ABB DRIVES

Technical guide book

ABB drives - Technical guide book

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Contents

1. **Direct torque control** explains what DTC is; why and how it has evolved; the basic theory behind its success; and the features and benefits of this new technology.

2. **EU Council Directives and adjustable speed electrical power drive systems** is to give a straightforward explanation of how the various EU Council Directives relate to power drive systems.

3. **EMC compliant installation and configuration for a power drive system** assists design and installation personnel when trying to ensure compliance with the requirements of the EMC Directive in the user's systems and installations when using AC drives.

4. **Guide to variable speed drives** describes basics of different variable speed drives (VSD) and how they are used in industrial processes.

5. **Bearing currents in modern AC drive systems** explains how to avoid damages.

6. **Guide to harmonics with AC drives** describes harmonic distortion, its sources and effect, and also distortion calculation and evaluation with special attention to the methods for reducing harmonics with AC drives.

7. **Dimensioning of a drive system**. Making dimensioning correctly is the fastest way of saving money. Biggest savings can be achieved by avoiding very basic mistakes. These dimensioning basics and beyond can be found in this guide.

8. **Electrical braking** describes the practical solutions available in reducing stored energy and transferring stored energy back into electrical energy.

9. **Guide to motion control drives** gives an overview of high performance drives and motion control.

10. **Functional safety** guide introduces the Machinery Directive and the standards that must be taken into account when designing a machine, in order to ensure operational safely.

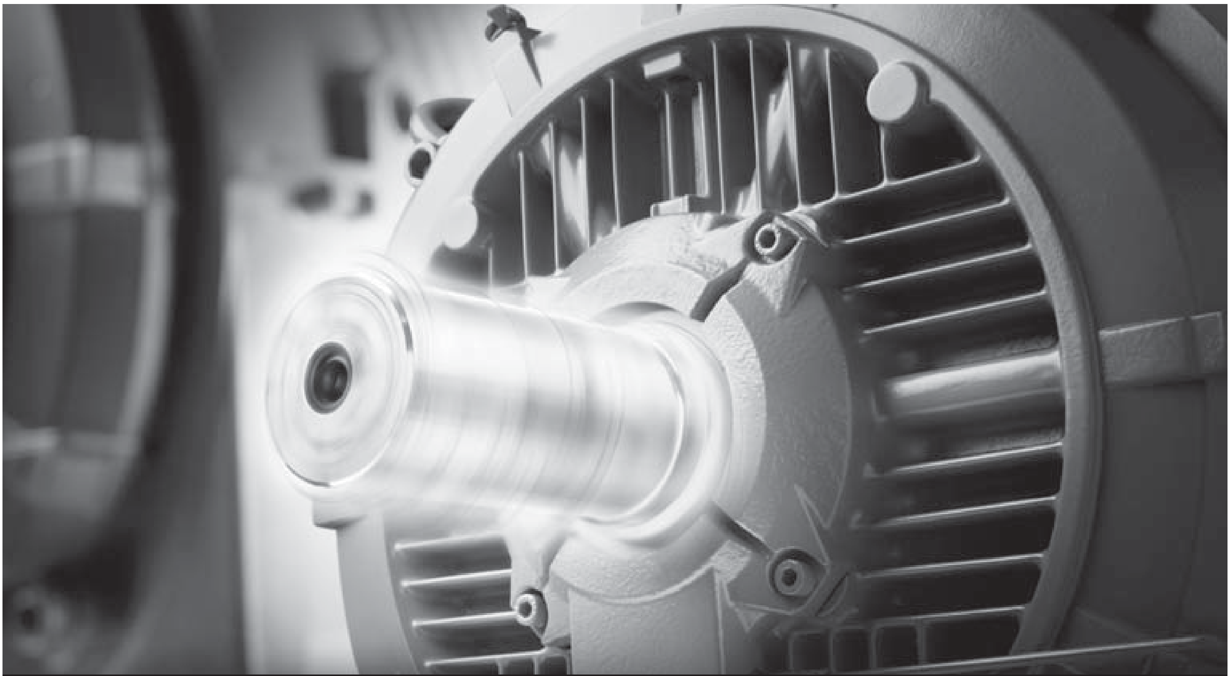

ABB drives

Technical guide No. 1 Direct torque control - the world's most advanced AC drive technology

Power and productivity
for a better world™

Technical guide No. 1
Direct torque control - the world's most advanced AC drive technology

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Chapter 1 - Introduction

General

Direct torque control - or DTC - is the most advanced AC drive technology developed by any manufacturer in the world.

This technical guide's purpose

The purpose of this technical guide is to explain what DTC is; why and how it has evolved; the basic theory behind its success; and the features and benefits of this new technology.

While trying to be as practical as possible, this guide does require a basic understanding of AC motor control principles.

It is aimed at decision makers including designers, specifiers, purchasing managers, OEMs and end-users; in all markets such as the water, chemical, pulp and paper, power generation, material handling, air conditioning and other industries.

In fact, anyone using variable speed drives (VSD) and who would like to benefit from VSD technology will find this technical guide essential reading.

Using this guide

This guide has been designed to give a logical build up as to why and how DTC was developed.

Readers wanting to know the evolution of drives from early DC techniques through AC to DTC should start at chapter 2 (page 8).

For those readers wanting answers about DTC's performance, operation and application potential, please go straight to chapter 3 (page 17) Questions and answers.

For an understanding of DTC's basic control theory, turn to page 28.

Chapter 2 - Evolution of direct torque control

What is a variable speed drive?

To understand the answer to this question we have to understand that the basic function of a variable speed drive (VSD) is to control the flow of energy from the mains to the process.

Energy is supplied to the process through the motor shaft. Two physical quantities describe the state of the shaft: torque and speed. To control the flow of energy we must therefore, ultimately, control these quantities.

In practice, either one of them is controlled and we speak of "torque control" or "speed control". When the VSD operates in torque control mode, the speed is determined by the load. Likewise, when operated in speed control, the torque is determined by the load.

Initially, DC motors were used as VSDs because they could easily achieve the required speed and torque without the need for sophisticated electronics.

However, the evolution of AC variable speed drive technology has been driven partly by the desire to emulate the excellent performance of the DC motor, such as fast torque response and speed accuracy, while using rugged, inexpensive and maintenance free AC motors.

Summary

In this section we look at the evolution of DTC, charting the four milestones of variable speed drives, namely:

– DC motor drives 9
– AC drives, frequency control, PWM 11
– AC drives, flux vector control, PWM 12
– AC drives, direct torque control 14

We examine each in turn, leading to a total picture that identifies the key differences between each.

DC motor drives

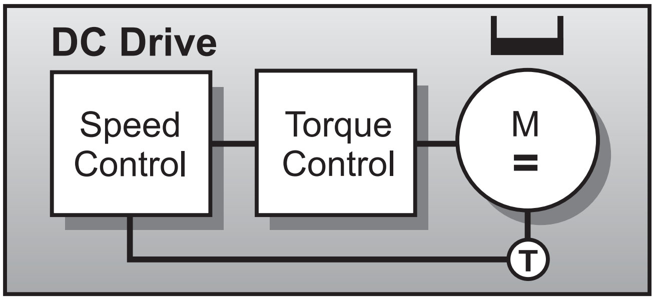


Figure 1: Control loop of a DC motor drive

Features

- Field orientation via mechanical commutator
- Controlling variables are armature current and field current, measured DIRECTLY from the motor
- Torque control is direct

In a DC motor, the magnetic field is created by the current through the field winding in the stator. This field is always at right angles to the field created by the armature winding. This condition, known as field orientation, is needed to generate maximum torque. The commutator-brush assembly ensures this condition is maintained regardless of the rotor position.

Once field orientation is achieved, the DC motor's torque is easily controlled by varying the armature current and by keeping the magnetising current constant.

The advantage of DC drives is that speed and torque - the two main concerns of the end-user - are controlled directly through armature current: that is the torque is the inner control loop and the speed is the outer control loop (see Figure 1).

Advantages

- Accurate and fast torque control
- High dynamic speed response
- Simple to control

Initially, DC drives were used for variable speed control because they could easily achieve a good torque and speed response with high accuracy.

A DC machine is able to produce a torque that is:

- **Direct** - the motor torque is proportional to the armture current: the torque can thus be controlled directly and accurately.
- **Rapid** - torque control is fast; the drive system can have a very high dynamic speed response. Torque can be changed instantaneously if the motor is fed from an ideal current source. A voltage fed drive still has a fast response, since this is determined only by the rotor's electrical time constant (ie, the total inductance and resistance in the armature circuit)
- **Simple** - field orientation is achieved using a simple mechanical device called a commutator/brush assembly. Hence, there is no need for complex electronic control circuitry, which would increase the cost of the motor controller.

Drawbacks

- Reduced motor reliability
- Regular maintenance
- Motor costly to purchase
- Needs encoder for feedback

The main drawback of this technique is the reduced reliability of the DC motor; the fact that brushes and commutators wear down and need regular servicing; that DC motors can be costly to purchase; and that they require encoders for speed and position feedback.

While a DC drive produces an easily controlled torque from zero to base speed and beyond, the motor's mechanics are more complex and require regular maintenance.

AC drives - Introduction

- Small size
- Robust
- Simple in design
- Light and compact
- Low maintenance
- Low cost

The evolution of AC variable speed drive technology has been partly driven by the desire to emulate the performance of the DC drive, such as fast torque response and speed accuracy, while utilising the advantages offered by the standard AC motor.

AC drives - Frequency control using PWM

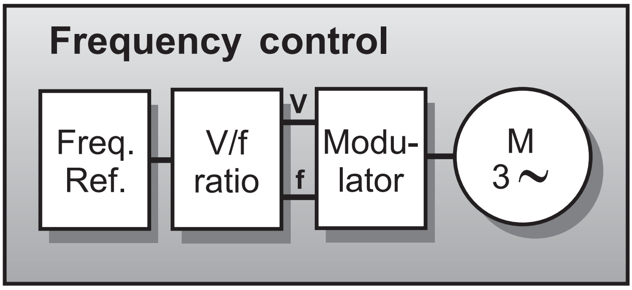


Figure 2: Control loop of an AC drive with frequency control using PWM

Features

- Controlling variables are voltage and frequency
- Simulation of variable AC sine wave using modulator
- Flux provided with constant V/f ratio
- Open-loop drive
- Load dictates torque level

Unlike a DC drive, the AC drive frequency control technique uses parameters generated outside of the motor as controlling variables, namely voltage and frequency.

Both voltage and frequency reference are fed into a modulator which simulates an AC sine wave and feeds this to the motor's stator windings. This technique is called pulse width modulation (PWM) and utilises the fact that there is a diode rectifier towards the mains and the intermediate DC voltage is kept constant. The inverter controls the motor in the form of a PWM pulse train dictating both the voltage and frequency.

Significantly, this method does not use a feedback device which takes speed or position measurements from the motor's shaft and feeds these back into the control loop.

Such an arrangement, without a feedback device, is called an "open-loop drive".

Advantages

- Low cost
- No feedback device required - simple

Because there is no feedback device, the controlling principle offers a low cost and simple solution to controlling economical AC induction motors.

This type of drive is suitable for applications which do not require high levels of accuracy or precision, such as pumps and fans.

Drawbacks

- Field orientation not used
- Motor status ignored
- Torque is not controlled
- Delaying modulator used

With this technique, sometimes known as scalar control, field orientation of the motor is not used. Instead, frequency and voltage are the main control variables and are applied to the stator windings. The status of the rotor is ignored, meaning that no speed or position signal is fed back.

Therefore, torque cannot be controlled with any degree of accuracy. Furthermore, the technique uses a modulator which basically slows down communication between the incoming voltage and frequency signals and the need for the motor to respond to this changing signal.

AC drives - Flux vector control using PWM

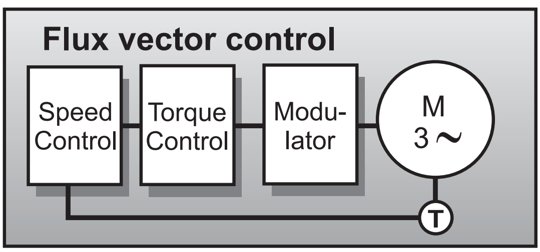


Figure 3: Control loop of an AC drive with flux vector control using PWM

Features

- Field-oriented control - simulates DC drive
- Motor electrical characteristics are simulated - “motor model”
- Closed-loop drive
- Torque controlled INDIRECTLY

To emulate the magnetic operating conditions of a DC motor, ie, to perform the field orientation process, the flux-vector drive needs to know the spatial angular position of the rotor flux inside the AC induction motor.

With flux vector PWM drives, field orientation is achieved by electronic means rather than the mechanical commutator/brush assembly of the DC motor.

Firstly, information about the rotor status is obtained by feeding back rotor speed and angular position relative to the stator field by means of a pulse encoder. A drive that uses speed encoders is referred to as a “closed-loop drive”.

Also the motor’s electrical characteristics are mathematically modelled with microprocessors used to process the data.

The electronic controller of a flux-vector drive creates electrical quantities such as voltage, current and frequency, which are the controlling variables, and feeds these through a modulator to the AC induction motor. Torque, therefore, is controlled INDIRECTLY.

Advantages

- Good torque response
- Accurate speed control
- Full torque at zero speed
- Performance approaching DC drive

Flux vector control achieves full torque at zero speed, giving it a performance very close to that of a DC drive.

Drawbacks

- Feedback is needed
- Costly
- Modulator needed

To achieve a high level of torque response and speed accuracy, a feedback device is required. This can be costly and also adds complexity to the traditional simple AC induction motor.

Also, a modulator is used, which slows down communication between the incoming voltage and frequency signals and the need for the motor to respond to this changing signal.

Although the motor is mechanically simple, the drive is electrically complex.

AC drives - Direct torque control

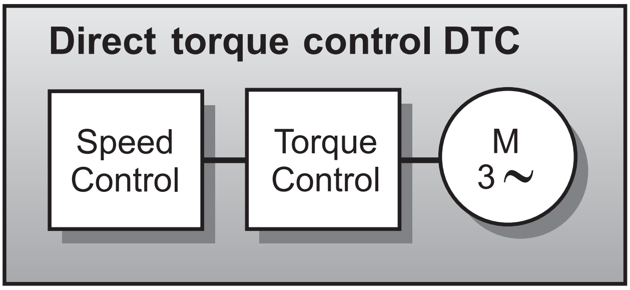


Figure 4: Control loop of an AC drive using DTC

Controlling variables

With the revolutionary DTC technology developed by ABB, field orientation is achieved without feedback using advanced motor theory to calculate the motor torque directly and without using modulation. The controlling variables are motor **magnetising flux** and **motor torque**.

With DTC there is no modulator and no requirement for a tachometer or position encoder to feed back the speed or position of the motor shaft.

DTC uses the fastest digital signal processing hardware available and a more advanced mathematical understanding of how a motor works.

The result is a drive with a torque response that is typically 10 times faster than any AC or DC drive. The dynamic speed accuracy of DTC drives will be 8 times better than any open loop AC drives and comparable to a DC drive that is using feedback.

DTC produces the first “universal” drive with the capability to perform like either an AC or DC drive.

The remaining sections in this guide highlight the features and advantages of DTC.

Comparison of variable speed drives

Let us now take a closer look at each of these control blocks and spot a few differences.

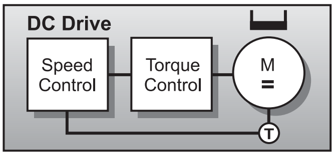


Figure 1: Control loop of a DC drive

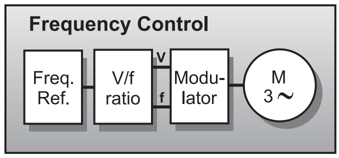


Figure 2: Control loop with frequency control

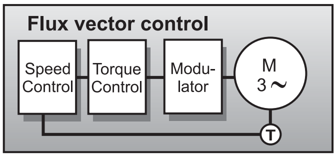


Figure 3: Control loop with flux vector control

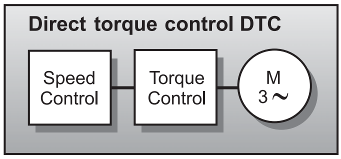


Figure 4 Control loop of an AC drive using DTC

The first observation is the similarity between the control block of the DC drive (Figure 1) and that of DTC (Figure 4).

Both are using motor parameters to directly control torque.

But DTC has added benefits including no feedback device is used; all the benefits of an AC motor (see page 10); and no external excitation is needed.

DRIVE	CONTROL VARIABLES
DC DRIVES	Armature Current, I_A Magnetising Current, I_M
AC DRIVES (PWM)	Output Voltage, U Output Frequency, f
Direct Torque Control	Motor Torque, T Motor Magnetising Flux, Ψ

Table 1: Comparison of control variables

As can be seen from table 1, both DC drives and DTC drives use actual motor parameters to control torque and speed. Thus, the dynamic performance is fast and easy. Also with DTC, for most applications, no tachometer or encoder is needed to feed back a speed or position signal.

Comparing DTC (Figure 4) with the two other AC drive control blocks (Figures 2 & 3) shows up several differences, the main one being that no modulator is required with DTC.

With PWM AC drives, the controlling variables are frequency and voltage which need to go through several stages before being applied to the motor. Thus, with PWM drives control is handled inside the electronic controller and not inside the motor.

Chapter 3 - Questions and answers

General

What is direct control?

Direct torque control - or DTC as it is called - is the very latest AC drive technology developed by ABB and is set to replace traditional PWM drives of the open- and closed-loop type in the near future.

Why is it called direct torque control?

Direct torque control describes the way in which the control of torque and speed are directly based on the electromagnetic state of the motor, similar to a DC motor, but contrary to the way in which traditional PWM drives use input frequency and voltage. DTC is the first technology to control the “real” motor control variables of torque and flux.

What is the advantage of this?

Because torque and flux are motor parameters that are being directly controlled, there is no need for a modulator, as used in PWM drives, to control the frequency and voltage. This, in effect, cuts out the middle man and dramatically speeds up the response of the drive to changes in required torque. DTC also provides precise torque control without the need for a feedback device.

Why is there a need for another AC drive technology?

DTC is not just another AC drive technology. Industry is demanding more and existing drive technology cannot meet these demands.

For example, industry wants:

- Better product quality which can be partly achieved with improved speed accuracy and faster torque control.
- Less down time which means a drive that will not trip unnecessarily; a drive that is not complicated by expensive feedback devices; and a drive which is not greatly affected by interferences like harmonics and RFI.
- Fewer products. One drive capable of meeting all appliction needs whether AC, DC or servo. That is a truly “universal” drive.
- A comfortable working environment with a drive that produces much lower audible noise.

These are just some of the demands from industry. DTC can deliver solutions to all these demands as well as bringing new benefits to many standard applications.

Who invented DTC?

ABB has been carrying out research into DTC since 1988 following the publication of the theory in 1971 and 1985 by German doctor Blaschke and his colleague Depenbrock. DTC leans on the theory of field oriented control of induction machines and the theory of direct self control. ABB has spent over 100 man years developing the technology.

Performance

What are the main benefits of DTC technology over traditional AC drive technology?

There are many benefits of DTC technology. But most significantly, drives using DTC technology have the following exceptional dynamic performance features, many of which are obtained without the need for an encoder or tachometer to monitor shaft position or speed:

- **Torque response:** - How quickly the drive output can reach the specified value when a nominal 100 percent torque reference step is applied.
  For DTC, a typical torque response is **1 to 2 ms** below 40 Hz compared to between 10-20 ms for both flux vector and DC drives fitted with an encoder. With open loop PWM drives (see page 11) the response time is typically well over 100 ms. In fact, with its torque response, DTC has achieved the natural limit. With the voltage and current available, response time cannot be any shorter. Even in the newer “sensorless” drives the torque response is **hundreds of milliseconds.**

- Accurate **torque control at low frequencies**, as well as full load torque at zero speed without the need for a feedback device such as an encoder or tachometer. With DTC, speed can be controlled to frequencies below 0.5 Hz and still provide **100 percent torque** right the way through to zero speed.

- **Torque repeatability:** - How well the drive repeats its output torque with the same torque reference command. DTC, without an encoder, can provide 1 to 2 percent torque repeatability of the nominal torque across the speed range. This is half that of other open-loop AC drives and equal to that of closed-loop AC and DC drives.

- **Motor static speed accuracy:** - Error between speed reference and actual value at constant load. For DTC, speed accuracy is 10 percent of the motor slip, which with an 11 kW motor, equals 0.3 percent static speed accuracy. With a 110 kW motor, speed accuracy is 0.1 percent without encoder (open-loop). This satisfies the accuracy requirement or 95 percent of industrial drives applications. However, for the same accuracy from DC drives an encoder is needed.

  In contrast, with frequency controlled PWM drives, the static speed accuracy is typically between 1 to 3 percent. So the potential for customer process improvements is significantly higher with standard drives using DTC technology.

  A DTC drive using an encoder with 1024 pulses/revolution can achieve a speed accuracy of 0.01 percent.

- **Dynamic speed accuracy:** - Time integral of speed deviation when a nominal (100 percent) torque speed is applied. DTC open-loop dynamic speed accuracy is between 0.3 to 0.4%sec. This depends on the gain adjustment of the controller, which can be tuned to the process requirements.

  With other open-loop AC drives, the dynamic accuracy is eight times less and in practical terms around 3%sec.If we furnish the DTC controller with an encoder, the dynamicspeed accuracy will be 0.1%sec, which matches servo drive performance.

What are the practical benefits of these performance figures?

- **Fast torque response:** - This significantly reduces the speed drop time during a load transient, bringing much improved process control and a more consistent product quality.

- **Torque control at low frequencies: -** This is particularly-beneficial to cranes or elevators, where the load needs to be started and stopped regularly without any jerking. Also with a winder, tension control can be achieved from zero through to maximum speed. Compared to PWM flux vector drives, DTC brings the cost saving benefit that no tachometer is needed.

- **Torque linearity:** - This is important in precision applications like winders, used in the paper industry, where an accurate and consistent level of winding is critical.

- **Dynamic speed accuracy:** - After a sudden load change, the motor can recover to a stable state remarkably fast.

FEATURE	RESULT	BENEFIT
Good motor speed accuracy without tachometer.	Allows speed to be controlled better than 0.5 percent accuracy. No tachometer needed in 95 percent of all applications.	Investment cost savings. Increased reliability. Better process control. Higher product quality. Leads to a true universal drive.
Excellent torque control without tachometer.	Drive for demanding applications. Allows required torque at all times. Torque repeatability 1 percent. Torque response time less than 5ms.	Similar performance to DC but without tachometer. Reduced mechanical failures for machinery. Less downtime. Lower investment.
Full torque at zero speed with or without tachometer/encoder.	No mechanical brake needed. Smooth transition between drive and brake. Allows drive to be used in traditional DC drive applications.	Investment cost saving. Better load control. Can use AC drive and motor instead of DC. Standard AC motor means less maintenance and lower cost.
Control down to zero speed and position with encoder.	Servo drive performance.	Cost effective, high performance torque drive; provides position control and better static accuracy. High accuracy control with standard AC motor.

Table 2: Dynamic performance features and benefits offered by DTC technology

Apart from excellent dynamic performance figures, are there any other benefits of DTC drive technology?

Yes, there are many benefits. For example, DTC drives do not need a tachometer or encoder to monitor motor shaft speed or position in order to achieve the fastest torque response ever from an AC drive. This saves initial cost.

FEATURE	RESULT	BENEFIT
Rapid control DC link voltage.	Power loss ride through.	Drive will not trip. Less down time. Avoids process interruptions. Less waste in continuous process.
Automatic start (Direct restart).	Starting with motor residual inductance present. No restarting delay required.	Can start into a motor that is running without waiting for flux to decay. Can transfer motor from line to drive. No restart. No interruptions on process.
Automatic start (Flying start).	Synchronises to rotating motor.	No process interruptions. Smooth control of machinery. Resume control in all situations.
Flux braking.	Controlled braking between two speed points.	Investment cost savings. Better process control. No delay required as in DC braking. Can be used for decelerating to other than zero speed. Reduced need for brake chopper and resistor.
Flux optimization.	Motor losses minimised. Less motor noise.	Controlled motor.
Self identification/ Auto-tuning.	Tuning the motor to drive for top performance.	Easy and accurate setup. No parameter tuning required. Less commissioning time. Guaranteed starting torque. Easy retrofit for any AC system.
No predetermined switching pattern of power devices.	Low noise. No fixed carrier, therefore acoustic noise reasonable due to “white” noise spectrum.	Cost savings in acoustic barriers in noise sensitive applications. No harmful mechanical resonances. Lower stresses in gearboxes, fans, pumps.
No limits on maximum acceleration and deceleration rate.	Can accelerate and decelerate in quickest time possible without mechanical constraints.	Better process control.

Table 3: User features and benefits offered by DTC technology

Also a DTC drive features rapid starting in all motor electromagnetic and mechanical states. The motor can be started immediately without delay.

It appears that DTC drives are most advantageous for high performance or demanding drive applications. What benefits does DTC bring to standard drives?

Standard applications account for 70 percent of all variable speed drives installed throughout industry. Two of the most common applications are in fans and pumps in industries like heating, ventilating and air conditioning (HVAC), water and food and drinks.

In these applications, DTC provides solutions to problems like harmonics and noise.

For example, DTC technology can provide control to the drive input line generating unit, where a conventional diode bridge is replaced with a controlled bridge.

This means that harmonics can be significantly reduced with a DTC controlled input bridge. The low level current distortion with a DTC controlled bridge will be less than a conventional 6-pulse or 12-pulse configuration and power factor can be as high as 0.99.

For standard applications, DTC drives easily withstand huge and sudden load torques caused by rapid changes in the process, without any overvoltage or overcurrent trip.

Also, if there is a loss of input power for a short time, the drive must remain energised. The DC link voltage must not drop below the lowest control level of 80 percent. To ensure this, DTC has a 25 microseconds control cycle.

What is the impact of DTC on pump control?

DTC has an impact on all types of pumps. Because DTC leads to a universal drive, all pumps, regardless of whether they are centrifugal or constant torque type (screw pumps) can now be controlled with one drive configuration, as can aerators and conveyors. DTC technology allows a drive to adjust itself to varying application needs.

For example, in screw pumps a drive using DTC technology will be able to adjust itself for sufficient starting torque for a guaranteed start.

Improved power loss ride through will improve pumping availability during short power breaks.

The inherent torque control facility for DTC technology allows the torque to be limited in order to avoid mechanical stress on pumps and pipelines.

What is the impact of DTC technology on energy savings?

A feature of DTC which contributes to energy efficiency is a development called motor flux optimization.

With this feature, the efficiency of the total drive (that is controller and motor) is greatly improved in fan and pump applications.

For example, with 25 percent load there is up to 10 percent total energy efficiency improvement. At 50 percent load there can be 2 percent total efficiency improvement.

This directly impacts on operating costs. This feature also significantly reduces the motor noise compared to that generated by the switching frequency of a traditional PWM drive.

Has DTC technology been used in many installations?

Yes, there are hundreds of thousands of installations in use. For example, one of the world's largest web machine manufacturers tested DTC technology for a winder in a film finishing process.

The Requirement:
Exact torque control in the winder so as to produce high quality film rolls.

The Solution:
Open-loop DTC drives have replaced traditional DC drives and latter flux vector controlled AC drives on the centre drives in the rewind station.

The Benefits:
Winder station construction simplified and reliability increased. The cost of one tachometer and associated wiring equals that of one 30 kW AC motor. This provides significant investment cost savings.

Operation

What is the difference between DTC and traditional PWM methods?

– **Frequency control PWM and flux vector PWM**

Traditional PWM drives use **output voltage** and **output frequency** as the primary control variables but these need to be pulse width modulated before being applied to the motor.

This modulator stage adds to the signal processing time and therefore limits the level of torque and speed response possible from the PWM drive.

Typically, a PWM modulator takes 10 times longer than DTC to respond to actual change.

– **DTC control**

DTC allows the motor's **torque** and **stator flux** to be used as primary control variables, both of which are obtained directly from the motor itself. Therefore, with DTC, there is no need for a separate voltage and frequency controlled PWM modulator. Another big advantage of a DTC drive is that no feedback device is needed for 95 percent of all drive applications.

Why does DTC not need a tachometer or position encoder to tell it precisely where the motor shaft is at all times?

There are four main reasons for this:

- The accuracy of the motor model (see page 29).
- Controlling variables are taken directly from the motor (see page 29).
- The fast processing speeds of the DSP and optimum pulse selector hardware (see page 30).
- No modulator is needed (see page 14).

When combined to form a DTC drive, the above features produce a drive capable of calculating the ideal switching voltages 40,000 times every second. It is fast enough to control individual switching pulses. Quite simply, it is the fastest ever achieved.

Once every 25 microseconds, the inverter's semiconductors are supplied with an optimum switching pattern to produce the required torque. This update rate is substantially less than any time constants in the motor. Thus, the motor is now the limiting component, not the inverter.

What is the difference between DTC and other sensorless drives on the market?

There are vast differences between DTC and many of the sensorless drives. But the main difference is that DTC provides accurate control even at low speeds and down to zero speed without encoder feedback. At low frequencies the nominal torque step can be increased in less than 1ms. This is the best available.

How does a DTC drive achieve the performance of a servo drive?

Quite simply because the motor is now the limit of performance and not the drive itself. A typical dynamic speed accuracy for a servo drive is 0.1%s. A DTC drive can reach this dynamic accuracy with the optional speed feedback from a tachometer.

How does DTC achieve these major improvements over traditional technology?

The most striking difference is the sheer speed by which DTC operates. As mentioned above, the torque response is the quickest available.

To achieve a fast torque loop, ABB has utilised the latest high speed signal processing technology and spent 100 man years developing the highly advanced motor model which precisely simulates the actual motor parameters within the controller.

For a clearer understanding of DTC control theory, see page 28.

Does a DTC drive use fuzzy logic within its control loop?

No. Fuzzy logic is used in some drives to maintain the acceleration current within current limits and therefore prevent the drive from tripping unnecessarily. As DTC is controlling the torque directly, current can be kept within these limits in all operating conditions.

A drive using DTC technology is said to be tripless. How has this been achieved?

Many manufacturers have spent years trying to avoid trips during acceleration and deceleration and have found it extraordinarily difficult. DTC achieves tripless operation by controlling the actual motor torque.

The speed and accuracy of a drive which relies on computed rather than measured control parameters can never be realistic. Unless you are looking at the shaft, you are not getting the full picture. Is this true with DTC?

DTC knows the full picture. As explained above, thanks to the sophistication of the motor model and the ability to carry out 40,000 calculations every second, a DTC drive knows precisely what the motor shaft is doing. There is never any doubt as to the motor's state. This is reflected in the exceptionally high torque response and speed accuracy figures quoted on pages 18 and 19.

Unlike traditional AC drives, where up to 30 percent of all switchings are wasted, a drive using DTC technology knows precisely where the shaft is and so does not waste any of its switchings.

DTC can cover 95 percent of all industrial applications. The exceptions, mainly applications where extremely precise speed control is needed, will be catered for by adding a feedback device to provide closed loop control. This device, however, can be simpler than the sensors needed for conventional closed loop drives.

Even with the fastest semiconductors some dead time is introduced. Therefore, how accurate is the auto-tuning of a DTC drive?

Auto-tuning is used in the initial identification run of a DTC drive (see page 29). The dead time is measured and is taken into account by the motor model when calculating the actual flux. If we compare to a PWM drive, the problem with PWM is in the range 20 to 30 Hz which causes torque ripple.

What kind of stability will a DTC drive have at light loads and low speeds?

The stability down to zero speed is good and both torque and speed accuracy can be maintained at very low speeds and light loads. We have defined the accuracies as follows:

Torque accuracy: Within a speed range of 2 to 100 percent and a load range of 10 to100 percent, the torque accuracy is 2 percent.

Speed accuracy: Within a speed range of 2 to 100 percent and a load range of 10 to 100 percent, the speed accuracy is 10 percent of the motor slip. Motor slip of a 37 kW motor is about 2 percent which means a speed accuracy of 0.2 percent.

What are the limitations of DTC?

If several motors are connected in parallel in a DTC-controlled inverter, the arrangement operates as one large motor. It has no information about the status of any single motor. If the number of motors varies or the motor power remains below 1/8 of the rated power, it would be best to select the scalar control macro.

Can DTC work with any type of induction motor?

Yes, any type of asynchronous, squirrel cage motor.

Chapter 4 - Basic control theory

How DTC works

Figure 5, below, shows the complete block diagram for direct torque control (DTC).

Walk around the block

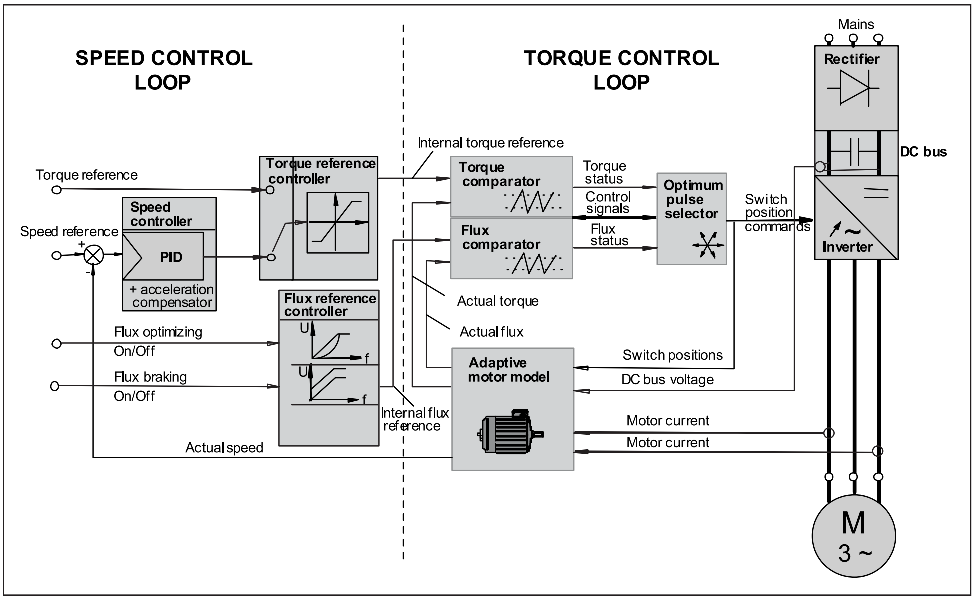
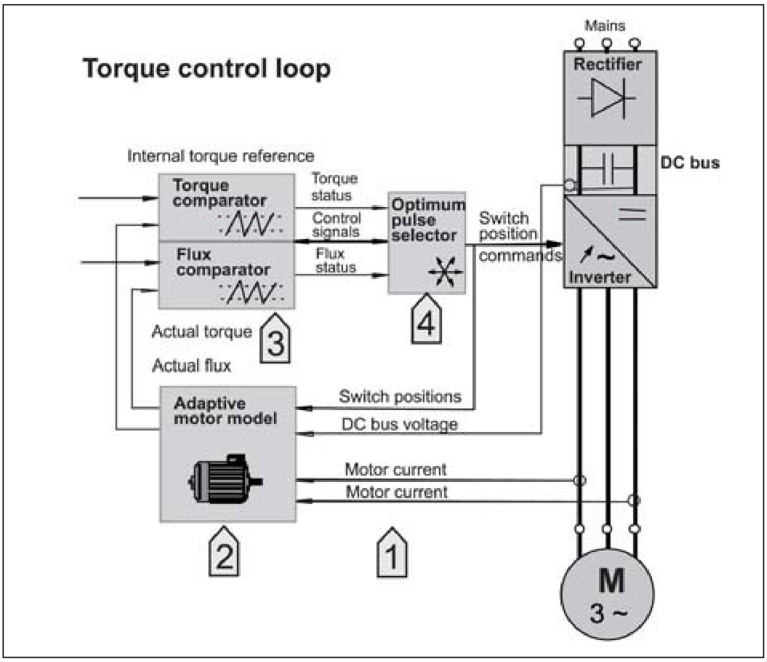


Figure 5: DTC comprises two key blocks: Speed control and torque control

The block diagram shows that DTC has two fundamental sections: the torque control loop and the speed control loop. Now we will walk around the blocks exploring each stage and showing how they integrate together.

Let's start with DTC's torque control loop.

Torque control loop



Step 1 Voltage and current measurements

In normal operation, two motor phase currents and the DC bus voltage are simply measured, together with the inverter's switch positions.

Step 2 Adaptive motor model

The measured information from the motor is fed to the Adaptive motor model.

The sophistication of this motor model allows precise data about the motor to be calculated. Before operating the DTC drive, the motor model is fed information about the motor, which is collected during a motor identification run. This is called **auto-tuning** and data such as stator resistance, mutual inductance and saturation coefficients are determined along with the motor's inertia. The identification of motor model parameters can be done without rotating motor shaft. This makes it easy to apply DTC technology also in retrofits. The extremely fine tuning of motor model is achieved when the identification run also includes running the motor shaft for some seconds.

There is no need to feed back any shaft speed or position with tachometers or encoders if the static speed accuracy requirement is over 0.5 percent, as it is for most industrial applications.

This is a significant advance over all other AC drive technology. The motor model is, in fact, key to DTC's unrivalled low speed performance.

The motor model outputs control signals which directly represent actual motor torque and actual stator flux. Also shaft speed is calculated within the motor model.

Step 3 Torque comparator and flux comparator

The information to control power switches is produced in the torque and flux comparator.

Both actual torque and actual flux are fed to the comparators where they are compared, every 25 microseconds, to a torque and flux reference value. Torque and flux status signals are calculated using a two level hysteresis control method.

These signals are then fed to the optimum pulse selector.

Step 4 Optimum pulse selector

Within the optimum pulse selector is the latest 40 MHz digital signal processor (DSP) together with ASIC hardware to determine the switching logic of the inverter. Furthermore, all control signals are transmitted via optical links for high speed data transmission.

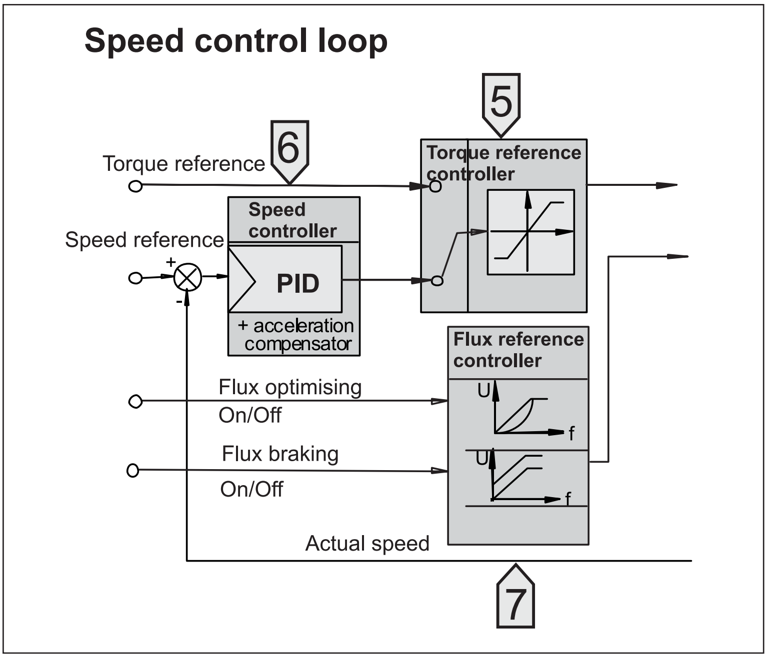
This configuration brings immense processing speed such that every 25 microseconds the inverter's semiconductor switching devices are supplied with an optimum pulse for reaching, or maintaining, an accurate motor torque.

The correct switch combination is determined every control cycle. There is no predetermined switching pattern. DTC has been referred to as "just-in-time" switching, because, unlike traditional PWM drives where up to 30 percent of all switch changes are unnecessary, with DTC each and every switching is needed and used.

This high speed of switching is fundamental to the success of DTC. The main motor control parameters are updated 40,000 times a second. This allows extremely rapid response on the shaft and is necessary so that the motor model (see step 2) can update this information.

It is this processing speed that brings the high performance figures including a static speed control accuracy, without encoder, of ±0.5 percent and the torque response of less than 2 ms.

Speed control



Step 5 Torque reference controller

Within the torque reference controller, the speed control output is limited by the torque limits and DC bus voltage.

It also includes speed control for cases when an external torque signal is used. The internal torque reference from this block is fed to the torque comparator.

Step 6 Speed controller

The speed controller block consists both of a PID controller and an acceleration compensator. The external speed reference signal is compared to the actual speed produced in the motor model. The error signal is then fed to both the PID controller and the acceleration compensator. The output is the sum of outputs from both of them.

Step 7 Flux reference controller

An absolute value of stator flux can be given from the flux reference controller to the flux comparator block. The ability to control and modify this absolute value provides an easy way to realise many inverter functions such as flux optimization and flux braking (see page 21).

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EU Council Directives and adjustable speed electrical power drive systems

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2

Chapter 1 - Introduction

This guide's purpose

The aim of this Technical guide No. 2* is to give a straight-forward explanation of how the various EU Council Directives relate to power drive systems (PDSs). For an explanation of the terminology of PDSs, see pages 21 and 22.

2

While Electromagnetic Compatibility (EMC) is the subject of most concern within the industry, it must be realised that the EMC Directive is only part of the overall EU initiative on common safety standards.

It is the intention of this guide to offer users of AC or DC power drive systems - whether machine builders, system designers, distributors, OEMs, end-users or installers - some clear practical guidelines and courses of action.

***Notes**

1 The content of this technical guide is ABB Oy's, Drives interpretation of events as of July 2007. However, we reserve the right to develop and evolve these interpretations as more details become available from notified bodies (see chapter 6), competent authorities (see chapter 6), organisations and from our own tests.

2 Other technical guides available in this series include:

Technical guide No. 1 -
Direct torque control (3AFE58056685)

Technical guide No. 3 -
EMC compliant installation and configuration for a power drive system (3AFE61348280)

Technical guide No. 4 -
Guide to variable speed drives (3AFE61389211)

Technical guide No. 5 -
Bearing currents in modern AC drive systems (3AFE64230247)

Technical guide No. 6 -
Guide to harmonics with AC drives (3AFE64292714)

Technical guide No. 7 -
Dimensioning of a drive system (3AFE64362569)

Technical guide No. 8 -
Electrical braking (3AFE64362534)

Technical guide No. 9 -
Guide to motion control drives (3AFE68695201)

Technical guide No. 10 -
Functional safety (3AUA0000048753)

How to use this guide

The guide is divided into 7 sections.

Section 4 looks at purchasing decisions for PDSs. Please note the following about the structure of this section:

Responsibilities and actions

Each type of purchaser is offered an explanation of their responsibilities. This is for awareness. No action is needed.

Following the responsibilities is a set of actions. If the purchaser follows these actions, step-by-step, then conforming to the relevant directives will be straightforward.

Tickboxes

Alongside the actions are tickboxes. Purchasers can photocopy the relevant pages and use them as a checklist with each item being ticked off as it is achieved.

Cross-referencing

Because of the complexity of conforming to each directive, this guide inevitably carries a lot of cross-references to other sections. In the margin you will come across:

Defined on page XX

You are advised to turn to the page number reference.

You will also notice other references within the text. These can be referred to if the item is unclear but is not essential for achieving compliance.

Key point:

Within the text you will see:

Key point

These are key observations that must be observed.

Chapter 2 - General questions and answers

It is very important that users of PDSs fully understand all the various rules and regulations and how they apply to PDSs. That is the purpose of this guide.

What are these EU Council Directives?

It is important to realise that EMC cannot be divorced from other European legislation. So before answering this question, we need to look at the **other** legislation and how it affects the purchase and installation of drives.

Quite simply there are **three directives** that mainly affect a drive's safety against risks and hazards. These are:

Directive	Mandatory	Page
Machinery Directive	**1995-01-01**	**pg 55**
Low Voltage Directive	**1997-01-01**	**pg 56**
EMC Directive	**1996-01-01**	**pg 57**

But more on each of these directives later. Let us first explain EMC and look at some concerns of the industry.

How does EMC affect me?

From January 1, 1996 the EU Council's Electromagnetic Compatibility Directive (89/336/EEC and it's successor 2004/108/EC) has been compulsory. It applies to all electrical and electronic equipment sold within the EU and affects virtually all manufacturers and importers of electrical and electronic goods.

Key point:

Electrical equipment that does not conform to the regulations may not be sold anywhere in the EEA (European Economic Area).

What is EMC?

EMC stands for **E**lectro**m**agnetic **C**ompatibility. It is the ability of electrical/electronic equipment to operate problem-free within an electromagnetic environment. Likewise, the equipment must not disturb or interfere with any other products or systems within its locality.

What is an electromagnetic environment?

The electromagnetic environment is everywhere but it varies from place to place. The reason is that there are many different sources of disturbance which can be natural or man-made.

Natural sources consist of electrical discharge between clouds, lightning or other atmospheric disturbances. While we cannot influence these sources we can protect our products and systems from their effects.

Man-made disturbances are those generated by, for example, electrical contacts and semiconductors, digital systems like microprocessors, mobile radio transmitters, walkie-talkies, portable car telephones and power drive systems.

Such a variety of equipment, each with its own emission characteristics, is often used so near to other electrical equipment that the field strengths they create may cause interferences.

Key point:

It is important that all PDSs are immune to these natural and man-made disturbances. While drives manufacturers strive to make their products immune, the directive lays down minimum standards for immunity, thereby ensuring all manufacturers achieve the same basic level.

How does electromagnetic interference show up?

Electromagnetic interference shows up in a variety of ways. Typical examples of interference include a poorly suppressed automobile engine or dynamo; an electric drill causing patterning on the TV screen; or crackling from an AM radio.

The microprocessor and power electronic component, switch rapidly and therefore, can cause interference at high frequencies, unless proper precautions are taken.

What emissions can drives cause?

The normal operation of any drive involves rapid switching of high voltages and this can produce radio frequency emission. It is this radiation and emission that have been seen to have the potential to disturb other circuits at frequencies below 200 MHz.

Modern equipment contains considerable communications and other digital electronics. This can cause considerable emissions at frequencies above 200 MHz.

How is this emission seen?

The main emission is via conduction to the mains. Radiation from the converter and conducting cables is another type of emission and it is especially demanding to achieve the radiated emission limits.

How do I avoid electromagnetic interference?

You need to ensure two things:

– that the equipment generates minimum emission.
– that the equipment is immune to outside effects.

Key point:

In the case of power drive systems, a lot depends on the quality of the installation.

Electromagnetic interference needs to be conducted to earth (ground potential) and no system can work unless it is properly grounded.

Drives manufacturers must comply with EMC standards then?

Unfortunately, the process is not that simple. Virtually everyone in the supply chain has a responsibility to ensure a product, a system and an installation complies with the essential requirements of the EMC Directive.

The key is to clearly understand who has responsibility for what. In the forthcoming pages we take a look at various types of purchasers and examine the steps each should take to meet all three directives mentioned on page 11.

Everyone from manufacturer to installer to user has a responsibility in complying with EMC rules.

If a drive is CE marked, I need not worry. True?

Again this is a big misconception. Just because a drive has CE marking does not necessarily mean it meets the EMC Directive.

Key point:

This will all become clear by referring to the section **purchasing decisions for PDSs**, page 21.

CE marking according to the EMC Directive cannot normally be applied to a module that is no more than a chassis with exposed terminals.

Chapter 3 - CE marking

What is CE marking and how relevant is it for drives?

CE marking, shown below, is the official signature of the **Declaration of conformity** (see pages 43 and 44) as governed by the European Commission. It is a very specific graphic symbol and must be separated from other marks.

CE marking is a system of self certification to identify equipment that complies with the relevant applicable directives.

If a drive is the subject of several directives and, for example, conforms with the **Low Voltage Directive** (see page 56), then, from 1997, it is compulsory that it shows **CE marking**. That marking shall indicate that the drive also conforms to the **EMC Directive** (page 57). CE marking shall indicate conformity only to the directive(s) applied by the manufacturer.

Key point:

NOTE: There must be technical documentation supporting the **Declaration of conformity**.
For more on **technical documentation**, please refer to pages from 36 to 40.

What is CE marking for?

CE marking is mainly for the benefit of authorities throughout the EU and EEA countries who control the movement of goods. CE marking shows that the product complies with the essential requirements of all relevant directives, mainly in the area of technical safety, compatibility issues and conformity assessment. There are three directives that are relevant to drives, but CE marking may be attached to indicate compliance with one of them only (see the previous page).

Is CE marking a quality mark?

Most definitely not. As CE marking is self certification, you can be assured that certification has been carried out.

What is the legal position regarding CE marking?

Anyone applying CE marking is legally liable and must be able to prove the validity of his actions to the authorities. CE marking confirms compliance with the directives listed in the Declaration of conformity (see pages 43 and 44).

What is the importance of CE marking for purchasers of drives?

As far as a purchaser of a drive is concerned, anything that carries the CE mark must have a functional value to him.

Thus, a complete drive product, which can be safely cabled and powered up on its own, shall carry the CE marking.

If I buy a CE marked drive, will I meet the technical requirements of the directives?

In practice, you will see drive products with CE marking. But it is important to understand just why the product was given CE marking in the first place.

Basically a drive has no functional value. It is only of practical use when connected to, say, a motor which in turn is connected to a load.

Therefore, as far as the Machinery Directive is concerned a drive cannot have CE marking unless it is part of a "process" comprising the drive, motor and load.

As for the EMC Directive, the equipment that make up a "process" include cabling, drives and motor. CE marking can only be affixed if all items forming such a "process" conform to the requirements of the directive. Therefore, the drive manuals include detailed instructions for installation.

However, in the eyes of the Low Voltage Directive, a built drive does have functionality. That is, through the drive's parameters you can program the drive and obtain an input and output signal. Thus, if a drive conforms to the Low Voltage Directive it can carry CE marking. Refer to pages from 58 to 60 for explanations of the three directives.

What happens if, as an end-user, I put together a system - do I have to put CE marking on?

Yes. Anyone putting together a system and commissioning it is responsible for the appropriate CE marking.

Key point:

Turn to page 31 for more details about the end-user's responsibilities.

What about spare parts that I buy for a drive? Do I negate the CE mark if I replace a component?

Equipment supplied before the application of the directives, can be repaired and supplied with spare parts to bring it back to the original specification. However, it cannot be enhanced or reinstalled without meeting the directives.

For equipment supplied after the application of the directives, the use of the manufacturer's spare parts should not negate the CE marking. However, the manufacturer or supplier should be consulted about upgrading, as some actions could affect the CE marking criteria.

If drives are classed as components, on subassemlies they cannot be EMC certified or carry a CE mark. Is this true?

You need to first understand the terminology now being applied to drives. See below and pages 21 and 22 for this.

A complete drive module (CDM) is normally a component in a system and as such has no functional value unless it is connected to the motor when it becomes a PDS.

The CDM shall be CE marked if it is to be installed with simple connections and adjustments that do not require any EMC-knowledge.

If awareness of the EMC implication is needed in order to install a CDM, it is not considered as an apparatus. Thus, it shall not be CE marked according to the EMC directives.

If a CDM or BDM is intended for incorporation in PDS by professional manufacturers only (panel builders, machine builders), it shall not be CE marked, nor is Declaration of conformity given by the CDM/BDM manufacturer. Instead installation instructions shall be supplied in order to help the professional manufacturers.

In summary

The EMC Directive defines equipment as any apparatus or fixed installation. As there are separate provisions for apparatus and fixed installations, it is important that the correct category of the equipment is determined.

In technical-commercial classifications the following terminology is frequently used: components, sub-assemblies, finished appliances (ie, finished products), a combination of finished appliances (ie, a system), apparatus, fixed installations and equipment.

The key issue here is whether the item to be considered is for end users or not:

– If it is meant for end users, the EMC directive applies
– If it is meant for manufacturers or assemblers, the EMC directive does not apply

Components or subassemblies intended for incorporation into an apparatus by the end users

A manufacturer may place components or sub-assemblies on the market which are:

– For incorporation into an apparatus by the end-user,
– Available to end users and likely to be used by them.

These components or sub-assemblies are to be considered as apparatus with regard to the application of the EMC. The instructions for use accompanying the component or sub-assembly should include all relevant information, and should assume that adjustments or connections can be performed by an end-user not aware of the EMC implications.

Some variable speed power drive products fall into this category, eg, a drive with enclosure and sold as a complete unit (CDM) to the enduser who installs it into his own system. All provisions of the EMC Directive will apply (CE mark, Declaration of conformity and technical documentation).

Components or subassemblies intended for incorporation into an apparatus by the other manufacturer or assembler

Components or sub-assemblies intended for incorporation into an apparatus or an other sub-assembly by other manufacturers or assemblers are not considered to be “apparatus” and are therefore not covered by the EMC Directive. These components include resistors, cables, terminal blocks, etc.

Some variable speed power drive products fall into this category as well, eg, basic drive module (BDM). These are meant to be assembled by a professional assembler (eg, panel builder or system manufacturer) into a cabinet not in the scope of delivery of the manufacturer of the BDM. According to the EMC Directive, the requirement for the BDM supplier is to provide instructions for installation and use.

Note:
The manufacturer or assembler of the panel or system is responsible for CE mark, Declaration of conformity and technical documentation.

Finished appliance

A finished appliance is any device or unit containing electrical and/or electronic components or sub-assemblies that delivers a function and has its own enclosure. Similarly than components, the interpretation finished appliance can be divided into two categories: it can be intended for the end users, or for the other manufacturers or assemblers.

Finished appliance intended for the end users

A finished appliance is considered as apparatus in the sense of the EMC Directive, if it is intended for the end-user and thus has to fulfill all the applicable provisions of the Directive.

Finished appliance intended for the other manufacturer or assembler

When the finished appliance is intended exclusively for an industrial assembly operation for incorporation into other apparatus, it is not an apparatus in the sense of the EMC Directive and consequently the EMC Directive does not apply for such finished appliances.

Systems (Combination of finished appliances)

A combination of several finished appliances which is combined, and/or designed and/or put together by the same person (ie, the system manufacturer) and is intended to be placed on the market for distribution as a single functional unit for an end-user and intended to be installed and operated together to perform a specific task.

All provisions of the EMC Directive, as defined for apparatus, apply to the combination as a whole.

Apparatus

Apparatus means any finished appliance or combination thereof made commercially available (ie, placed on the market) as a single functional unit, intended for the end-user, and liable to generate electromagnetic disturbance, or the performance of which is liable to be affected by such disturbance.

Fixed installation

A particular combination of several types of apparatus, equipment and/or components, which are assembled, installed and intended to be used permanently at a predefined location.

Equipment

Any apparatus or fixed installation

Chapter 4 - Purchasing decisions for PDSs

What you need to know and do

Starting on page 23, we offer a step-by-step guide relating to your purchasing requirements for power drive systems.

Key point:

Before turning to page 23, you **need to know** the following terms for PDSs and their component parts, which may be unfamiliar to many users.

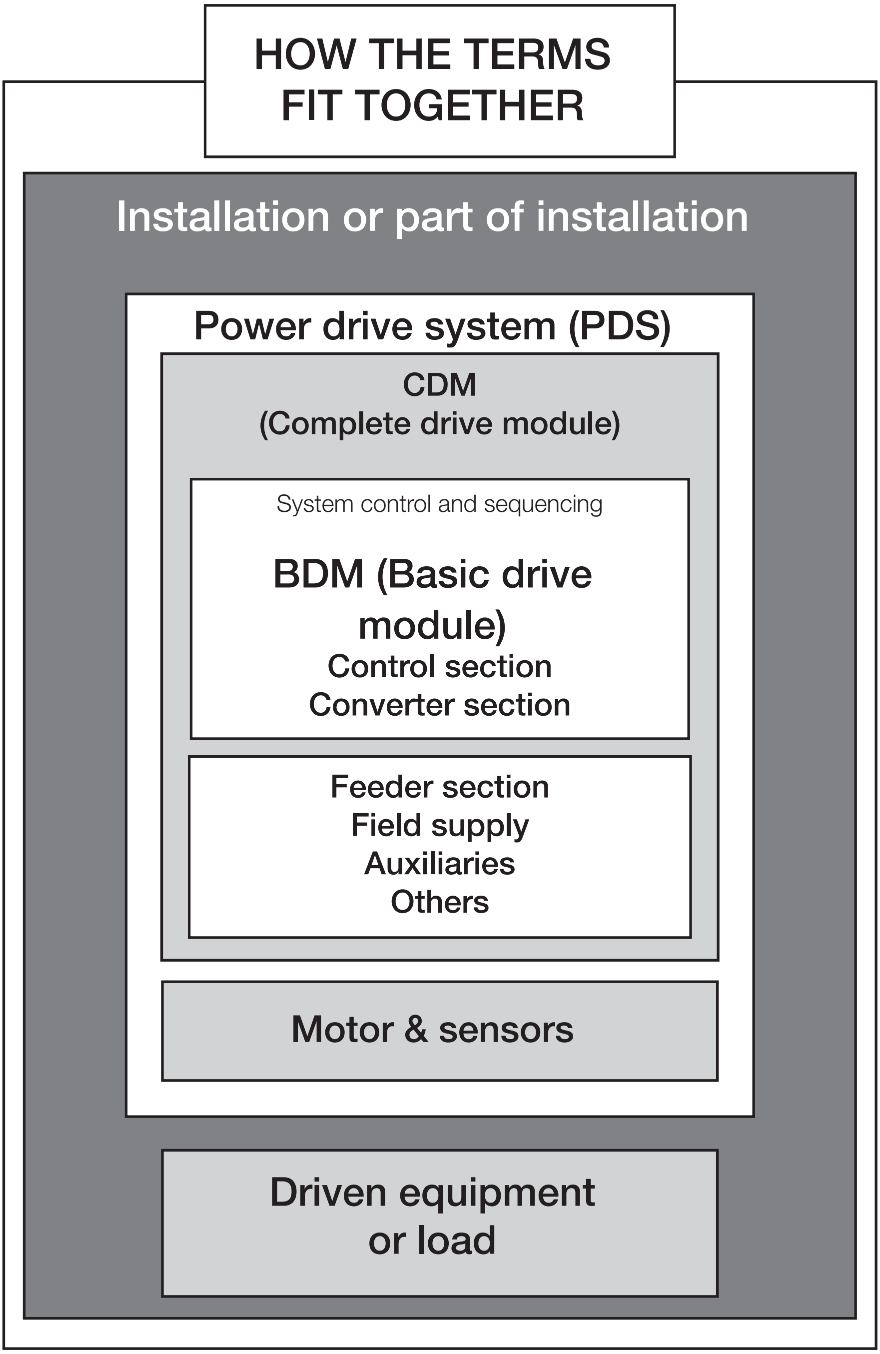
TERMS THAT YOU MUST KNOW

1. Basic drive module (BDM) consists of the converter section and the control circuits needed for torque or speed. A BDM is the essential part of the power drive system taking electrical power from a 50 Hz constant frequency supply and converting it into a variable form for an electric motor.

2. Complete drive module (CDM) consists of the drive system without the motor and the sensors mechanically coupled to the motor shaft. The CDM also includes the Basic Drive Module (BDM) and a feeder section. Devices such as an incoming phase-shift transformer for a 12-pulse drive are considered part of the CDM.

3. Power drive system, or PDS, is a term used throughout this technical guide. A PDS includes the frequency converter and feeding section (the CDM and BDM), motors, sensors, all cabling, filters, panels and any other components needed to make the PDS work effectively.

Note: The load is not considered part of the PDS, but the CDM can incorporate the supply sections and ventilation.



Now we strongly advise you turn to page 23, to discover the type of person you are.

To make this technical guide easy to use, we have also identified certain types of people who will be involved in the purchasing of drives.

Please identify the type nearest to your job function and turn to the relevant section

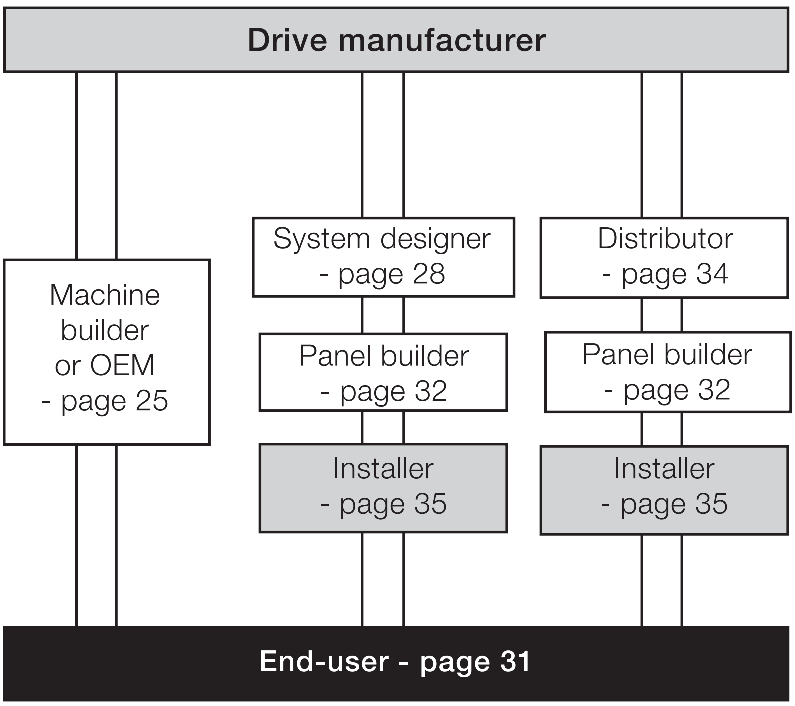
WHO ARE YOU?

	IF THIS IS YOU, TURN NOW TO PAGE...
Machine builder is a person who buys either a PDS, CDM or BDM and other mechanical or electrical component parts, such as a pump, and assembles these into a machine. **Note:** A machine is defined as an assembly of linked parts or components, at least one of which moves. It includes the appropriate actuators, control and power circuits joined together for a specific application, in particular for processing, treatment, moving or packaging of a material.	**25**
System designer carries out all the electrical design of the power drive system, specifying all component parts which comprise a PDS.	**28**
End-user is the final customer who will actually use the machine, PDS or CDM/BDM.	**31**
Panel builder constructs enclosures into which a panel builder will install a variety of components, including a CDM/BDM and sometimes the motor. However, the built enclosure does not constitute a machine.	**32**

Continued overleaf...

WHO ARE YOU?

	IF THIS IS YOU, TURN NOW TO PAGE...
Distributor acts as the sales distribution channel between the CDM/BDM manufacturer and the end-user, machine builder, OEM, panel builder or system designer.	34
Installer carries out the entire electrical installation of the PDS.	35
Original equipment manufacturer (OEM) For the purposes of purchasing drives, an OEM will normally fall into the category of a machine builder, system designer or panel builder. Therefore, if you identify yourself as an OEM, refer to the relevant pages for each of these job functions.	25 28 32



NOTE: Before reading this section we strongly urge you to familiarise yourself with the terms explained on pages 21-24.

If you are a machine builder buying a PDS...

...You have the following responsibilities:

1. Because you are building a complete machine, which includes coupling up the motors to the PDS and providing the mechanical guarding and so on, you are liable for the total mechanical and electrical safety of the machine as specified in the **Machinery Directive**.

   Therefore, the PDS is ultimately your responsibility. You need to ensure that the entire PDS meets the **Machinery Directive**. Only then can **CE marking** be applied to the whole machine.

2. You are also responsible for the electrical safety of all parts of the PDS as specified in the **Low Voltage Directive**.

3. You must ensure electrical equipment and components are manufactured in accordance with the **EMC Directive**. The manufacturer of these parts is responsible for EMC for that particular part. Nevertheless you are responsible for EMC for the machine. You may choose electrical parts not in accordance with the EMC directive, but then you have the responsibility for compliance of parts.

   Note: Be aware that combining CE marked sub-assemblies may not automatically produce an apparatus that meets the requirements.

4. You must ensure that the PDS or its component parts carry **declarations of conformity** in accordance with the electrical safety requirements of the **Low Voltage Directive**.

5. You must be able to assure an **authority** and customers that the machine has been built according to the **Machinery Directive**, the **Low Voltage Directive** and the **EMC Directive**. It may be necessary to issue technical documentation to demonstrate compliance. You must keep in mind that you and only you have responsibility for compliance with directives.

6. A **Declaration of conformity** according to the directives above must be issued by the **machine builder** and **CE marking** must then be affixed to the machine or system.

7. Any machine that does not comply must be withdrawn from the market.

Actions you must take

To meet the **Machinery Directive** (see page 55) you need to:

a. Comply with the following mechanical safety checklist. **The aim is to eliminate any risk of accident throughout the machinery's life. This is not a complete list, the detailed list is contained within the Machinery Directive:**

- [ ] Eliminate risk as far as possible, taking the necessary protective measures if some risks cannot be eliminated.
- [ ] Inform users of the residual risks; indicate whether any training is required and stress the need for personal protective equipment.
- [ ] Machinery design, construction and instructions must consider any abnormal use.
- [ ] Under the intended conditions of use, the discomfort, fatigue and stress of the operator must be reduced.
- [ ] The manufacturer must take account of the operator's constraints resulting from the use of personal protective equipment.
- [ ] Machinery must be supplied with all essential equipment to enable it to be used without risk.

b. Comply with the following electrical safety checklist: **To ensure the electrical safety of all parts of the PDS as specified in the Low Voltage Directive (refer to page 56) you need to comply with the following safety checklist, which is not necessarily complete.**

- [ ] The electricity supply should be equipped with a disconnecting device and with emergency devices for prevention of unexpected startup.
- [ ] The equipment shall provide protection of persons against electric shock from direct or indirect contact.

The equipment is protected against the effects of:

- [ ] overcurrent arising from a short circuit.
- [ ] overload current.
- [ ] abnormal temperatures.
- [ ] loss of, or reduction in, the supply voltage.
- [ ] overspeed of machines/machine elements.

The electrical equipment is equipped with an equipotential bonding circuit consisting of the:

- PE terminal.
- conductive structural parts of the electrical equipment and the machine.
- protective conductors in the equipment or the machine.

- [ ] The control circuits and control functions ensure safe operation including the necessary inter-lockings, emergency stop, prevention of automatic re-start, etc.

Defined on page 40

c. Compile a **technical file** for the machine, including the PDS.

Key point:

Generally, must carry **CE marking** and have a **Declaration of conformity**.

For machines that pose a high risk of accident, a **type certification** (see page 46) is required from a **notified body**. Such machinery is included in Annex IV of the **Machinery Directive**.

The **type certificate** issued should be included in the **technical file** for the machine or safety component. Refer now to page 40.

- [ ] 2. Declarations of conformity from each of the component suppliers whose products make up the PDS and incorporate them into the technical documentation, referring to all three directives. If buying a PDS from a system designer (see below), he should be able to provide all declarations. If system designer or component supplier cannot provide a Declaration of conformity, the responsibility of demonstrating compliance according to EMC Directive or Low Voltage Directive lies on machine builder.

☐ 3. Pass this technical documentation to a notified body. The machine builder SHOULD NOT pass the file on to an end-user. Based on the technical documentation, obtain a Certificate of Adequacy or technical report from a notified body.

Defined on pages 43, 45 and 46

☐ 4. Issue a Declaration of conformity for the entire machine. Only then can you apply CE marking.

☐ 5. Pass the Declaration of conformity related to all three directives on to the end-user of the machine.

☐ 6. Apply **CE marking** to the machine.

☐ 7. Congratulations! You have successfully complied with the main requirements for safe and efficient operation of a machine.

If you are a system designer

You have the following responsibilities:

1. The PDS is a complex component of the machine. Therefore, the **Machinery Directive** has to be complied with by issuing a **Declaration of incorporation**.

2. Because a PDS is not a machine, the only directives which need to be complied with are the **Low Voltage Directive** and the **EMC Directive**.

3. The responsibility for **Declaration of conformity** and applying **CE marking** rests with both the system designer and the supplier of the component parts which make up the power drive system.

The system designer has to decide if he is going to place his delivery on the market as a single functional unit or not

– if the answer is YES, the delivery shall be classified as a system.

– if the answer is NO, the delivery shall be classified as an installation.

A. If the delivery is classified as a system, the system designer has to choose one of two paths to follow:

Path 1

All components have EMC compliance

1. **EMC behaviour is based on a component's performance.**

2. Responsibility lies with the **component suppliers** for CE marking of individual **complex** components

3. PDS is an system according to the **EMC Directive** (as placed on the market as a single functional unit).

4. The **Declaration of conformity** as well as the instructions for use must refer to the system as whole. The system designer assumes responsibility for compliance with the Directive.

Note 1: The system designer is responsible for producing the instructions for use for the particular system as whole.
Note 2: Be aware that combining two or more CE marked sub-assemblies may not automatically produce a system that meets the requirements.

5. No **CE marking** is required for a system as whole, as long as each part bears the CE mark.

Actions you must take

- [ ] 1. Follow all **installation guidelines** issued by each of the component suppliers.
- [ ] 2. Issue **instructions for use** in order to operate the system.
- [ ] 3. Issue technical documentation for the system.
- [ ] 4. Issue a **Declaration of conformity.**
- [ ] 5. **DO NOT** issue a **CE mark.**

Path 2

Components without EMC compliance

1. EMC behaviour is designed at the system level (no accumulated cost by device specific filters etc).

2. Responsibility lies with the **system designer** who decides the configuration (place or a specific filter, etc).

3. PDS is a system according to the **EMC Directive** (as placed on the market as a single functional unit).

4. **Declaration of conformity** and **CE marking** are required for the system.

Actions you must take

☐ 1. Follow the **installation guidelines** issued by each of the component suppliers.

☐ 2. Optimise the construction of the installation to ensure the design meets the required EMC behaviour, ie, the location of filters.

Defined on pages 36 - 46

☐ 3. Issue **instructions for use** in order to operate the system.

☐ 4. Issue **technical documentation** for the system.

☐ 5. Issue a **Declaration of conformity** and **CE mark**.

B. If the delivery is an installation, the system designer has one path to follow:

All components have EMC compliance

1. **EMC behaviour is based on a component's performance.**

2. Responsibility lies with the **component suppliers** for CE marking of individual **complex components.**

3. PDS is an **installation** according to the **EMC Directive.**

4. No **Declaration of conformity** or **CE marking** is required for a fixed installation, (such as an outside broadcast radio station) DOC and CE marking are needed.

Actions you must take

- [ ] 1. Follow all **installation guidelines** issued by each of the component suppliers.
- [ ] 2. Transfer all installation guidelines and Declaration of conformity for each of the components, as issued by suppliers, to the machine builder.
- [ ] 3. **DO NOT** issue a **Declaration of conformity** or **CE marking** as this is not allowed for **fixed installations.**

If you are an end-user buying a CDM/BDM or PDS

Key point:

An **end-user** can make an agreement with the drive's supplier so that the supplier acts as the **machine builder**. However, the **end-user** is still responsible for the machine's safety.

The supplier who acts as the **machine builder** will issue a **Declaration of conformity** when the work is complete.

Once an intermediary **panel builder** incorporates a CDM/BDM into a panel, he creates a part of a PDS.

The panel builder then has the same responsibilities as the drive's manufacturer.

...You have the following responsibilities

1. For the total mechanical and electrical safety of the machine of which the drive is part of, as specified in the **Machinery Directive**.
2. For the electrical safety of the drive as specified in the **Low Voltage Directive**.
3. To ensure the drive carries a **Declaration of conformity** in accordance with the electrical safety requirements of the **Low Voltage Directive**.
4. To be able to demonstrate to the authorities that the machine to which the drive is being fitted has been built to both the **Machinery Directive** and **Low Voltage Directive**.
5. The manufacturer of the drive is responsible for determining the EMC behaviour of the drive.
6. The resulting EMC behaviour is the responsibility of the assembler of the final product, by following the manufacturer's recommendations and guidelines.

Actions you must take

The following needs to be completed by either the end-user directly or the third party engaged to build the machine.

1. To meet the **Machinery Directive** (refer to page 55) you need to **follow the actions listed for a machine builder on pages 25-28.**

2. Follow installation instruction issued by manufacturers in order to fulfill the requirements of the **EMC Directive** and the **Low Voltage Directive**.

3. Ensure that equipment (CDM/BDM/PDS) is operated according to manufacturer's instruction in order to guarentee right way of operation.

If you are a panel builder buying a CDM/BDM

...You have the following responsibilities:

1. The panel builder has two options:

Option A - To buy non-CE marked components

This could save the panel builder money because he buys components which are not tested for EMC or safety. However, the responsibility is then the panel builder's and this will incur considerable costs as the entire panel needs to be tested.

If the panel builder buys non-CE marked components, the drive may be made to conform without further testing if the components themselves have been tested. However, tested components do not carry the CE mark but must carry suitable instructions for installation. It is these instructions which must be demonstrably met.

Option A - Actions to meet these responsibilities

- [ ] 1. Follow the **installation guidelines** issued by each of the component suppliers.
- [ ] 2. Optimise the construction of the installation to ensure the design meets the required EMC behaviour, ie, the location of filters.
- [ ] 3. Issue **technical documentation** for the system. Defined on pages 36-46.

☐ 4. If you choose to assess yourself you must make reference to EMC Directives:

2004/108/EC

And to harmonised standard:

EN 61800-3

And you must make reference to LVD Directive:

2006/95/EC

And corresponding harmonized standard:

EN 61800-5-1 or EN 50178

☐ 5. Once testing is completed, the results need to be included in the **technical documentation (TD)** for the panel.

☐ 6. **Technical documentation** shall be assessed by youself in order to demonstrate compliance. You may use **Notified Body** for assessment as well.

☐ 7. You must then issue the **Declaration of conformity** and **CE marking** for the panel.

Option B - To buy CE marked components

Option B - Actions to meet these responsibilities

☐ 1. Buying CE marked components creates a system or an apparatus (refer to page 17-20) depending on the nature of the panel.

☐ 2. Although the panel builder does not have to carry out tests, he must ensure he conforms to the installation guidelines given by each of the component manufacturers.
Note: Be aware that combining two or more CE-marked components may not automatically produce a system, which meets the requirements.

☐ 3. Beware! These guidelines could differ greatly from those given for normal installation purposes because the components will be in close proximity to each other.

☐ 4. Issue **instructions for use** in order to operate the system or **apparatus**.

- [ ] 5. Issue **technical documentation**.
- [ ] 6. Issue a **Declaration of conformity.**
- [ ] 7. Apply **CE marking** to your panel in the case of an apparatus. In the case of a system **DO NOT** apply **CE marking.**

Additional actions

The panel can be either sold on the open market or use as part of a machine. For each option there is a different requirement:

- [ ] 1. If you know that the panel is to be used as part of a machine then you must request from the CDM / BDM manufacturer a **Declaration of incorporation**.
- [ ] 2. The **Declaration of incorporation** must be supplied with the panel to the **machine builder**, but **CE marking** based on Machinery Directive MUST NOT be affixed. This is because **CE marking** always needs a **Declaration of conformity**.

Key point:

The **Declaration of incorporation** CAN NOT be used to apply **CE marking.**

- [ ] 3. The **machine builder** will need this **Declaration of incorporation** because he has to construct a **technical documentation (TD**) for the machine and in that file all the declarations need to be included.

If you are a distributor buying a CDM/BDM...

...You have the following responsibilities:

1. If a distributor is selling boxed products, like CDMs and BDMs (drives), direct from the manufacturer, his only responsibility is to pass on the **installation guidelines** to the end-user, **machine builder** or **system designer**. In addition, the **Declaration of conformity** must be passed to the **machine builder** or **system designer.**

2. Both the **installation guidelines** and the **Declaration of conformity** are available from the manufacturer.

Actions you must take to meet these responsibilities

1. Pass all **installation guidelines** and **declaration of conformities** to either the **end-user, machine builder** or **system designer.**

If you are an installer buying a CDM/BDM or PDS...

...You have the following responsibilities:

1. You must ensure that the **installation guidelines** of the **machine builder** and/or **system designer** are adhered to.

Actions you must take to meet these responsibilities

1. Follow **machinery builder** and/or **system designer Installation guidelines.**

2. See Technical guide No. 3 for recommended installation guidelines.

Chapter 5 - Terminology

Technical documentation (TD)

APPLIED TO:	electrical equipment
RESPONSIBILITY:	electrical equipment manufacturer, system designer, panel builder, OEM, installer
REQUIRED BY:	EMC Directive, Low Voltage Directive

What is technical documentation?

Technical documentation (TD) must be provided for the entire equipment or system and, if required, is used to show a **competent authority** that you have met the essential requirements of the **EMC Directive** (see page 57) and Low Voltage Directive (see page 56).

The TD consists of three parts:

1. A description of the product.

2. Procedures used to ensure conformity of the product to the requirements.

3. A statement from a notified body, if third party assessment route is chosen.
   Note: Using a notified body is voluntary and can be decided by the manufacturer

Key point:

The full content of the technical documentation are given on pages 36-39.

Why is technical documentation deemed to be important?

Anyone placing a product onto the market within the EU must be able to show that the product meets the requirements of the appropriate **EU Council Directive** and must be able to demonstrate this to a **competent authority** without further testing.

Technical documentation allows the appropriate **Declaration of conformity** to be drawn up.

Will customers always receive a copy of technical documentation?

The content of the technical documentation is meant for the authorities, and thus the electrical equipment manufacturer does not have to give the technical documentation or any part of it to the customer.

However, as the customer needs to know whether the product is in conformance, he will obtain this assurance from the documentation delivered with the product. It is not required to supply a declaration of conformity with the product, but the end-user may ask for this from the manufacturer.

What is the shelf life of technical documentation?

Any technical documentation must be accessible to the appropriate authorities for 10 years from the last relevant product being delivered.

How do I ensure that tests are always carried out?

The whole system is based on self certification and good faith. In various parts of Europe the methods of ensuring compliance will vary. Supervision of these regulations is achieved through market control by a competent authority. If the equipment fails to meet the requirements of the EMC and Low Voltage Directives competent authorities can use the safeguard clause of the Directives (withdraw the product from the market, take legal action).

Can drive manufacturers help more?

Manufacturers accept that there is a need to work more closely with OEMs and machine builders where the converter can be mounted on the machine. A standard assembly or design should be achieved so that no new parts of technical documentation need to be created.

However, the idea of mounting several drives in motor control centres (MCCs) must be much more carefully thought out by system specifiers, as the summing of high frequency emissions to determine the effects at the MCC terminals is a complex issue and the possibilities of cross coupling are multiplied.

How to make up a TD

1. Description of the product

(Note: You can photocopy these pages and use as a tickbox checklist)

i. identification of product

☐ a. brand name.

☐ b. model number.

☐ c. name and address of manufacturer or agent.

☐ d. a description of the intended function of the apparatus.

☐ e. any limitation on the intended operating environment.

ii. a technical description

☐ a. a block diagram showing the relationship between the different functional areas of the product.

☐ b. relevant technical drawings, including circuit diagrams, assembly diagrams, parts lists, installation diagrams.

☐ c. description of intended interconnections with other products, devices, etc.

☐ d. description of product variants.

2. Procedures used to ensure product conformity

i. details of significant design elements

☐ a. design features adopted specifically to address EMC and electrical safety problems.

☐ b. relevant component specifications.

☐ c. an explanation of the procedures used to control variants in the design together with an explanation of the procedures used to assess whether a particular change in the design will require the apparatus to be re-tested.

☐ d. details and results of any theoretical modelling of performance aspects of the apparatus.

☐ e. a list of standards applied in whole or part.

☐ f. the description of the solution adopted in order to comply with the directive.

ii. test evidence where appropriate

☐ a. a list of the EMC and electrical safety tests performed on the product, and test reports relating to them, including details of test methods, etc.

☐ b. an overview of the logical processes used to decide whether the tests performed on the apparatus were adequate to ensure compliance with the directive.

☐ c. a list of the tests performed on critical sub-assemblies, and test reports or certificates relating to them.

3. If chosen a statement from notified body

This will include:

☐ i. reference to the exact build state of the apparatus assessed

☐ ii. comment on the technical documentation.

☐ iii. statement of work done to verify the contents and authenticity of the design information.

☐ iv. statement, where appropriate, on the procedures used to control variants, and on environmental, installation and maintenance factors that may be relevant.

4. Actions by the notified body

The **notified body** will study the **technical documentation** and issue the statement and this should be included in the **technical documentation.**

Note: When compiling the **technical documentation** you may need all **Declarations from suppliers**, ie, **Declaration of conformity** and **Declaration of incorporation** depending on the parts, to ensure they carry **CE marking.**

Technical file (for mechanical safety aspects)

APPLIED TO: machines and safety components

RESPONSIBILITY: machine builder / system designer

REQUIRED BY: Machinery Directive

What is a technical file?

A technical file is the internal design file which should show how and where the standards are met and is all that is needed if self certifying the equipment by the standards compliance route.

If a Declaration of incorporation is included in a set of papers and this claims to meet the appropriate parts of the standards and simply instructs the user to meet the standards with other parts of his machine, it is possible to use this as a part of a technical file.

How to make up a technical file

Drawings and diagrams

1. Overall drawings of the machine.

2. Control circuit diagrams.

Health and safety

1. All drawings, calculations and test results used to check the machine's conformity with essential health and safety requirements.

Machine design

1. Lists of the essential health and safety requirements, **harmonised standards**, other standards and technical specifications used when designing the machine.

2. Description of methods used to eliminate hazards presented by the machine.

Other certificates required

1. A technical report or certificate issued by a **notified body** - if required.

2. A copy of the instructions for the machine.

3. For series produced machines, the control measures that are used to ensure that subsequent manufacture remains in conformity with the directive.

Certificate of Adequacy

APPLIED TO: machines / safety components

RESPONSIBILITY: notified body / machine builder

REQUIRED BY: Machinery Directive

What if standards cannot be wholly implemented?

In this case the adequacy of the **technical file** is proved by a **Certificate of Adequacy** issued by a **notified body.**

How to obtain a Certificate of Adequacy

The **Certificate of Adequacy** is a document drawn up by a **notified body**. Once the body has established that the **technical file** contains all the necessary information, the **Certificate of Adequacy** will be issued.

Key point:

The **Certificate of Adequacy** provided should be included in the **technical file.**

Statement

APPLIED TO: electrical equipment

RESPONSIBILITY: notified body

REQUIRED BY: EMC Directive

When the statement is needed

The primary way for manufacturer (or his authorised representative in the Community) to demonstrate the compliance is to use internal production control method. If the manufacturer chooses, he may use other method based on an assessment of a **notified body**.

How to obtain the statement

The manufacturer shall present the **technical documentation** to the **notified body** and request the **notified body** for an assessment thereof. The manufacturer shall specify to the **notified body** which aspects of the essential requirements must be assessed.

The **notified body** shall review the **technical documentation** and assess whether the **technical documentation** properly demonstrates that the requirements of the **Directive**. If the compliance of the apparatus is confirmed, the **notified body** shall issue a statement confirming the compliance of the apparatus.

Key point:

The **statement** provided shall be included in the **technical documentation**.

Report

APPLIED TO: electrical equipment

RESPONSIBILITY: notified body / competent body

REQUIRED BY: Low Voltage Directive

What if standards cannot be wholly implemented?

In the event of a challenge the manufacturer or importer may submit a report issued by a notified body. This report is based on the technical file.

How to obtain a report

The report is a document drawn up by a notified body. Once the body has established that the technical documentation contains all the necessary information and the equipment fulfils the requirements of the Low Voltage Directive, the report will be issued.

Key point:

The report provided should be included in the technical documentation.

Declaration of conformity (for EMC and electrical safety aspects)

APPLIED TO:	electrical equipment and electrical equipment of machines
RESPONSIBILITY:	equipment manufacturer
REQUIRED BY:	Low Voltage Directive and EMC Directive

How to obtain a Declaration of conformity

You need to provide the following:

1. a reference to the Directive(s),
2. an identification of the apparatus to which it refers (including name, type and serial number),
3. the name and address of the manufacturer and, where applicable, the name and address of his authorised representative in the Community,
4. a dated reference to the specifications under which conformity is declared,
5. the date of the declaration,
6. the identity and signature of the person empowered to bind the manufacturer or his authorised representative.

Declaration of conformity (for mechanical safety aspects)

APPLIED TO:	machines
RESPONSIBILITY:	machine builder
REQUIRED BY:	Machinery Directive

How to obtain a Declaration of conformity

You need to provide the following:

1. business name and full address of the manufacturer or, his authorised representative;
2. name and address of the person authorised to compile the technical file, who must be established in the Community;

3. description and identification of the machinery, including generic denomination, function, model, type, serial number and commercial name;

4. a sentence expressly declaring that the machinery fulfils all the relevant provisions of the machinery Directive

5. where appropriate, the name, address and identification number of the notified body which carried out the EC type-examination and the number of the EC type-examination certificate;

6. where appropriate, the name, address and identification number of the notified body which approved the full quality assurance system;

7. a list to the harmonised standards or the other technical standards and specifications used;

9. the place and date of the declaration as well as the identity and signature of the person empowered to draw up the declaration on behalf of the manufacturer or his authorised representative.

Declaration of incorporation

APPLIED TO:	machines or equipment intended for incorporation into other machinery
RESPONSIBILITY:	drives manufacturer / machine builder / panel builder
REQUIRED BY:	Machinery Directive

What is a Declaration of incorporation?

Drives manufacturers must meet the appropriate parts of the Machinery Directive and provide a Declaration of incorporation which states that the drive does not comply on its own and must be incorporated in other equipment.

This declaration will show the standards that have been applied to the parts of the system within the manufacturer's scope.

This declaration includes a statement restricting the user from putting the equipment into service until the machinery into which it is to be incorporated, or of which it is to be a component, has been found, and declared, to be in conformity with the provisions of the Machinery Directive and the national implementing legislation, ie, as a whole including the equipment referred to in this declaration.

The declaration then lists the standards relating to the Machinery and Low Voltage Directives which the manufacturer has met.

It concludes that the entire equipment must meet the provisions of the directive.

Quite simply, the manufacturer passes on the responsibility to the machine or system builder.

Is there no way out of this type of declaration?

No. You must understand that because the manufacturer may be supplying only one part in a machinery, such as the inverter, the manufacturer is legally obliged to ensure that whoever puts the system together must check that it is safe.

Only then can the machine or system builder use the Declaration of incorporation in his technical file of the machine.

Key point:

Most manufacturers will include a Declaration of incorporation covering the Machinery Directive for all built PDS products.

What a Declaration of incorporation contains

1. business name and full address of the manufacturer or his authorised representative;

2. description and identification of the partly completed machinery including generic denomination, function, model, type, serial number and commercial name;

3. a sentence declaring which essential requirements of the Directive are applied and fulfilled;

4. an undertaking to transmit, in response to a reasoned request by the national authorities, relevant information on the partly completed machinery;

5. a statement that the partly completed machinery must not be put into service until the final machinery into which it is to be incorporated has been declared in conformity with the provisions of the Directive;

6. the place and date of the declaration as well as the identity and signature of the person empowered to draw up the declaration on behalf of the manufacturer or his authorised representative.

Type certification

APPLIED TO: machines and safety components

RESPONSIBILITY: machine builder/approved body

REQUIRED BY: Machinery Directive

How to obtain type certification

Type certification is carried out by an **notified body** who will establish that the unit supplied, along with a **technical file**, may be used safely and that any **standards** have been correctly applied.

Once the **type certification** has established this, a **type examination certificate** will be issued.

Chapter 6 - Authorities and bodies

The responsibility for product conformity is given to the manufacturer. If there is any doubt about conformity, then the Authorities can demand technical documentation to show that a product complies with the directives concerning the product.

When assessing product conformity, a manufacturer can use a third party to examine the conformity.

The following types of authorities and bodies exist:

Competent authority

A **competent authority** in any EU or EEA country supervises markets to prevent hazardous products being sold and marketed. They can also withdraw such products from markets.

Notified body

A **notified body** issues type certificates for products, which have their own directives and/or require type testing.

To find a suitable competent authority or **notified body** you can contact:
EU Commission
Enterprise and Industry DG
Information and Documentation Centre
BREY 5 / 150
B-1049 Brussels
Belgium
Ph: +32 2 296 45 51

Or you may find contact through web.site: http://ec.europa.eu/enterprice/electr_equipment/

Chapter 7 - Standards and directives

The use of standards is voluntary, but compliance with directives without the use of harmonised standards is extremely difficult.

There are two ways to show that a power drive system or part of it conform:

– Use of harmonised standards (EN).

– By way of a technical documentation when no harmonised standards exist, or if all parts of a harmonised standard cannot be applied.

Key point:

It is recommended to use technical documentation even when standards are harmonised as it makes it easier to show conformity afterwards, if required by authorities.

Directive or standard?

The legislation of the European Union is defined by different directives.

The directives concerning power drive systems are known as new approach directives, which means that they do not include exact figures or limits for products. What they do include is essential requirements mainly for health and safety which make the application of the relevant harmonised standards mandatory.

The requirements of directives are firmly established in standards. Standards give exact figures and limits for products.

The responsibility for defining standards in Europe rests with three committees: CEN, for areas of common safety, CENELEC, for electrical equipment and ETSI, for telecommunications.

Harmonised standards for PDSs

To remove technical barriers to trade in EU or EEA countries, the standards are harmonised in member states.

In the harmonisation procedure, all member states are involved in developing the Committee's proposals for their own national standard. A standard becomes harmonised when published in the Official Journal of the EU.

The idea is that if a product conforms to the **harmonised standard**, it is legally manufactured and when placed onto the market in one country, it must be freely marketed in other member countries.

How to recognise a European standard

Harmonised standards come in the following format:

XX EN 60204-1

where

XX = the national prefix (eg BS = UK; SFS = Finland)
EN = the abbreviation of Euronorm
60204-1 = an example of a standard number

The numbering of European standards follows a well structured and organized sequence:
- EN 50225:1996 (the year of availability of the EN is separated from the number by a colon)
- EN 50157-2-1:1996 (the part number is indicated by a hyphen)

The first two numerals indicate the origin of the standard:
- 40xxx to 44xxx cover domains of common CEN/CENELEC activities in the IT field
- 45xxx to 49xxx cover domains of common CEN/CENELEC activities outside the IT field
- 50xxx to 59xxx cover CENELEC activities, where
  - EN 50xxx refer to the standards issued by CENELEC only
  - EN 55xxx refer to the implementation of CISPR documents
- 60000 to 69999 refer to the CENELEC implementation of IEC documents with or without changes

European standards are adopted and confirmed by CENELEC member countries by adding national prefix before the standard id (for example: SFS-EN 60601-1, DIN EN 60601-1, BS EN 60601-1).

There is also some clue as to a standard's status:

prEN 50082-2 = proposal for standard sent to member states
ENV 50 = pre-standard which is in force for 3 years to obtain practical experience from member states

Your questions answered

Which standards directly relate to drives?

At the moment, there are three **Product Specific Standards** which relate to the compliance with EU directives. They are called as "EN 61800-3 Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods", which relates to **EMC Directive**, "EN 61800-5-1 Adjustable speed electrical power drive systems - Part 5-1: Safety requirements - Electrical, thermal and energy", which relates to **Low Voltage Directive** and EN 61800-5-2 Adjustable speed electrical power drive systems - Part 5-2: Safety requirements - Functional safety", which relates to **Machinery Directive.**

In addition there are other standards, which need to be taken account:

- EN 60204-1, Electrical Equipment of Machines, which, in addition to being a **Low Voltage Directive** standard for all electrical equipment, is also an electrical safety standard under the **Machinery Directive**.
- EN 50178 according to **Low Voltage Directive** and
- EN 61800-1/2/4, which give rating specifications for Power Drive Systems (LV DC, LV AC and MV AC PDS respectively).
- EN 61000-3-2 and EN 61000-3-12, which give requirements for harmonic current caused by equipment

What are the issues of EN 61800-3 and drives?

For emissions there are two main aspects to be considered:

Conducted emissions: these are seen on the power supply cables and will also be measured on the control connections, while radiated emissions are air borne.

Conducted emissions at low frequencies are known as harmonics, which have been a familiar problem to many users of a PDS. Where harmonics are concerned EN 61800-3 refers to EN 61000-3-2, which applies for equipment under 16 A per phase. In addition, the harmonics standard EN 61000-3-12 applies up to 75 A per phase.

At the moment following groups can be separated
- Below 16 A per phase
  - Professional, over 1kW => No limits.
  - Other > the limits specified.
- Between 16 A and 75 A per phase
  - Equipment for public low voltage systems => the limits specified.
  - Equipment for other systems => the limits specified

Conformity with conducted emissions can be helped by good product design and is readily achieved, in most situations, using filters, providing this is for a single drive.

Radiated emissions: These are more problematic. While it is possible to make the drive enclosure into a Faraday cage and thereby have all radiation attenuated to earth, in practice it is the outgoing connections where inadequate cabling radiates emissions and cross couples with other cables in the vicinity. Important attenuation methods are shielded cables and 360° grounding.

What are the solutions to radiated emissions?

The most important solutions are good installation practice, tight enclosure, shielded cables and 360° grounding. (See Technical guide No. 3 for tips and advice).

Do I have to conform to the standards?

The use of standards is voluntary, but compliance with a Directive without the use of **Harmonised Standards** is difficult in the majority of cases.

Can I be fined for not conforming?

Yes. Failure to comply with any of the Directives will be a criminal offence.

The Product Specific Standard EN 61800-3

This standard defines the required emission and immunity levels of PDSs and the test methods to measure the levels. In Europe, the standard takes precedence over all generic or product family EMC standards previously applicable.

The standard defines two environments where equipment can be used:

First environment
– environment that includes domestic premises, it also includes establishments directly connected without intermediate transformers to a low voltage power supply network which supplies buildings used for domestic purposes. Houses, apartments, commercial premises or offices in a residential building are examples of this kind of locations.

Second environment

– environment that includes all establishments other than those directly connected to a low voltage power supply network which supplies buildings used for domestic purposes. Industrial areas, technical areas of any building fed from a dedicated transformer are examples of second environment locations

The standard divides PDSs and their component parts into four categories depending on the intended use

PDS of category C1:

A PDS with rated voltage less than 1,000 V and intended for use in the first environment. A (PDS (or CDM) sold "as built" to the end-user.

Description

Placed on the market. Free movement based on compliance with the EMC Directive. The **EC Declaration of Conformity** and **CE Marking** are required.

The PDS manufacturer is responsible for EMC behaviour of the PDS under specified conditions. Additional EMC measures are described in an easy-to-understand way and can be implemented by a layman.

When PDS/CDM is going to be incorporated with another product, the resulting EMC behaviour of that product is the responsibility of the assembler of the final product, by following the manufacturer's recommendations and guidelines.

PDS of category C2:

PDS with rated voltage less than 1,000 V, which is neither a plug in device nor a movable device and is intended to be installed and commissioned only by a professional.

A PDS (or CDM/BDM) sold to be incorporated into an apparatus, system or installation.

Description:

Placed on the market. Intended only for professional assemblers or installers who have the level of technical competence of EMC necessary to install a PDS (or CDM/BDM) correctly. The manufacturer of the PDS (or CDM/BDM) is responsible for providing **Installation Guidelines**. The **EC Declaration of Conformity** and **CE Marking** are required.

When a PDS/CDM/BDM is to be incorporated with another product, the resulting EMC behaviour of that product is the responsibility of the assembler of the final product.

PDS of category C3:

PDS with rated voltage less than 1,000 V, intended for use in the second environment.

A PDS (or CDM/BDM) sold "as built" to the end-user or in order to be incorporated into an apparatus, system or installation.

Description
Placed on the market. Free movement based on compliance with the EMC Directive. The **EC Declaration of Conformity** and **CE Marking** are required.

The PDS manufacturer is responsible for EMC behaviour of the PDS under specified conditions. Additional EMC measures are described in an easy-to-understand way and can be implemented by a layman.

When PDS/CDM is going to be incorporated with another product, the resulting EMC behaviour of that product is the responsibility of the assembler of the final product, by following the manufacturer's recommendations and guidelines.

PDS of category C4:

PDS with rated voltage equal to or above 1,000 V, or rated current equal to or above 400 A, or intended for use in complex systems in the second environment.

A PDS (or CDM/BDM) sold to be incorporated into an apparatus, system or installation.

Description
Category C4 requirements include all other EMC requirements but radio frequency emission. They assessed only when it is installed in its intended location. Therefore category C4 PDS is treated as a fixed installation, and thus has no requirement for **EC Declaration of Conformity** or **CE Marking**.

The EMC directive requires the accompanying documentation to identify the fixed installation, its electromagnetic compatibility characteristics and responsible person, and to indicate the precautions to be taken in order not to compromise the conformity of that installation.

In order to comply the above requirements in the case of category C4 PDS (or CDM/BDM), the user and the manufacturer shall agree on an EMC plan to meet the EMC requirements of the intended application. In this situation, the user defines the EMC characteristics of the environment including the whole installation and the neighborhood. The manufacturer of PDS shall provide information on typical emission levels and installation guidelines of the PDS which is to be installed. Resulting EMC behaviour is the responsibility of the **installer** (eg, by following the EMC plan).

Where there are indications of non-compliance of the category C4 PDS after commissioning, the standard includes procedure for measuring the emission limits outside the boundary of an installation.

Examples concerning applications of different approaches

1. BDM used in domestic or industrial premises, sold without any control of the application.

The manufacturer is responsible that sufficient EMC will be achieved even by a layman. Although the EMC Directive applies to the apparatus and fixed installations only (generally components are excluded), it states that the components which are intended for incorporation into apparatus by the end user and which liable to generate electromagnetic disturbances are included. Thus, if members of the public (**end-users**) buy a component off the shelf, they will not have to worry about compliance when they fit it to their machine. Therefore, the responsibility for compliance and **CE Marking** such components under EMC lies with the manufacturer. Depending of intended installation location category C1 or C3 equipment is allowed.

2. PDS or CDM/BDM for domestic or industrial purposes, sold to professional assembler.

This is sold as a sub-assembly to a professional assembler who incorporates it into a machine, apparatus or system. Conditions of use are specified in the manufacturer's documentation. Exchange of technical data allows optimisation of the EMC solutions. In addition of categories C1 and C3, also category C2 is allowed.

3. PDS or CDM/BDM for use in installations.

The conditions of use are specified at the time by the purchase order; consequently an exchange of technical data between supplier and client is possible. It can consist of different commercial units (PDS, mechanics, process control etc).

The combination of systems in the installation should be considered in order to define the mitigation methods to be used to limit emissions. Harmonic compensation is an evident example of this, both for technical and economical reasons.

In addition of categories C1, C2 and C3, also category C4 is allowed.

4. PDS or CDM/BDM for use in machine.

PDS or CDM/BDM combined with application device (machine) such as a vacuum cleaner, fan, pump or such like, ie, ready to use apparatus. Similarly inverters (E.Q. subassemblies of BDMs) come under this class of components. On their own they do not have an intrinsic function for the **end-user**, but are sold to professional **installers** who incorporate them into a machine, apparatus or system. They are not on sale directly to the **end-user**.

Therefore for EMC Directive point of view the PDS/CDM/BDM here is a component which is excluded from the directive. The machine builder is responsible for all EMC issues. The manufacturer of PDS/CDM/BDM is responsible for providing installation, maintenance and operation instructions to the machine builder in order to achieve compliance with EMC Directive.

Nevertheless, it is recommended to use category C1, C2, C3 or C4 PDS/CDM/BDM rather than drives without any compliance.

Machinery Directive 98/37/EC

How does the Machinery Directive affect my drive?

This directive concerns all combinations of mechanically joined components, where at least one part is moving and which have the necessary control equipment and control and power input circuits.

The directive concerns all machines but not those like lifts, which have a specific directive.

The new machinery Directive 2006/42/EC has been published. Since the old directive 98/37/EC can be used until December 29, 2009, the changes due to the new directive will be consider in the future editions of this Guide.

Key point:

As far as drives are concerned, the new version of EN 60204-1, ed. 5, is already published. The old and the new versions can be used until June 1, 2009. After that date only the new version shall be applied.

On its own, the **complete drive module (CDM)** does not have a functional value to the user. It always needs its motor coupled to the driven load before it can function effectively. Thus, it cannot carry the **CE marking** based on the **Machinery Directive**.

Where can I obtain a Machinery Directive copy?

To obtain a copy of the **Machinery Directive** you can contact a local competent authority or download it from European Unions web-site related to the legislation (http://europa.eu.int/eur-lex/).

Low Voltage Directive

How does the LVD affect my drive?

2006/95/EC

This directive concerns all electrical equipment with nominal voltages from 50 V to 1 kV AC and 75 V to 1.5 kV DC.

The aim of the directive is to protect against electrical, mechanical, fire and radiation hazards. It tries to ensure that only inherently safe products are placed on the market.

All parts of a PDS from converters and motors to control gear must conform with the **Low Voltage Directive**.

To guarantee that a product complies, the manufacturer must provide a **Declaration of conformity**. This is a Declaration that the product conforms to the requirements laid down within this Directive.

If a product conforms to the Directive and has a **Declaration of conformity**, then it must carry the **CE marking.**

In the case of a power drive system, the **Declaration of conformity** is needed for each of its component parts. Thus, the **Declaration of conformity** for the complete drive module (CDM) and for the motor have to be given separately by the manufacturer of each product.

Key point:

Most manufacturers will include a **Declaration of conformity** covering the **Low Voltage Directive** for all built PDS/CDMs. These are drives built into an enclosure, which can be wired up to the supply and switched on without any further work being undertaken. This is in contrast to an open chassis (BDM), which is a component and needs an enclosure.

Why is the Declaration of conformity important?

Key point:

Without the **Declaration of conformity** the CDM could not carry the **CE marking** and therefore it could not be sold within EEA countries and therefore could not be used legally in any system.

EMC Directive

How does the EMC Directive affect my drive?

2004/108/EC

The intention of the **EMC Directive** is, as its name implies, to achieve EMC compatibility with other products and systems. The directive aims to ensure emissions from one product are low enough so as not to impinge on the immunity levels of another product.

There are two aspects to consider with the **EMC Directive**:

- the **immunity** of the product.
- the **emissions** from that product.

Although the directive expects that EMC should be taken into account when designing a product, in fact EMC cannot be handled by design only – it shall be measured quantitatively as well.

Key point:

Most drives bear **CE-marking**. Newertheless, some cases drives are part of the machinery or process equipment/system and classified as components they are not included into the EMC directive.

The **machine builder**, therefore, has the final responsibility to ensure that the machine including any PDS and other electrical devices, meets the EMC requirements.

At each stage of the manufacturing process, from component to system, each manufacturer is responsible for applying the appropriate parts of the directive. This may be in the form of instructions on how to install or fit the equipment without causing problems. It does not imply that there is a string of **Declarations of conformity** to be compiled into a manual.

Who has the responsibility to ensure CE marking?

A frequency converter is likely to be only a part of a power drive system.

Yet it is the entire system or machinery that must meet the requirements of the EMC Directive.

So, drives manufacturers are in a position to choose whether to put **CE marking** on to a frequency converter to indicate compliance with the EMC Directive or to deliver it as a component without **CE marking**.

Key point:

It is the responsibility of the person who finally implements the system to ensure EMC compliance.

Either the **machine builder** or **system supplier** has the final responsibility that the machine or system including the drive and other electrical and electronic devices will meet the EMC requirements.

A drive manufacturer is able to help **machine builder** or **system supplier** by providing BDM/CDM/PDS which are according to the EMC directive and **CE-marked**.

Summary of responsibilities

Summary of manufacturer's responsibilities in the application of EC Directives to systems containing a PDS:

Warnings & guide

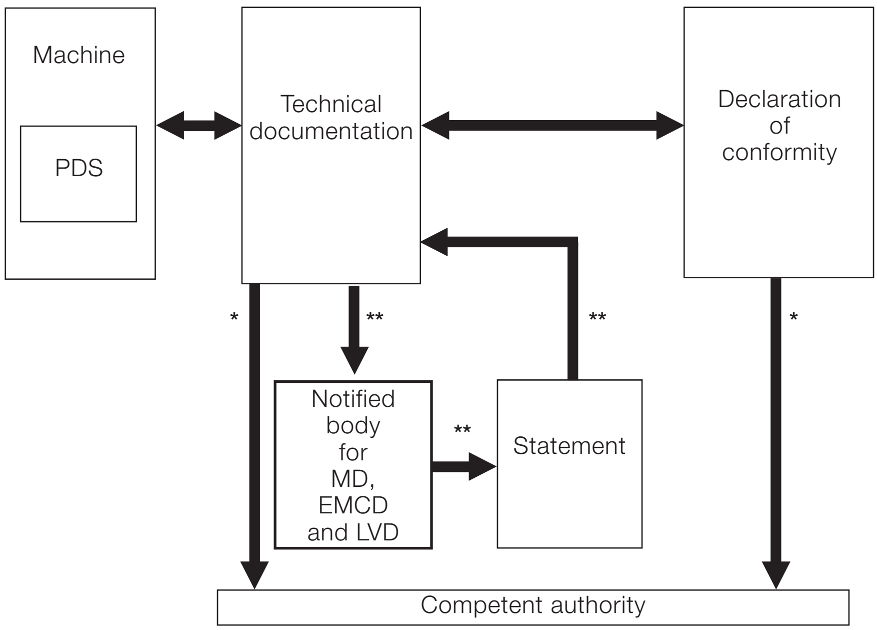
Power drive system

Machinery Directive	Low Voltage Directive	EMC Directive
Any safety relevant standard such as EN 61800-5-2, EN 60204-1, etc	EN 61800-5-1 EN 50178 EN 60204-1	EN 61800-3
TECHNICAL FILE	TECHNICAL FILE	TECHNICAL DOCUMENTATION
Apply Harmonised Standards as far as possible	Apply Harmonised Standards	Apply Harmonised Standards
Declaration of Incorporation	EU Declaration of Conformity	EU Declaration of Conformity
No CE marking as the PDS is a component of the machine	CE mark applied	CE mark applied

If some of the directives result in CE marking, the PDS (or CDM or BDM) can be CE marked with the corresponding Declaration of conformity.

An analogue of this procedure occurs for each end product which is to be combined with a PDS. However, check all directives applicable to the end product.

Achieving conformity with EC Safety Directives



* Only if required during market surveillance
** Optional procedure, if chosen by the manufacturer

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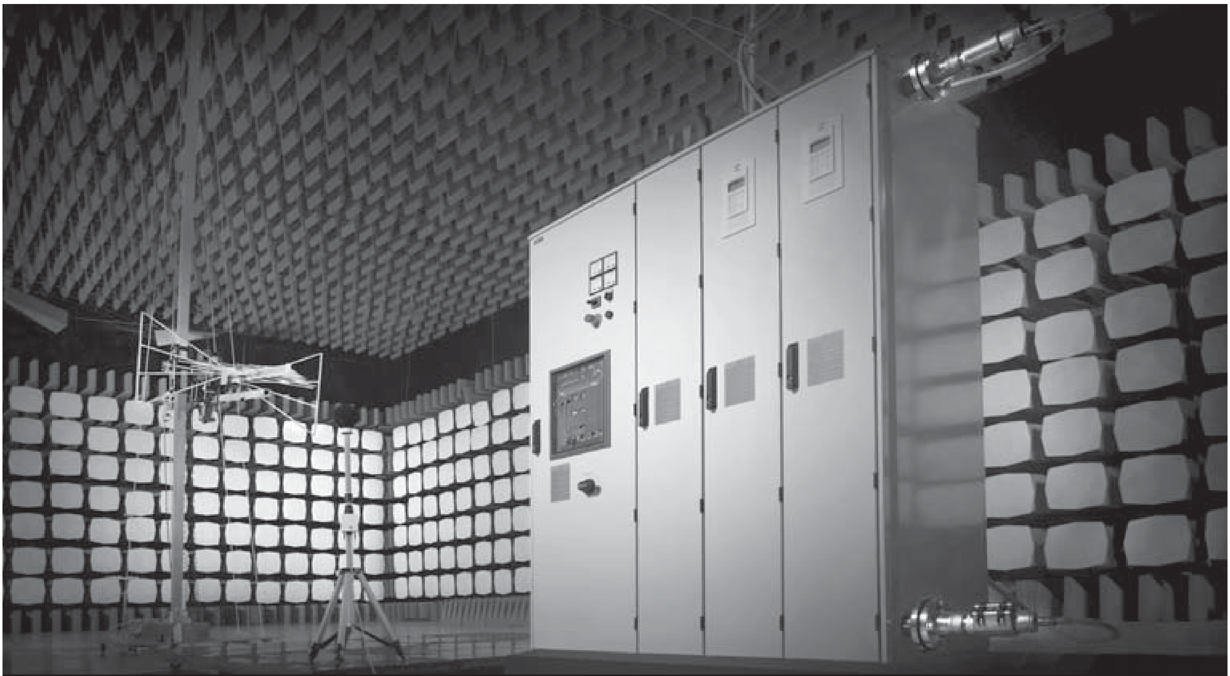

ABB drives

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EMC compliant installation and configuration for a power drive system

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Chapter 1 - Introduction

General

This guide assists design and installation personnel when trying to ensure compliance with the radio frequency requirements of the EMC Directive in the user's systems and installations when using AC drives. The radio frequency range starts from 9 kHz. However, most standards at the moment deal with frequencies that are higher than 150 kHz.

The frequency range below 9 kHz, that is, harmonics, is dealt with technical guide No. 6 "Guide to harmonics with AC drives".

3

Purpose of this guide

The purpose of this guide is to guide original equipment manufacturers (OEM), system integrators and panel builders (assemblers) in designing or installing AC drive products and their auxiliary components into their own installations and systems. The auxiliaries include contactors, switches, fuses, etc. By following these instructions it is possible to fulfill EMC requirements and give CE marking when necessary.

Directives concerning the drive

There are three directives that concern variable speed drives. They are the Machinery Directive, Low Voltage Directive and EMC Directive. The requirements and principles of the directives and use of CE marking are described in technical guide No. 2 "EU Council Directives and adjustable electrical power drive systems". This document deals only with the EMC Directive.

Who is the manufacturer?

According to the EMC Directive (2004/108/EC), the definition of a manufacturer is following: "This is the person responsible for the design and construction of an apparatus covered by the Directive with a view to placing it on the EEA market on his own behalf. Whoever modifies substantially an apparatus resulting in an "as-new" apparatus, with a view to placing it on the EEA market, also becomes the manufacturer."

Manufacturer's responsibility

According to the EMC Directive the manufacturer is responsible for attaching the CE mark to each unit. Equally the manufacturer is responsible for writing and maintaining technical documentation (TD).

OEM customer as a manufacturer

It is well known that OEM customers sell equipment using their own trademarks or brand labels. Changing the trademark, brand label or the type marking is an example of modification resulting in "as new" equipment.

Frequency converters sold as OEM products shall be considered components (complete drive module (CDM) or basic drive module (BDM)). Apparatus is an entity and includes any documentation (manuals) intended for the final customer. Thus, the OEM-customer has sole and ultimate responsibility concerning the EMC of equipment, and he shall issue a Declaration of Conformity and technical documentation for the equipment.

Panel builder or system integrator as a manufacturer

According to the EMC Directive, a system is defined as a combination of several types of equipment, finished products, and/or components combined, designed and/or put together by the same person (system manufacturer) intended to be placed on the market for distribution as a single functional unit for an end-user and intended to be installed and operated together to perform a specific task.

A panel builder or system integrator typically undertakes this kind of work. Thus, the panel builder or system integrator has sole and ultimate responsibility concerning the EMC of the system. He cannot pass this responsibility to a supplier.

In order to help the panel builder/system integrator, ABB Oy offers installation guidelines related to each product as well as general EMC guidelines (this document).

Definitions

The EMC Product Standard for Power Drive Systems, EN 61800-3 (or IEC 61800-3) is used as the main standard for variable speed drives. The terms and definitions defined in the standard are also used in this guide.

Practical installations and systems

This guide gives practical EMC examples and solutions that are not described in product specific manuals. The solutions can be directly used or applied by the OEM or panel builder.

Earthing principles

The earthing and cabling principles of variable speed drives are described in the manual “Grounding and cabling of the drive system”, code 3AFY61201998. It also includes a short description of interference phenomena.

Product-specific manuals

Detailed information on the installation and use of products, cable sizes etc. can be found in the product specific manuals. This guide is intended to be used together with product specific manuals.

Chapter 2 - Definitions

Electromagnetic compatibility (EMC) of PDS

EMC stands for Electromagnetic compatibility. It is the ability of electrical/electronic equipment to operate without problems within an electromagnetic environment. Likewise, the equipment must not disturb or interfere with any other product or system within its locality. This is a legal requirement for all equipment taken into service within the European Economic Area (EEA). The terms used to define compatibility are shown in figure 2-1.

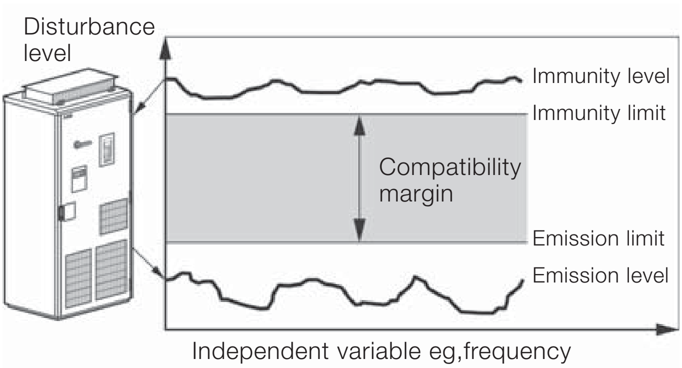

Figure 2-1 Immunity and emission compatibility.

As variable speed drives are described as a source of interference, it is natural that all parts which are in electrical or airborne connection within the power drive system (PDS) are part of the EMC compliance. The concept that a system is as weak as its weakest point is valid here.

Immunity

Electrical equipment should be immune to high-frequency and low-frequency phenomena. High-frequency phenomena include electrostatic discharge (ESD), fast transient burst, radiated electromagnetic field, conducted radio frequency disturbance and electrical surge. Typical low-frequency phenomena are mains voltage harmonics, notches and imbalance.

Emission

The source of high-frequency emission from frequency converters is the fast switching of power components such as IGBTs and control electronics. This high-frequency emission can propagate by conduction and radiation.

Power drive system

The parts of a variable speed drive controlling driven equipment as a part of an installation are described in EMC Product Standard EN 61800-3. A drive can be considered as a basic drive module (BDM) or complete drive module (CDM) according to the standard.

It is recommended that personnel responsible for design and installation have this standard available and be familiar with this standard. All standards are available from the national standardization bodies.

Systems made by an OEM or panel builder can consist more or less of the PDS parts alone, or there can be many PDSs in a configuration.

The solutions described in this guide are used within the definition of power drive system, but the same solutions can, or in some cases, should, be extended to all installations. This guide gives principles and practical EMC examples, which can be applied to a user's system.

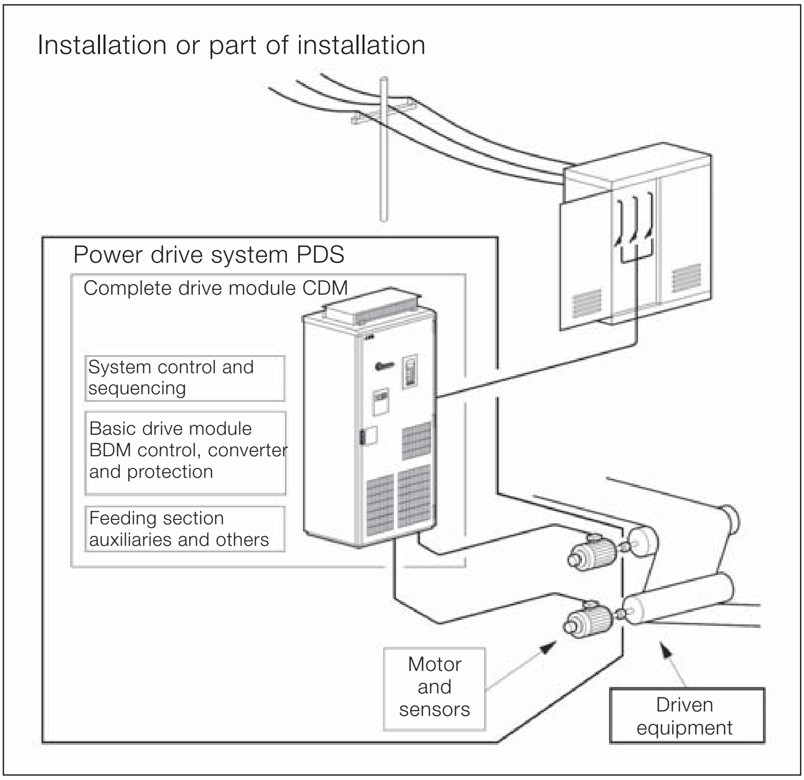

Figure 2-2 Abb reviations used in drives.

Types of equipment

The EMC Directive (2004/108/EC) defines equipment as any apparatus or fixed installation. As there are separate provisions for apparatus and fixed installations, it is important that the correct category of the equipment (PDM, CDM or BDM) is determined.

In technical-commercial classifications the following terminology is frequently used: components, sub-assemblies, finished appliances (ie, finished products), a combination of finished appliances (ie, a system), apparatus, fixed installations and equipment.

The key issue here is whether the item is meant for end users or not:
- if it is meant for end users, the EMC directive applies;
- if it is meant for manufacturers or assemblers, the EMC directive does not apply.

Components or sub-assemblies intended for incorporation into an apparatus by the end users

A manufacturer may place components or sub-assemblies on the market, which are:
- for incorporation into an apparatus by the end-user,
- available to end-users and likely to be used by them.

These components or sub-assemblies are to be considered as apparatus with regard to the application of the EMC. The instructions for use accompanying the component or sub-assembly should include all relevant information, and should assume that adjustments or connections can be performed by an end user not aware of the EMC implications.

Some variable speed power drive products fall into this category, eg, a drive with enclosure and sold as a complete unit (CDM) to the end user who installs it into his own system. All provisions of the EMC Directive will apply (CE mark, EC declaration of conformity and technical documentation).

Components or sub-assemblies intended for incorporation into an apparatus by other manufacturers or assemblers

Components or sub-assemblies intended for incorporation into an apparatus or another sub-assembly by other manufacturers or assemblers are not considered to be “apparatus” and are therefore not covered by the EMC Directive. These components include resistors, cables, terminal blocks, etc.

Some variable speed power drive products fall into this category as well, eg, basic drive modules (BDM). These are meant to be assembled by a professional assembler (eg, panel builder or system manufacturer) into a cabinet not in the scope of delivery of the manufacturer of the BDM. According to the EMC Directive, the requirement for the BDM supplier is to provide instructions for installation and use.

Note:
The manufacturer or assembler of the panel or system is responsible for the CE mark, the EC Declaration of Conformity, and the technical documentation.

Finished appliance

A finished appliance is any device or unit containing electrical and/or electronic components or sub-assemblies that delivers a function and has its own enclosure. Similarly to components, the interpretation “finished appliance” can be divided into two categories: it can be intended for end users, or for other manufacturers or assemblers.

Finished appliance intended for end users

A finished appliance is considered as apparatus in the sense of the EMC Directive if it is intended for the end-user and thus has to fulfill all the applicable provisions of the Directive.

Variable speed power drive products that fall into this category are whole power drive systems (PDS) or complete drive modules (CDM). In this case all provisions of the EMC Directive will apply (CE mark, EC Declaration of Conformity, and technical documentation). The drive product manufacturer is responsible for the CE mark, EC Declaration of Conformity, and technical documentation.

Finished appliance intended for other manufacturer or assembler

When the finished appliance is intended exclusively for an industrial assembly operation for incorporation into other apparatus, it is not an apparatus in the sense of the EMC Directive and consequently the EMC Directive does not apply for such finished appliances.

The variable speed power drive products that fall into this category are basic drive modules (BDM). The approach is the same as for components or sub-assemblies when they are intended for incorporation into an apparatus by another manufacturer or assembler. Thus the manufacturer or assembler of the panel or system is responsible for all actions relating to the EMC Directive.

Systems (combination of finished appliances)

A combination of several finished appliances which is combined, and/or designed and/or put together by the same party (ie, the system manufacturer) and is intended to be placed on the market for distribution as a single functional unit for an end-user and intended to be installed and operated together to perform a specific task.

All provisions of the EMC Directive, as defined for apparatus, apply to the combination as a whole. The variable speed power drive products that fall into this category are power drive systems (PDS). Thus the manufacturer of the PDS is responsible for all actions relating to the EMC Directive.

Apparatus

Apparatus means any finished appliance or combination thereof made commercially available (ie, placed on the market) as a single functional unit, intended for the end-user, and liable to generate electromagnetic disturbance, or the performance of which is liable to be affected by such disturbance.

Fixed installation

A particular combination of several types of apparatus, equipment and/or components, which are assembled, installed and intended to be used permanently at a predefined location.

Equipment

Any apparatus or fixed installation

CE marking for EMC

Components or sub-assemblies intended for incorporation into an apparatus by the end users need to carry the CE marking for EMC.

Components or sub-assemblies intended for incorporation into an apparatus by another manufacturer or assembler do not need to carry the CE marking for EMC.
Note: The products may carry the CE marking for other directives than EMC.