

Rotating electrical machines —

Part 25: Guide for the design and performance of cage induction motors specifically designed for converter supply

ICS 29.160

National foreword

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**Rotating electrical machines
Part 25: Guide for the design and performance
of cage induction motors
specifically designed for converter supply**

Drehende elektrische Maschinen
Teil 25: Leitfaden für den Entwurf
und das Betriebsverhalten von
Induktionsmotoren mit Käfigläufer,
die speziell für Umrichterbetrieb
bemessen sind

This Technical Specification was approved by CENELEC on 2005-06-04.

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CENELEC

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Europäisches Komitee für Elektrotechnische Normung

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Foreword

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Annex ZA has been added by CENELEC.

Endorsement notice

The text of the Technical Specification IEC/TS 60034-25:2004 was approved by CENELEC as a Technical Specification without any modification.

CONTENTS

INTRODUCTION.....	6
1 Scope.....	7
2 Normative references	7
3 Terms and definitions	8
4 System characteristics.....	9
4.1 General	9
4.2 System information.....	9
4.3 Torque/speed considerations.....	9
4.3.1 General	9
4.3.2 Torque/speed capability.....	10
4.3.3 Voltage/speed characteristics	11
4.3.4 Limiting factors on torque/speed capability	11
4.3.5 Resonant speed bands	12
4.3.6 Duty cycles.....	12
4.4 Converter control types	12
4.4.1 General	12
4.4.2 Converter type considerations	13
4.5 Converter output voltage generation.....	14
4.5.1 Pulse Width Modulation (PWM)	14
4.5.2 Hysteresis (sliding mode)	14
4.5.3 Influence of switching frequency.....	15
4.5.4 Multi-level converters	16
4.6 Motor requirements	16
5 Losses and their effects.....	18
5.1 General	18
5.2 Losses in motors supplied from voltage-source converters	18
5.3 Location of the extra losses and ways to reduce them	19
5.4 Converter features to reduce the motor losses	19
5.5 Temperature and life expectancy.....	20
5.6 Determination of motor efficiency	20
6 Noise, vibration and oscillating torques	20
6.1 Noise and vibration in an induction motor supplied from a converter.....	20
6.1.1 General	20
6.1.2 Changes in noise emission due to changes in speed	21
6.1.3 Magnetically excited noise.....	22
6.1.4 Torsional oscillation.....	22
6.2 Sound power level determination and limits	23
6.2.1 Methods of measurement	23
6.2.2 Test conditions	23
6.2.3 Sound power level limits	23
6.3 Vibration level determination and limits	23
6.3.1 Method of measurement	23
6.3.2 Test conditions	24
6.3.3 Vibration level limits	24

7	Motor insulation electrical stresses	24
7.1	General	24
7.2	Causes	24
7.3	Winding electrical stress	26
7.4	Insulation stress limitation	28
7.5	Responsibilities	28
7.6	Converter characteristics	29
7.7	Methods of reduction of voltage stress	29
7.8	Motor choice	30
8	Bearing currents	30
8.1	Sources of bearing currents in converter-fed motors	30
8.1.1	General	30
8.1.2	Magnetic asymmetry	30
8.1.3	Electrostatic buildup	31
8.1.4	High frequency voltages	31
8.2	Generation of high frequency bearing currents	31
8.2.1	General	31
8.2.2	Circulating current	32
8.2.3	Shaft grounding current	32
8.2.4	Capacitive discharge current	32
8.3	Common-mode circuit	32
8.3.1	General	32
8.3.2	System common-mode current flow	32
8.4	Stray capacitances	33
8.4.1	General	33
8.4.2	Major component of capacitance	33
8.4.3	Other capacitances	34
8.5	Consequences of excessive bearing currents	34
8.6	Preventing high frequency bearing current damage	35
8.6.1	Basic approaches	35
8.6.2	Other preventive measures	35
9	Installation	37
9.1	Grounding, bonding and cabling	37
9.1.1	General	37
9.1.2	Grounding	37
9.1.3	Bonding of motors	38
9.1.4	Motor power cables	38
9.2	Reactors and filters	43
9.2.1	General	43
9.2.2	Output reactors	43
9.2.3	Voltage limiting filter (dv/dt filter)	43
9.2.4	Sinusoidal filter	43
9.2.5	Motor termination unit	43
	Annex A (informative) Converter output spectra	45
	Annex ZA (normative) Normative references to international publications with their corresponding European publications	48
	Bibliography	

Figure 1 – Component parts of a PDS.....	6
Figure 2 – Torque/speed capability	10
Figure 3 – Converter output current	10
Figure 4 – Converter output voltage	11
Figure 5 – Effects of switching frequency on motor and converter losses	15
Figure 6 – Effects of switching frequency on acoustic noise	15
Figure 7 – Effects of switching frequency on torque ripple	16
Figure 8 – Example of measured losses W , as a function of frequency f and supply type	18
Figure 9 – Additional losses ΔW of a motor (same motor as Figure 8) due to converter supply, as a function of pulse frequency f_p , at 50 Hz rotational frequency.....	19
Figure 10 – Fan noise as a function of fan speed	21
Figure 11 – Typical surges at the terminals of a motor fed from a PWM converter	25
Figure 12 – Typical voltage surges on one phase at the converter and at the motor terminals (2 ms/division)	25
Figure 13 – Individual short rise time surge from Figure 12 (1 μ s/division)	26
Figure 14 – Definition of the peak rise time t_r of the voltage at the motor terminals	27
Figure 15 – First turn voltage as a function of the surge rise time	27
Figure 16 – Discharge pulse occurring as a result of converter generated voltage surge at motor terminals (100 ns/division)	28
Figure 17 – Limiting curves of impulse voltage V_{pk} , measured between two motor phase terminals, as a function of the impulse rise time t_r	29
Figure 18 – Possible bearing currents.....	31
Figure 19 – Motor capacitances	34
Figure 20 – Bearing pitting due to electrical discharge (pit diameter 30 μ m to 50 μ m)	35
Figure 21 – Fluting due to excessive bearing current	35
Figure 22 – Bonding strap from motor terminal box to motor frame	38
Figure 23 – Examples of shielded motor cables and connections	39
Figure 24 – Parallel symmetrical cabling of high-power converter and motor.....	40
Figure 25 – Converter connections with 360° HF cable glands, showing the ‘Faraday Cage’	41
Figure 26 – Motor end termination with 360° connection	41
Figure 27 – Cable shield connection	42
Figure 28 – Characteristics of preventative measures	44
Figure A.1 – Typical frequency spectra of converter output voltage of a) constant frequency PWM control and b) hysteresis control.....	45
Figure A.2 – Typical frequency spectra of converter output voltage of a) random PWM control and b) hysteresis control	46
Figure A.3 – Typical time characteristics of motor current of a) constant frequency PWM control and b) hysteresis control	46
Table 1 – Significant factors affecting torque/speed capability	11
Table 2 – Motor design considerations.....	16
Table 3 – Motor parameters	17
Table 4 – Sound power level as a function of output power.....	23
Table 5 – Effectiveness of bearing current countermeasures	36

INTRODUCTION

This introduction is intended to explain the aim of this part of IEC 60034.

Motor categories

There are 2 categories of cage induction motors, which can be applied in variable speed electric drive systems.

- Standard cage induction motors, designed for general purpose application. The design and performance of these motors are optimized for operation on a fixed-frequency sinusoidal supply. Nevertheless they are generally also appropriate for use in variable speed drive systems.

Guidance on this field of application is given in IEC 60034-17.

- Cage induction motors specifically designed for converter operation. The design and construction of such motors may be based on standard motors with standardized frame sizes and dimensions, but with modifications for converter operation.

This category is covered by this part of IEC 60034, and it is recommended that the motor be marked with a reference to this part of IEC 60034.

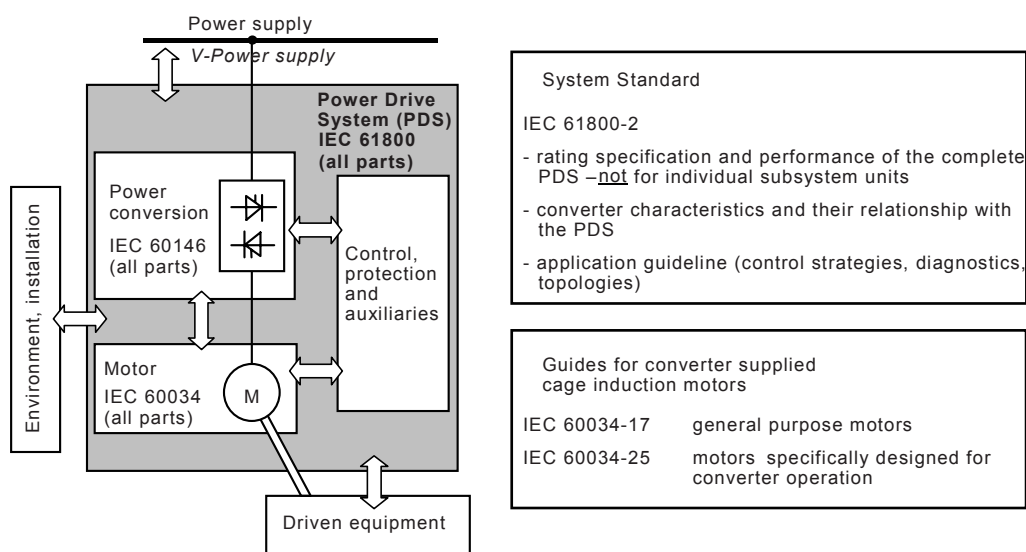
Motors for converter supplies greater than 1 000 V, or for converters other than voltage source, will be considered in later editions of this part of IEC 60034.

Incorporation of the motor into the power drive system

Figure 1 illustrates the Power Drive System (PDS). A PDS consists of a motor and a Complete Drive Module (CDM). It does not include the equipment driven by the motor. The CDM consists of a Basic Drive Module (BDM) and its possible extensions such as the feeding section or some auxiliaries (for example ventilation). The BDM contains converter, control and self-protection functions. The rating and performance of the complete PDS is covered in general by IEC 61800-2.

NOTE Figure 1 of IEC 61800-2 provides further details of the structure of a PDS.

The motor itself and additional specific requirements for its proper incorporation into the PDS are covered by the IEC 60034 series.



IEC 445/04

Figure 1 – Component parts of a PDS

ROTATING ELECTRICAL MACHINES –

Part 25: Guide for the design and performance of cage induction motors specifically designed for converter supply

1 Scope

This part of IEC 60034 describes the design features and performance characteristics of polyphase cage induction motors specifically designed for use on voltage source converter supplies up to 1 000 V. It also specifies the interface parameters and interactions between the motor and the converter including installation guidance as part of a power drive system.

NOTE 1 For motors operating in potentially explosive atmospheres, additional requirements as described in the IEC 60079 series apply.

NOTE 2 This technical report is not primarily concerned with safety. However, some of its recommendations may have implications for safety, which should be considered as necessary.

NOTE 3 Where a converter manufacturer provides specific installation recommendations, they should take precedence over the recommendations of this technical report.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60034-1, *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)*
Amendment 1 (1995)
Amendment 2 (1996)

IEC 60034-6, *Rotating electrical machines – Part 6: Methods of cooling (IC Code)*

IEC 60034-9, *Rotating electrical machines – Part 9: Noise limits*

IEC 60034-14, *Rotating electrical machines – Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher – Measurement, evaluation and limits of vibration severity*

IEC 60034-17, *Rotating electrical machines – Part 17: Cage induction motors when fed from converters – Application guide*

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

IEC 61800-3, *Adjustable speed electrical power drive systems – Part 3: EMC product standard including specific test methods*

IEC 61800-5-1, *Adjustable speed electrical power drive systems – Part 5-1: Safety requirements – Electrical, thermal and energy*

3 Terms and definitions

For the purposes of this part of IEC 60034, the following terms and definitions apply.

3.1

bonding

electrical connection of metallic parts of an installation together and to ground (earth)

NOTE For the purposes of this part of IEC 60034, this definition combines elements of IEC 195-01-10 (equipotential bonding) and IEC 195-01-16 (functional equipotential bonding).

3.2

converter

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

[IEC 61800-2, 2.2.1]

NOTE This definition is taken from IEC 61800-2, and for the purposes of this part of IEC 60034 embraces the terms Complete Drive Module (CDM) and Basic Drive Module (BDM) as used in the IEC 61800 series.

3.3

EMC (electromagnetic compatibility)

ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[IEV 161-01-07]

3.4

field weakening

motor operating mode where motor flux is less than the flux corresponding to the motor rating

3.5

peak rise time

time interval between the 10 % and 90 % points of the zero to peak voltage (see Figure 14)

3.6

Power Drive System

PDS

system consisting of power equipment (composed of converter section, AC motor and other equipment such as, but not limited to, the feeding section), and control equipment (composed of switching control – on/off for example –, voltage, frequency, or current control, firing system, protection, status monitoring, communication, tests, diagnostics, process interface/port, etc.)

3.7

protective earthing

PE

earthing a point or points in a system or in an installation or in equipment for the purposes of electrical safety

[IEV 195-01-11]

3.8

skip band

small band of operating frequencies where steady-state operation of the PDS is inhibited

3.9

surface transfer impedance

quotient of the voltage induced in the centre conductor of a coaxial line per unit length by the current on the external surface of the coaxial line

[IEV 161-04-15]

4 System characteristics

4.1 General

Although the steps in specifying motor and converter features are similar for any application, the final selections are greatly influenced by the type of application. In this Clause, these steps are described and the effects of various application load types are discussed.

4.2 System information

Complete application information, that considers the driven load, motor, converter, and utility power supply, is the best way to achieve the required performance of the motor in the system. In general this information should include:

- The power or torque requirements at various speeds.
- The desired speed range of the load and motor.
- The acceleration and deceleration rate requirements of the process being controlled.
- Starting requirements including the frequency of starts and a description of the load (the inertia reflected at the motor, load torque during starting).
- Whether the application is a continuous process or a duty cycle of starts, stops, and speed changes.
- A general description of the type of application including the environment in which the drive system components will operate.
- A description of additional functionality that may not be met with the motor and converter only (for example: motor temperature monitoring, ability to bypass the converter if necessary, special sequencing circuits or speed reference signals to control the drive system).
- A description of the available electrical supply power and wiring. The final configuration may be affected by the requirements of the system selected.

4.3 Torque/speed considerations

4.3.1 General

The typical torque/speed characteristics of converter-fed cage induction motors, the significant influencing factors and their consequences are shown in Figure 2, Figure 3 and Figure 4. Depending on the performance requirements of the power drive systems, different motor designs are possible for an adaptation of the individual limiting values.

NOTE Figure 2 to Figure 4 do not show the possible skip bands (see 4.3.5).

4.3.2 Torque/speed capability

Figure 2 shows the torque/speed capability of converter-fed cage induction motors. The maximum available torque is limited by the rating of the motor and by the current limitation of the converter. Above the field-weakening frequency f_0 and speed n_0 the motor can operate with constant power with a torque proportional to $1/n$. If the minimum breakdown torque (which is proportional to $1/n^2$) is reached, the power has to be further reduced proportional to $1/n$, resulting in torque proportional to $1/n^2$ (extended range). The maximum speed $n_{\max}$ is limited by the mechanical strength and stability of the rotor, by the speed capability of the bearing system, and by other mechanical parameters.

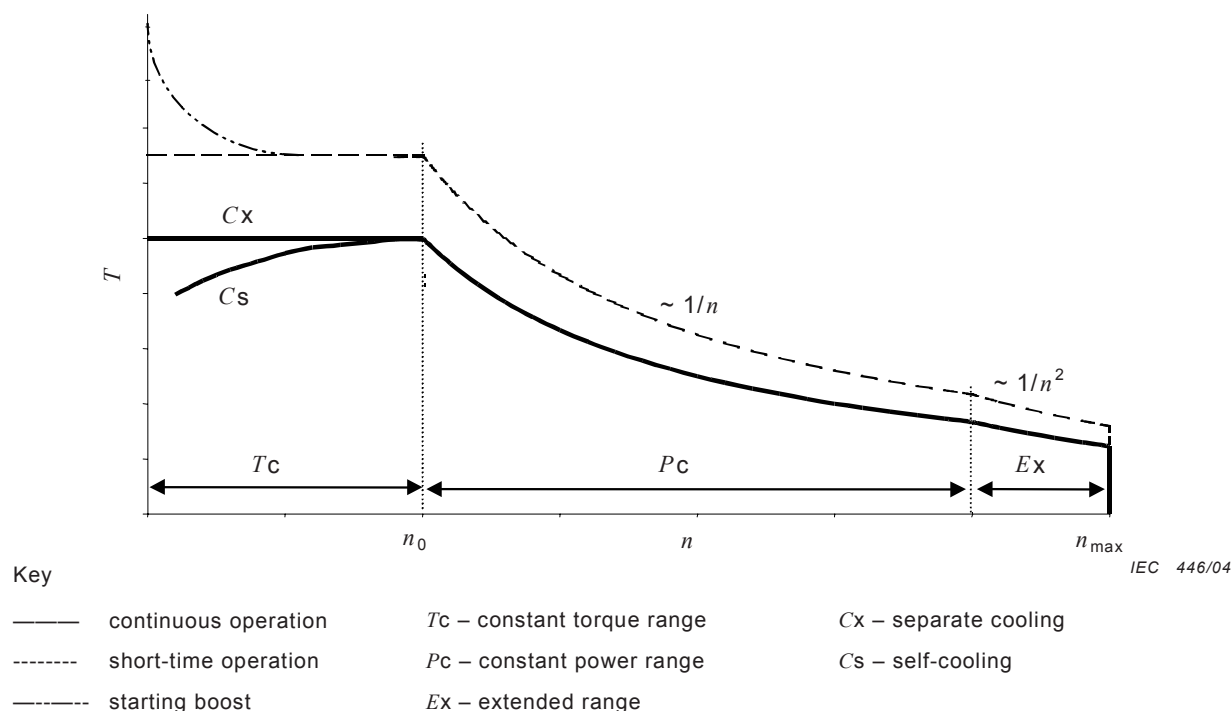


Figure 2 – Torque/speed capability

Figure 3 shows the corresponding converter output current (I) capability.

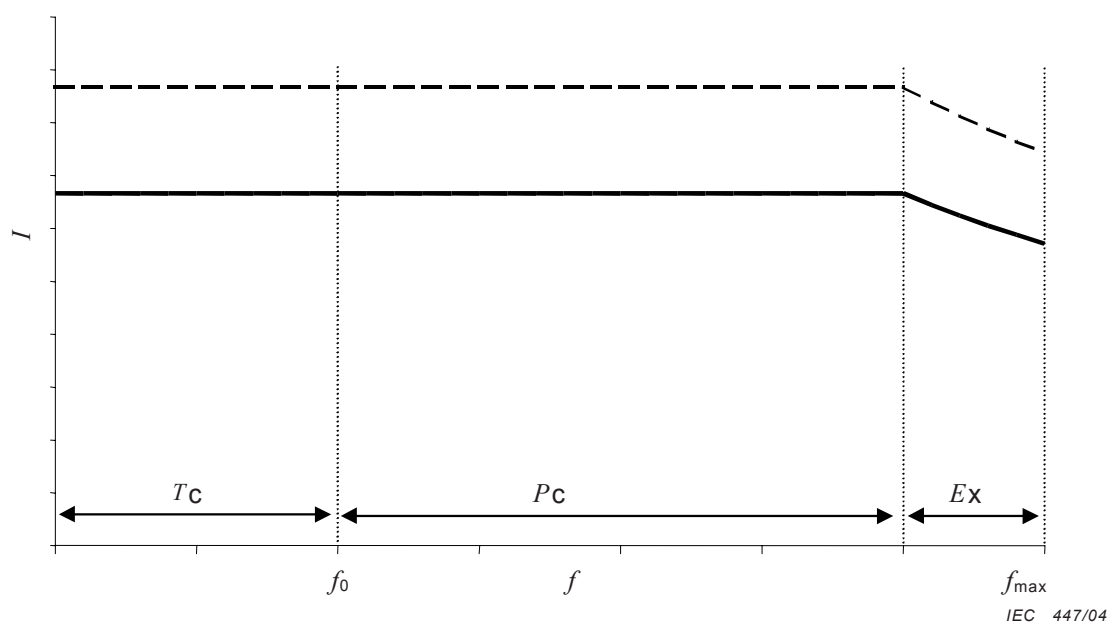
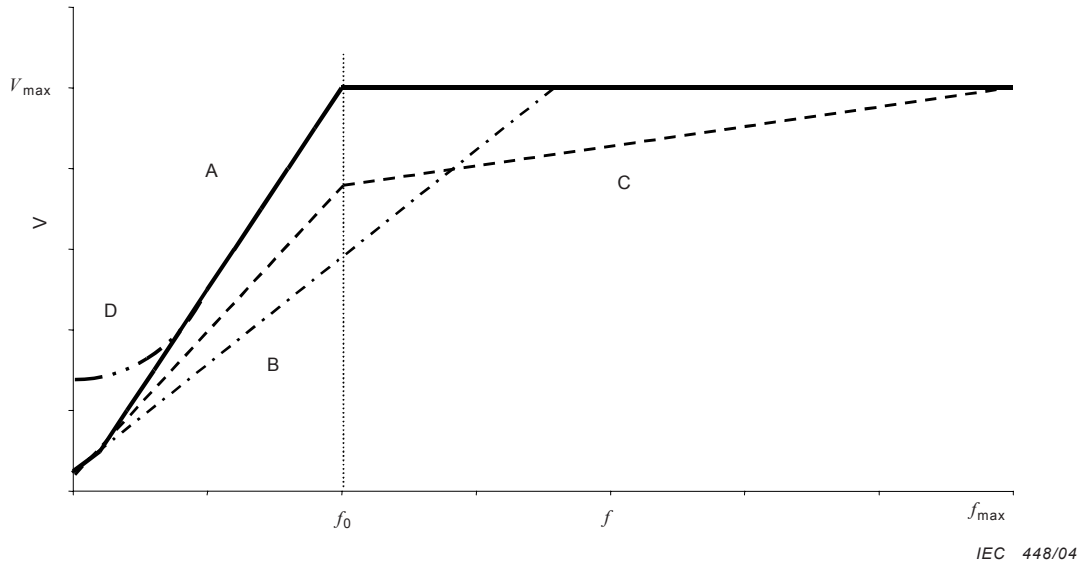


Figure 3 – Converter output current

4.3.3 Voltage/speed characteristics

The converter output voltage (V) can be varied with speed in several ways, as shown in Figure 4.



Key

- A The voltage increases with speed, and the maximum converter output voltage $V_{\max}$ is achieved at the field-weakening frequency f_0 .
- B The voltage increases with speed, and the maximum converter output voltage $V_{\max}$ is achieved above f_0 . This provides an extended speed range at constant flux (constant torque), but the available torque is reduced in this speed range.
- C The voltage increases with speed up to f_0 , and then increases at a lower rate, the maximum converter output voltage $V_{\max}$ being achieved at $f_{\max}$. This avoids excessive torque reduction in the constant flux range.
- D A voltage boost is applied at very low speeds to improve starting performance.

In all of these cases, the voltage-speed dependence may be linear or non-linear, according to the torque-speed requirements of the load.

Figure 4 – Converter output voltage

4.3.4 Limiting factors on torque/speed capability

The significant factors which influence the torque/speed capability are shown in Table 1.

Table 1 – Significant factors affecting torque/speed capability

Condition	Motor	Converter and motor
Breakaway	Maximum flux capability	Maximum current
Constant flux	Cooling (I^2R losses due to current variations)	Maximum current
Field weakening (reduced flux)	Maximum speed (mechanical strength and stability)	Maximum voltage
	Maximum torque (breakdown torque)	
Dynamic response	Equivalent circuit parameters (determined by modelling)	Control capability

4.3.5 Resonant speed bands

The speed range of a converter-fed motor may include speeds that can excite resonances in parts of the motor stator, in the motor/load shaft system or in the driven equipment. Depending on the converter, it may be possible to skip the resonant frequencies. However, even when resonant frequencies are skipped, the load will be accelerated through that speed if the motor is set to run at any speed above this resonant speed. Decreasing the acceleration time can help minimize the time spent in resonance.

4.3.6 Duty cycles

4.3.6.1 General

Duty cycle applications are those in which transitions between speeds or loads are common (see IEC 60034-1). Several aspects of this type of application affect the motor and the converter.

- Motor heat dissipation is variable, depending on rotation speed and cooling method.
- Torque demands above motor full-load torque may be required. Operation above motor full load may be required to accelerate, handle peak loads, and even decelerate the load. Operation above motor rated current will increase motor heating. This may require a higher thermal class of insulation, a motor rated for the overload, or evaluation of the duty cycle to determine if the motor has enough cooling for the application (see IEC 60034-1, Duty type S10).
- DC injection, dynamic, or regenerative braking may be required to reduce the motor speed. Regardless of whether the motor is generating torque to drive the application, generating power back to the converter due to the motor being driven by the load, or supplying braking torque during deceleration by applying DC current to the windings, motor heating takes place approximately proportionally to the square of the current while applied. This heating should be included in the duty cycle analysis. Furthermore, the transient torques imposed on the shaft by braking should be controlled to a level that will not cause damage.

NOTE IEC 61800-6 provides information on load duty and current determination for the entire PDS.

4.3.6.2 High impact loads

High impact loads are a special case of duty and are encountered in certain intermittent torque applications (for example IEC 60034-1, Duty type S6). In these applications, the load is applied or removed from the motor very quickly. It is also possible for this load torque to be positive (against the direction of rotation of the motor) or negative (in the same direction as motor rotation).

The impact load will result in a rapid increase or decrease in current demand (from the converter). If the torque is negative, the motor may generate current back into the converter. These transient currents create stresses in the stator winding. The magnitude of these transient currents is a function of the size of the converter and of the motor.

4.4 Converter control types

4.4.1 General

There are various converter control types: scalar, vector (sensorless or feedback), direct flux and motor torque control, etc. Each type has different characteristics, which are described in 4.4.1.1 to 4.4.1.3.

4.4.1.1 Scalar control

Scalar control is the original concept in a V/Hz converter. In such a converter, the output voltage is controlled according to the output frequency. Figure 4 shows examples of the ways in which this may be done.

With converter output voltage proportional to frequency, the motor is operating with approximately constant flux even without speed feedback signals.

Voltage boost (a fixed voltage which is added to the converter output voltage), conventional IR (stator winding resistance voltage drop) compensation, or advanced dynamic voltage compensation are commonly used options to improve starting and operating performance in the low speed region.

Voltage boost has more effect at low speeds when the motor voltage is low, and care should be taken to ensure that the boost voltage is not so high that the motor saturates.

IR compensation, where at light loads the amount of boost voltage is proportional to the amount of current in the motor, is an improvement. Many scalar controls use special algorithms to dynamically compensate for the voltage drop caused by motor stator resistance and inductance. This provides even better starting and operating performance in the low speed region, and, by using additional motor voltage and current feedback signals, such controls can generate torque values close to vector control even at lower frequency regions.

Scalar control is generally applied where fast response to torque or speed commands is not required (for example, with centrifugal pumps and fans) and it is particularly useful if multiple motors are to be supplied from a single converter.

4.4.1.2 Vector control

An AC vector controlled converter essentially decouples the components of the motor current producing the magnetising flux and the torque, in order to control them separately.

This decoupling is achieved by calculation of the motor characteristics using an equivalent circuit (mathematical model) with or without speed feedback signals.

According to the level of performance required, different approaches may be taken for this equivalent circuit calculation. In addition, a speed feedback (sensor) signal may further improve the performance.

4.4.1.3 Direct flux and motor torque control

A direct flux and motor torque controlled converter has a hysteresis (also known as 'sliding mode') control type, which adjusts the flux and the torque of the motor by mathematical model calculation of the motor, with or without speed feedback signals.

In this control type, there is no modulator, every switching transition of each converter power semiconductor being considered separately. In addition, a speed feedback (sensor) signal may further improve the performance.

The philosophy is to reach the required motor torque and speed as quickly as possible.

4.4.2 Converter type considerations

All three types of control can be used for constant torque applications, as well as for applications where the torque increases with speed (for example, centrifugal pumps or fans). However, when selecting a converter, each aspect of the performance requirement should be considered to ensure optimal operation.

In general, the following aspects should be noted.

- Using scalar control, it is possible to operate motors of different ratings in parallel with one converter (multi-motor operation).
- Scalar control is typically insufficient for dedicated low speed load requirements (below approximately 10 % of base speed), although the low speed performance can be improved by applying dynamic voltage compensation.
- The steady state torque capability of scalar control can be made equivalent to the sensorless vector control by applying dynamic voltage compensation.
- The most significant difference between scalar control and vector or direct flux and motor torque control is the dynamic response.
- Vector or direct flux and motor torque control may be required if one or more of the following characteristics are needed:
 - operation around zero speed;
 - precise torque control;
 - high peak torque at low speed.
- Using vector control or direct flux and motor torque control, multi-motor operation can be realized with or without speed feedback, provided that motors of the same rating are used.
- The characteristics of vector control and those of direct flux and motor torque control are almost equivalent, because both use mathematical model calculations of the motor with or without flux or speed sensors.

Further details are available in IEC 61800-2.

4.5 Converter output voltage generation

4.5.1 Pulse Width Modulation (PWM)

PWM covers those schemes of output voltage generation where the transition switching commands of the converter are generated from a "carrier frequency" synchronized controller (the "modulator").

The modulator controls the converter output switching pattern in such a way that the output voltage is equal to the desired reference value.

NOTE The output voltage is to be understood as an average value for times related to the switching frequency, and an instantaneous value for times related to the fundamental output frequency of the converter.

The carrier frequency may optionally be synchronized to line or to output frequency. It may be selected to reduce losses, current ripple or generated noise, and it may be kept fluctuating ("wobbling", or "random" PWM) to distribute the harmonic spectra of the output voltage over a wide range.

Additionally, special control techniques may be used to optimize the current waveform or spectrum, for example to achieve minimum current peaks or to eliminate certain harmonics.

4.5.2 Hysteresis (sliding mode)

Hysteresis covers those schemes of output voltage generation where the transition switching commands of the converter are generated from a "carrierless" (and therefore unsynchronized) controller. Transition switching occurs as soon as a certain difference is exceeded between an actual and a reference value of a control parameter.

Hysteresis switching can be used with several control parameters: voltage, current, flux or torque, depending on the type of control.