performance of the drive system, because they limit the response time of the speed controller.

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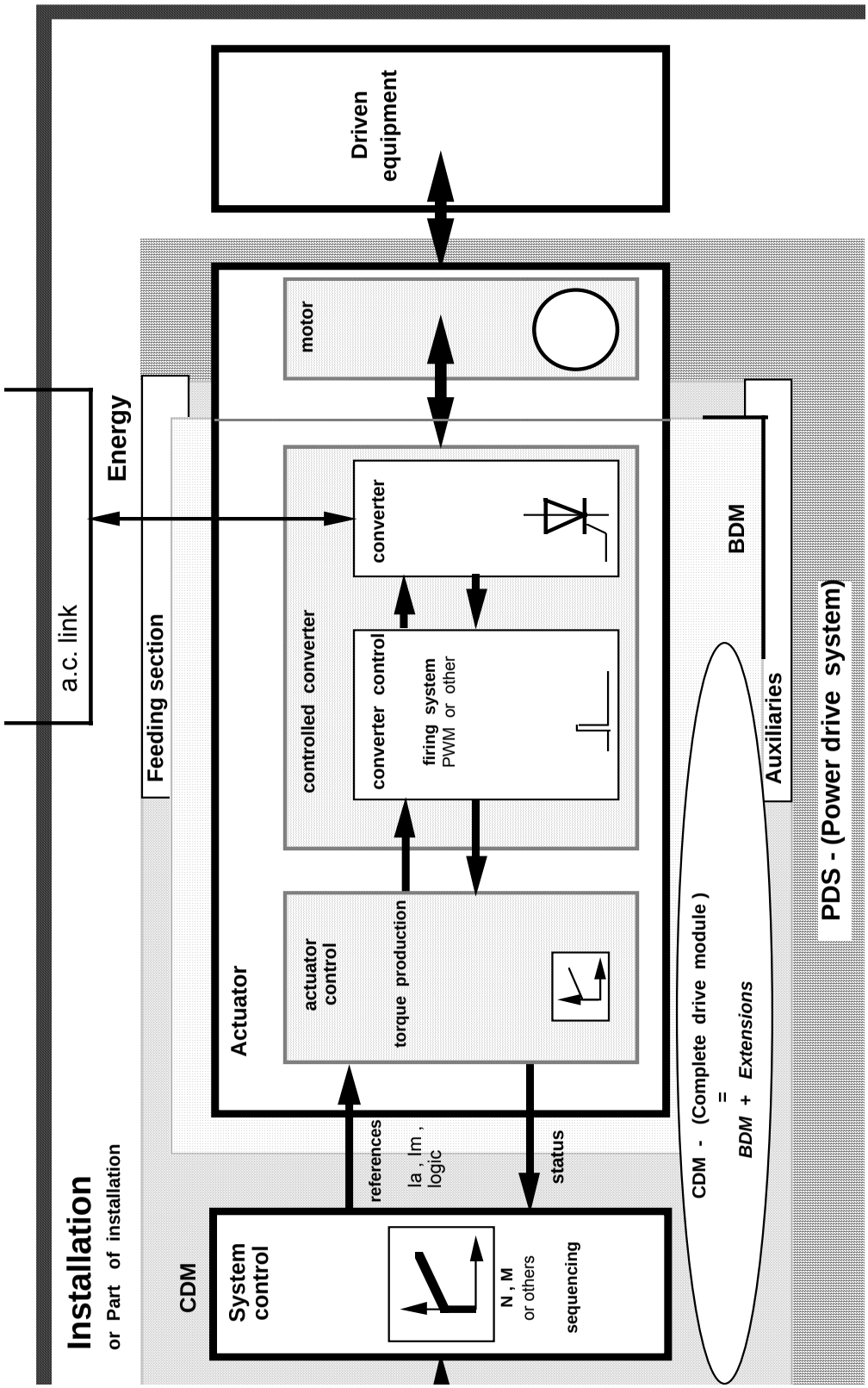


Figure D-8
STRUCTURE OF A DRIVE SYSTEM

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D.5.3.1 Effect of Torsional Elasticity

The connection of a motor to a driven equipment, by a shaft and/or gearing, generates a NTF (natural torsional frequency) depending on the mass inertia and from the transmission elasticity as follows.

$$NTF = \frac{1}{2\pi}\left[\frac{K(J_M + J_D)}{J_M - J_D}\right]^{1/2}$$

where:

J_M is the motor inertia
J_D is the driven equipment inertia
K is the transmission spring constant (1/K = elasticity)

This equation refers to a two mass system. (A system with three or more masses presents two or more NTFs.) In many cases the NTF frequency is very high.

If we have:

$$NTF >> 10 / T_R$$

where T_R is the requested response time of the speed controller, the speed time response is relatively independent of the electrical and mechanical parameters of the drive. It is more related to the control characteristics, particularly to the mechanical and electrical quality of the sensor, and to the lead time constant and damping factor of the speed controller.

Also, the maximum speed transient deviation will depend on the inertia of the drive system and/or the magnitude of the step when a step load is applied.

In some cases, especially when the transmission shaft has a low value of spring constant (for example if it is long), and the inertia of the driven equipment is high, the NTF frequency of the drive can be less than $10 / T_R$.

In this case, to avoid vibration during operation, the speed controller response time is to be tuned to a higher value with respect to the NTF, depending upon the values of the mechanical parameters (i.e. mass inertia and spring constant of the transmission. As a consequence, for the same value of inertia and the same control characteristics, the maximum speed transient deviation for a step load change is higher for such a system, than that experienced in a system where naturally $NTF > 10 / T_R$.

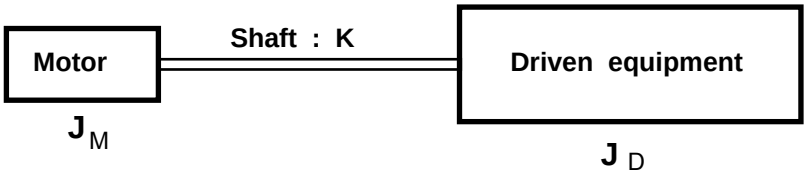


Figure D-9
MECHANICAL DIAGRAM

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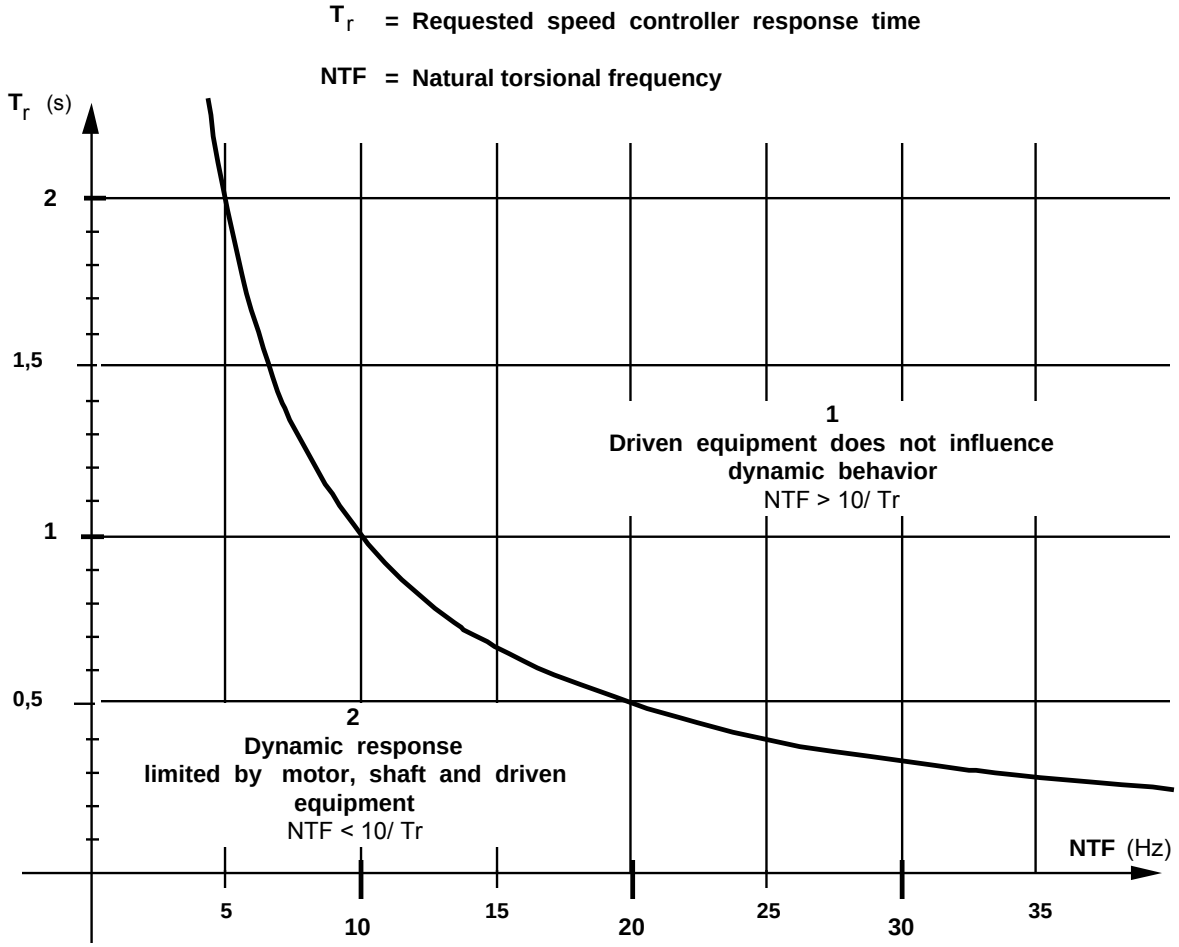


Figure D-10
SIMPLE STABILITY CRITERION

D.5.3.2 Effects of the Backlash

Gearing backlash introduces a non-linearity into a drive system, when there is the possibility of a torque reversal (for example a step reduction in the speed reference, demanding a slow down on a drive system, supplied by a four quadrant converter). (See Figure 2-3).

A torque reversal opens the backlash causing, for a very short time, the disconnection of the motor from the driven equipment, and a resulting reduction of the system inertia. Thus the speed controller takes up the gear play (backlash) in a very short time. At this point the system can be shocked into torsional vibration, damped out after a number of cycles (depending upon the damping factor of the system).

This temporary vibration can be reduced, but not always eliminated, by a special backlash compensation function.

In processes requiring good dynamic drive performance, it is therefore necessary to minimize gear backlash.

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Annex E
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PROTECTION

E.1 INTRODUCTION

This annex helps the user understand how to protect PDS/CDM/BDM properly. These techniques are applied differently but can have a common classification according to physical phenomena. The application will also depend on the installation itself. The following guide gives only general information for availability of the equipment.

E.2 EQUIPMENT AVAILABILITY

Equipment availability refers to continuing performance of the equipment. These protection circuits react primarily to external factors which influence the drive system.

E.2.1 Equipment Protection Circuits

These protection circuits should prevent equipment failures and also damage to the plant or the components. Exceeding the limiting values will cause these protection circuits to come into operation. The limiting values are established below destruction thresholds for the components.

E.2.2 Types of Equipment Alarms and Faults

Alarms and faults are classified into four categories according to how critical the fault is and how quickly protection action is required. Examples are given in Figure E-1. The four categories can be used according to the application. When used, they are defined in such a way that stopping of the equipment to eliminate the fault will cause the least possible interruption of the driven equipment within the process. Such strategies have to be agreed between user and manufacturer. The indicated alarms and faults can be individually displayed in the equipment monitoring system or send to the control room monitors.

The following categories of messages which may be used, indicate abnormal conditions of the equipment.

a) Alarm

A message indicating abnormal condition, which does not require immediate action (e.g., earth fault). An alarm will stay effective until reset and disappears only after the cause has been eliminated.

b) Light fault 1

A fault typically related to temperature rise with long time constant. Production of the process can be stopped in a reasonable time, which has to be agreed upon between the user and manufacturer according to the production schedule, for example stop of production without loss of produced material.

c) Light fault 2

Production is continued for a short, reasonable time to be agreed upon between user and manufacturer according to the process. Material can be stored before tripping of the equipment.

d) Heavy fault

The equipment is tripped directly and production is interrupted immediately. Material in the driven equipment and/or process may be lost as scrap.

E.2.3 Alarm and Fault Listing

Messages needed and setting values are proposed by the manufacturer and should be agreed upon between user and manufacturer. Examples are shown in Figure E-1. These examples illustrate those associated with CDM applied in a coordinated drive system utilizing high performance drives. Simple drive applications may provide alarm and trip functions only.

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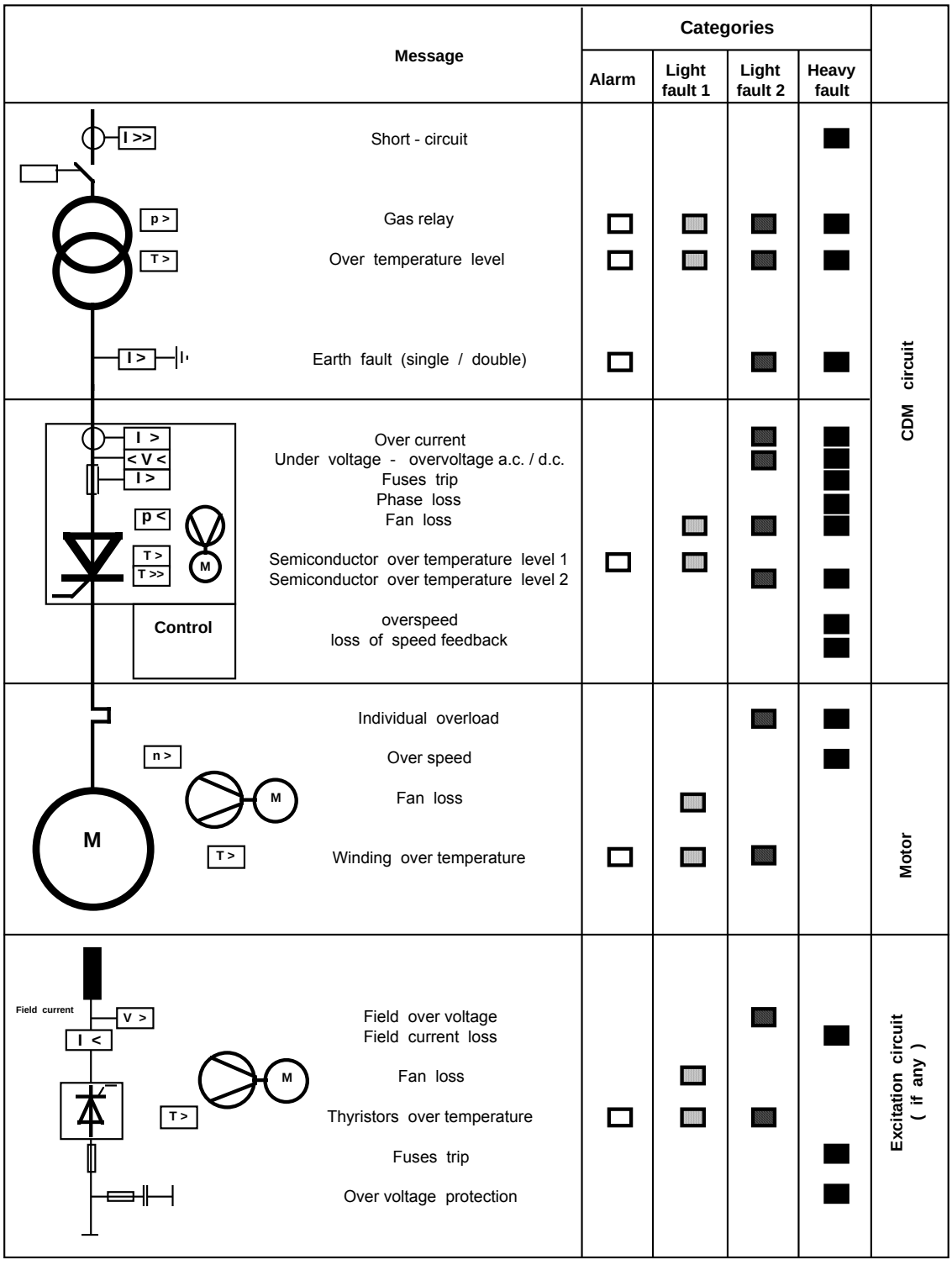


Figure E-1
PROTECTION CLASSIFICATION

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E.3 SYSTEM PROTECTION (FEATURES AND DEVICES)

The purpose of this clause is to help the user consider techniques and select the necessary devices to properly protect the system. The system includes, but is not limited to:

a) line feeders;
b) line isolation transformers;
c) motors;
d) power factor correction capacitor banks;
e) system control circuits.

Protection for these auxiliaries is provided through the co-ordination of current interruption devices, circuit impedance, surge arrestors, relays and alarm devices. These devices prevent dangerous overvoltage, overcurrent, and overtemperature conditions.

Mechanical sensors are also provided on motors, transformers, and other equipment, when needed to detect overspeed, excessive vibration, loss of lubrication, loss of ventilation and other improper running conditions. They signal shutdown of the system before mechanical damage occurs.

E.4 PROTECTION OF THE DRIVE SYSTEM

E.4.1 Protection Included in the CDM/BDM

The exact requirements for the drive system protection (See Figure E-1) will depend on the mission and configuration of the equipment. To protect the equipment from damage caused by other contingencies, protection is recommended according to Figure E-1.

A well designed system provides also protection against contingencies, both internal and external to the drive system. These include:

a) power source irregularities
- voltage transients,
- under/over voltage,
- phase loss, phase reversal,
- phase unbalance,
- outages;

b) overcurrent conditions
- fault currents,
- ground currents,
- internal faults,
- overloads;

c) ventilation loss;
d) overtemperature of equipment;
e) sudden pressure change in liquid filled reactors and transformers;
f) overspeed of motors;
g) excessive vibration of motors;
h) loss of motor lubrication.

NOTE – Transient earth currents should be taken into account due to load/system earth capacitance.

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E.4.2 Specific Motor Protection

Motors and motor branch circuits are effectively protected by apparatus using relay devices which can disconnect the converter. Besides overcurrent and overload protection, it is highly recommended that winding overtemperature be used for motors over 400 Hp (300 kW).

E.4.3 Specific Transformer Protection

Isolation transformer protection is typically provided by relays. Overcurrent protection in the primary circuits is required. Ground fault and differential current protection are commonly provided on larger units. Care should be taken in selecting relays for this application, including consideration of harmonics.

Surge protection is typically provided on the primary side of isolation transformers. When properly co-ordinated, it can protect the entire drive system from line voltage surges caused by electrical storms and switchgear transients.

E.5 MACHINERY ASPECTS AND OTHER REFERENCE DOCUMENTS

IEC60204: *Electrical Equipment Of Industrial Machines*

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Annex F
(Informative)
Topologies

F.1 CONVERTER TOPOLOGIES (CONFIGURATIONS)

F.1.1 Introduction

Figures F-1 and F-2 suggest classifications of power converter topologies appropriate to feed d.c. drive systems.

F.1.2 Converter Topologies

Figure F-1 shows the main configurations for line-commutated converters.

Figure F-2 shows the self-commutated converter (choppers) configurations.

Figure F-3 explains the symbols used for line-commutated converters.

Figure F-4 explains the symbols used for choppers.

F.2 CONSEQUENCES

As mentioned in 5.4, there is a d.c. ripple current feeding the motor which is dependent on the topology of the converter. The ripple current has a direct effect on the commutation quality of the motor. Tests described in 7.4.2.4 are intended to be made with the defined converter of the drive.

It is possible that motor tests are made in the motor manufacturer's premises with converter ripple in class A. These tests are not representative of the final commutation behavior of the motor. In such a case experience recommends that a black commutation be obtained (code 1 according to table 10) at 1,5 times the rated current. Such a result generally provides proper operation with class C ripple converters.

Commutation of a d.c. motor depends on many parameters, including air humidity. During the prime time of running, the motor has to develop a correct patina. Several parameters are important for successfully obtaining and maintaining this "patina," on the commutator:

- the commutator surface runout;
- the roughness of the copper surface;
- improper undercutting of the mica;
- the brush finish;
- the brush rocker position;
- the brush grade and tension.

Experience has shown that proper values are:

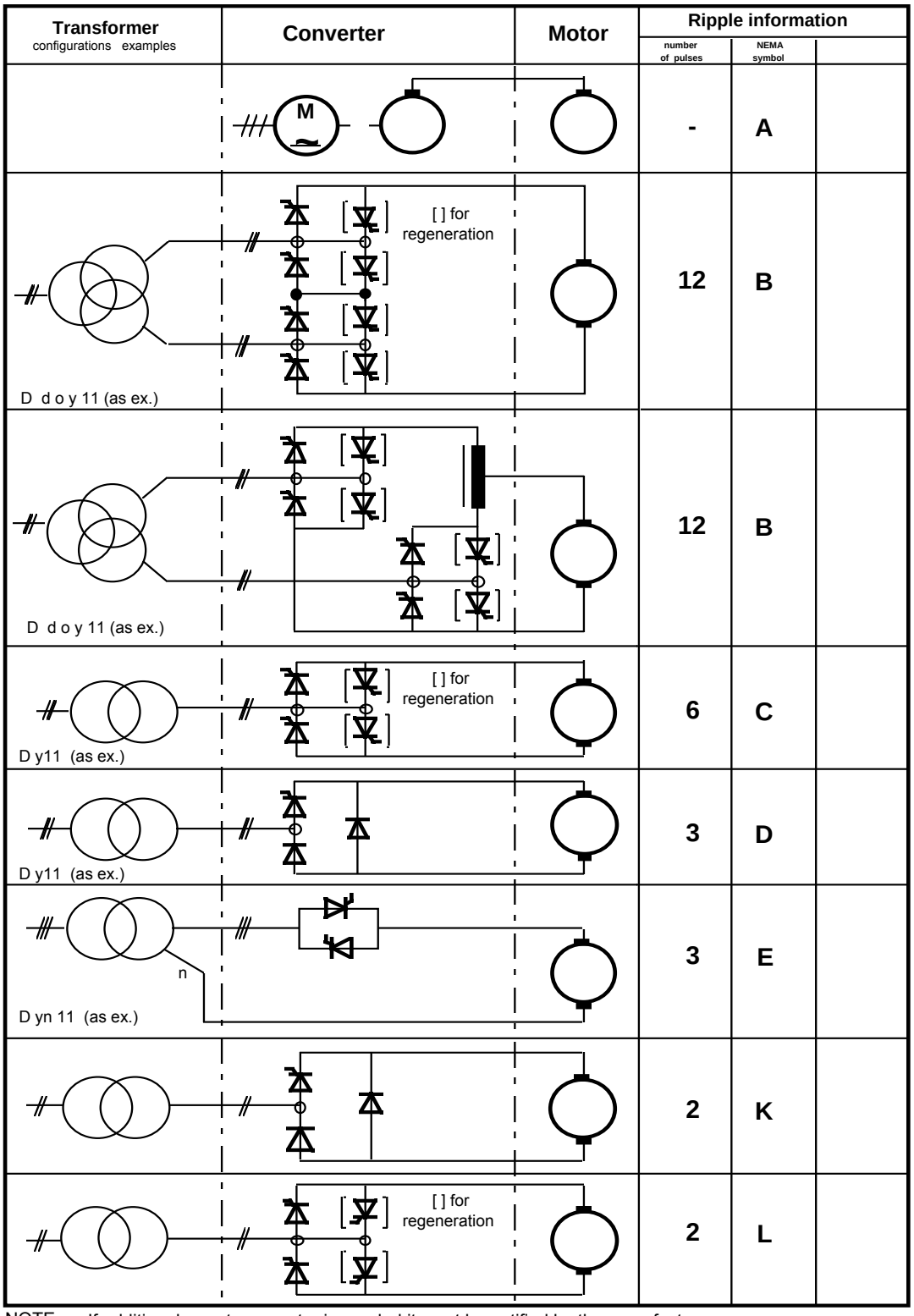
- commutator surface runout < 20 µm for motor size less than or equal to 250 mm axis height
- commutator surface runout < 30 µm for larger motors
- roughness for industrial motors 0,9 µm < R_a < 1,8 µm (from a few kW to hundreds of kWs)
- roughness for small motors 0,5 µm < R_a < 1,0 µm (< 1 kW), with sufficient density of peaks.

R_a is the mean value of roughness: the arithmetic mean value of all values (y) of the roughness profile on the evaluation length (l).

$$R_a = \frac{\sum_0^l |y| \cdot \Delta x}{l} \qquad \text{with} \qquad \frac{\sum_0^l y \cdot \Delta x}{l} = 0$$

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NOTE - If additional armature reactor is needed it must be notified by the manufacturer

Figure F-1
MAIN CONFIGURATIONS FOR LINE - COMMUTATED CONVERTERS

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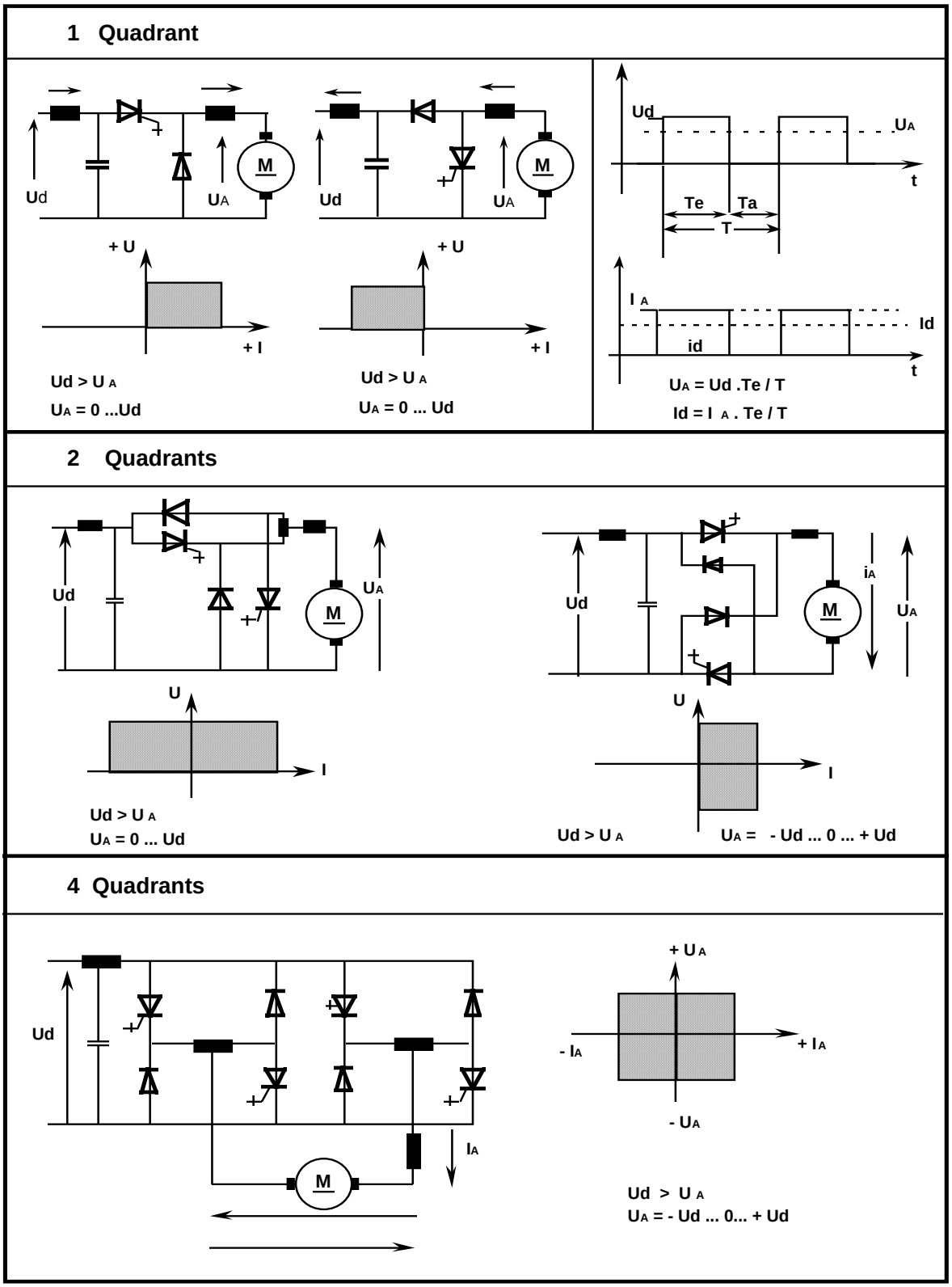
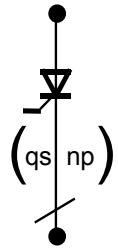


Figure F-2
SELF COMMUTATED CONVERTERS (CHOPPERS)

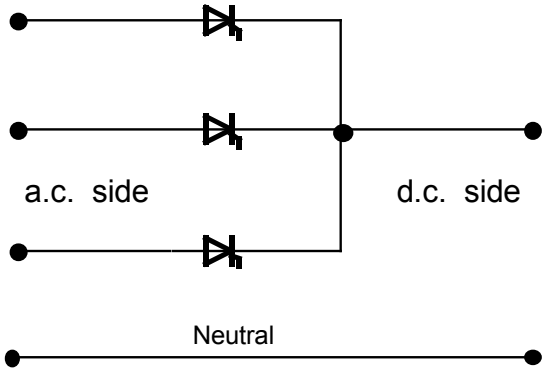
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NOTE – A polyphase converter is figured here by a single-line diagram, in which the polyphase links are represented by their equivalent single line.

Figure F.3a – Diagram of a valve with q thyristors in series (= a branch), p branches in parallel (= a valve with all necessary protective devices)



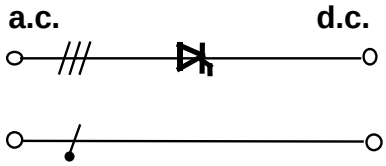
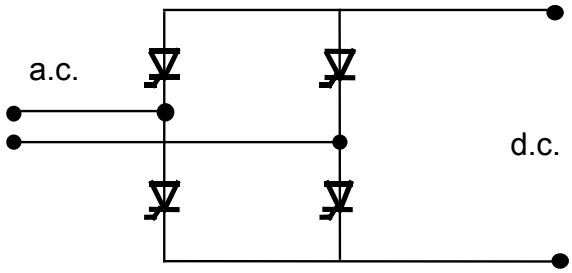


Figure F.3b – Example of a three-phase converter



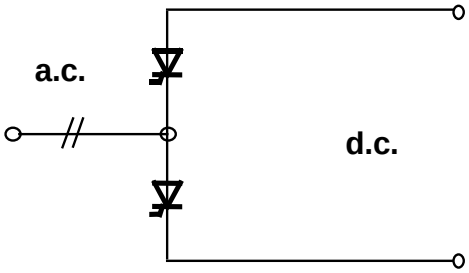
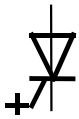
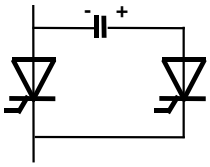
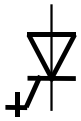


Figure F.3c – Example of a single-phase Graetz bridge

Figure F-3
SYMBOLS FOR CONVERTERS

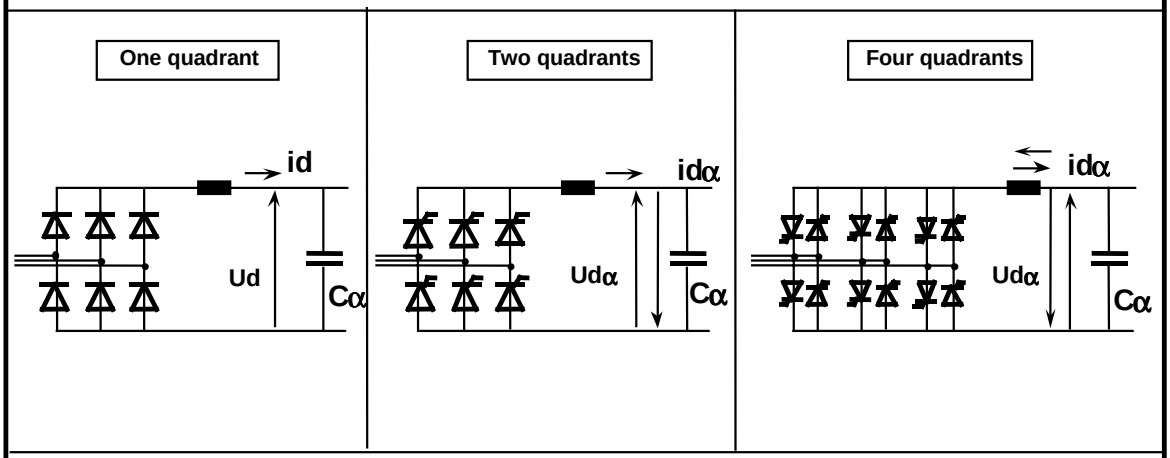
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	Diode	Thyristor	Thyristor (self-commutated)	Transistor	GTO
Symbol of the switch					
Valve					

NOTE - The symbols of the switch may be changed from the self-commutated thyristor to a transistor or a gate-turn-off thyristor without changing the function.

AC line converter combinations — AC to DC link



NOTE - These a.c. line converter combinations are to be selected with respect to the chosen one-, two-, or four-quadrant operation of the d.c. drive system

Figure F-4
SYMBOLS FOR CHOPPERS

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Annex G
(Informative)
MONITORING FEATURES

G.1 GENERAL

Monitoring of the complete drive system is divided into two parts:

- monitoring of CDM status;
- monitoring of motor status.

In addition, there are two ways of monitoring, which can lead to two different strategies:

- monitoring for a stand alone drive system;
- monitoring for a drive system integrated in an overall automation system.

The monitoring system of the CDM normally gives more detailed information about failure and status on a local control panel (included in the CDM or BDM), either by LED, or alphanumeric code on LED or LCD or terminal (hand held programmer, personal computer).

G.2 TECHNOLOGY

Systems based on analogue circuit design have normally a less sophisticated monitoring system using LED for status and faults. Some displays may be provided (local and/or remote) for, but are not limited to the following:

- maximum safe speed;
- maximum speed;
- current limit;
- actual load current;
- actual speed;
- other limited conditions;
- faults.

Systems based on microprocessor design normally present a great deal of information (status, alarms, fault) via numeric codes or clear language. These systems allow control to be carried out from a simple keyboard and display. Display may provide for, and is not limited to:

- parameter modifications (such as gain of controllers, acceleration, deceleration, etc.);
- monitoring of control variables (such as speed, voltage, current actual values or references);
- historical record of variables etc.

These systems may offer the possibility of sophisticated communications by means of serial or parallel link(s) in point-to-point connection or multidrop bus.

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