ENGINEERING
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Brochure | Chemical & Pharmaceutical

Planning and project engineering of AC drives in chemical and pharmaceutical applications

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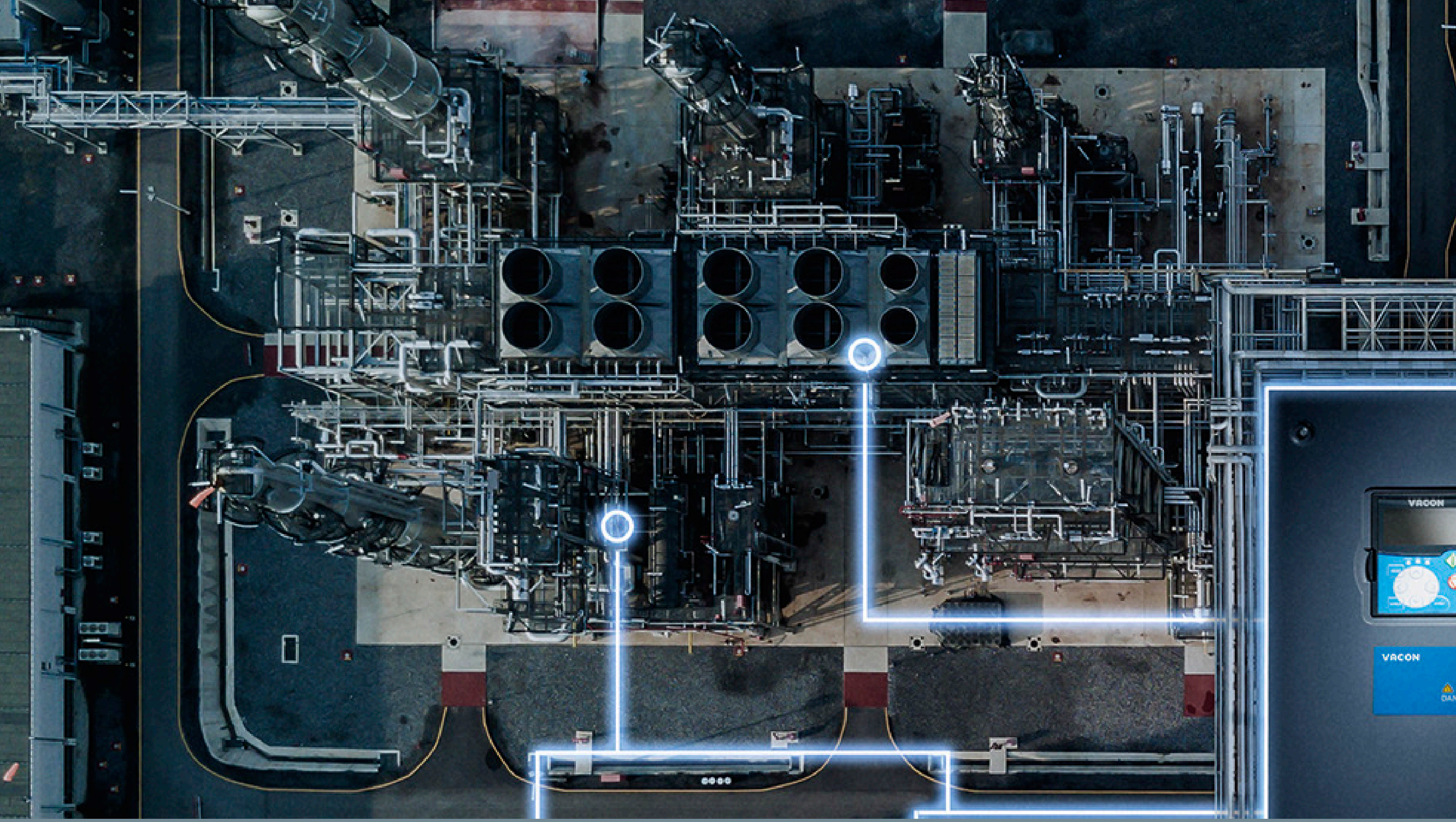
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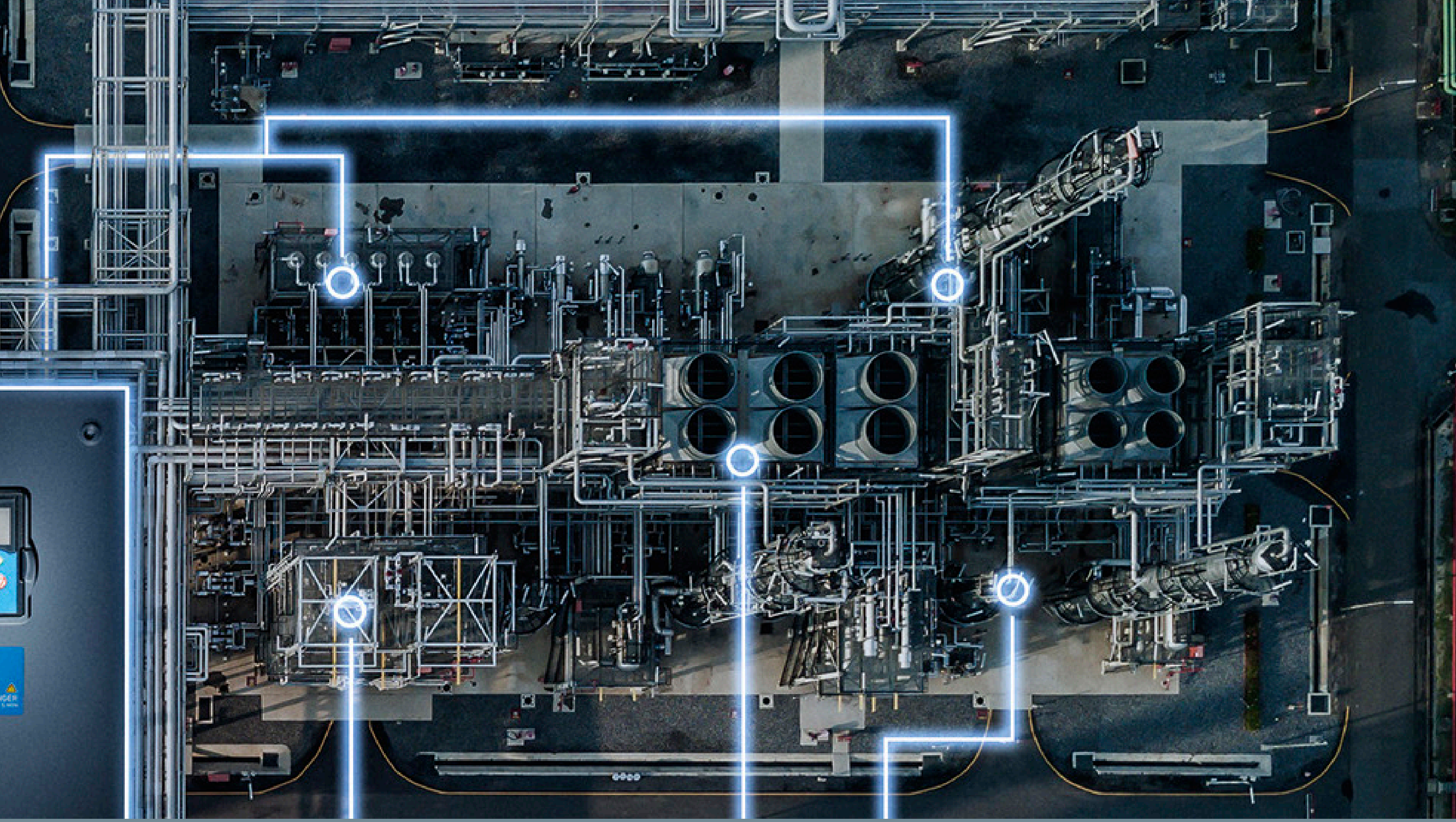


Assistance in planning and design

The Danfoss Engineering Guide for the chemical and pharmaceutical industries is aimed at chemical companies as well as design engineers and panel manufacturers.
It is designed as an extensive aid for professional engineers and project engineering specialists whose scope of work includes the project engineering of variable speed drives for chemical plants, as well as cosmetics and pharmaceutical plants, using AC drives.

Our specialists have coordinated the contents of this Engineering Guide with professional engineers in the industry to answer important questions and maximize the benefits for plant engineers, operators, and design engineers.

The descriptions in the individual sections are deliberately kept short. They do not serve as comprehensive explanations of technical topics, but only present these topics and their special requirements for project engineering. In this way, the Engineering Guide for the chemical and pharmaceutical industry offers support for the project engineering of AC drives, as well as the evaluation of the technical features of various AC drives.

Questions that are not directly linked to the actual tasks of an AC drive often arise during the project engineering of variable speed drives. These questions are instead related to the integration of these devices into the power drive system and the system as a whole.
It is therefore essential to consider not only the AC drive but also the entire power drive system.
This system is composed of the motor, AC drive, wiring, and general ambient conditions, including the mains supply and environmental conditions as well as safety guidelines.

Project engineering and design of variable speed power drive systems is vitally important. It is precisely during this stage that the planner or the project engineer determines the quality of the power drive system, the operating and maintenance costs, and ensures safe, trouble-free operation. Carefully considered project engineering up front helps to avoid undesired side effects during later operation of the power drive system.

Anyone involved in project engineering with AC drives should consider the general technical conditions of these devices up front.

The Engineering Guide for the chemical and pharmaceutical industry is an optimal tool to ensure the greatest possible predictability and thus contribute to the operational safety of the entire system.

It is divided into two parts. The first part provides background information on the use of AC drives in general. This includes energy efficiency, reduced life cycle costs and longer lifetime.
In the second part, the Engineering Guide for the chemical and pharmaceutical industry guides you through the necessary steps for planning and project engineering of a system and provides tips for retrofitting variable speed control in existing systems. It provides all the necessary information on the points that you must consider in order to ensure safe operation of the system when selecting and dimensioning the mains supply, environmental and ambient conditions, the motor and its wiring, as well as selection and dimensioning of the AC drive and related accessories and features. If you take all the contents of this guide into account during project engineering, you will ultimately find the optimum system configuration for safe and reliable operation.

Part 1: General information on AC drives

Reduce costs and increase productivity

Compared to mechanical solutions, electronic speed control has the potential to considerably reduce energy consumption and mechanical wear. Both of these significantly reduce operating costs. The more frequently power drive systems operate under partial load, the higher the potential savings in terms of energy and maintenance costs. Thanks to the high energy-savings potential, the additional cost of electronic speed control can be recovered within a short timescale. Modern solutions have a very positive influence in many areas on the process and on the availability of the entire system.

- **High energy-saving potential**
  With electronic speed control, the flow, pressure or differential pressure is regulated according to the actual need. In practice, systems run predominantly at partial load and not at full load.
  In continuous flow machines with a quadratic torque characteristic, the difference between full and partial load operation determines the amount of energy saved.
  The greater the energy savings, the shorter the payback period.

- **Startup current limitation**
  Switching on systems operating directly from the supply network generates peak currents that can reach six to eight times the rated current. AC drives limit the startup current to the rated motor current. As a result, they eliminate the current peaks at power-up and prevent voltage dips due to a short-term high load on the supply network. Avoiding these current peaks lowers the system load on the supply network, which reduces provision costs and eliminates the need for maximum power regulation devices.

- **Reduced system wear**
  AC drives start and stop motors smoothly and continuously.
  In contrast to motors operated directly from the grid, there is no torque surge or load surge with AC drive operation. This protects the entire power system.
  In this way, speed control significantly reduces wear. Repair and maintenance costs also decrease due to longer operating intervals and less material wear.

- **Expanded control range**
  AC drives allow motors to be operated in the oversynchronous range (output frequency above 50/60 Hz. This can provide a short-term increase in performance. The extent to which oversynchronous operation is possible depends on the maximum output current and the overload capacity of the AC drive and the connected motor. In practice, pumps, compressors and fans are often operated in the frequency range of 55 to 87 Hz / 65 to 104Hz.

- **Low noise emission**
  Systems operating at partial load are quieter. Variable speed operation therefore significantly reduces noise levels.

Extended lifetime

Power drive systems operating at partial load are subject to less wear and tear, which is evident in an extended lifetime.

Operation in the oversynchronous range must be cleared with the motor manufacturer and machine OEM.

The reduced and optimized system pressure in the pipes also has an advantageous effect.

Retrofitting

AC drives can be retrofitted in existing power drive systems with little effort.

Motor and control system independency

Some motor manufacturers might try to influence machine builders, system integrators and end users to go for a bundling package to increase their share. This might look as an easy way but compromises in most cases on efficiency and availability. Carrying out an Automatic Motor Adaptation (AMA) function on site will perfectly match the VSD to any motor, taking into account the motor design, the length of motor cable and the ambient temperature. This will ensure the most efficient combination of components in the total power drive system. Chose a drive which can work with all state-of-the-art motor technologies and fieldbus systems to be prepared for later upgrades of your plant. Danfoss Drives provide tools to support you during this important step.

Are the same efficiencies really the same?

Thorough planning saves money

At first glance, a comparison of efficiencies reveals no great differences among the various devices. But is that really true? Do two devices with the same power and the same efficiency have the same losses?

The efficiency of an AC drive is calculated as the ratio of the output power to the input power. It is usually stated in round numbers without fractional digits. In the worst case, AC drives with the same efficiency rating can therefore differ by nearly 1%.

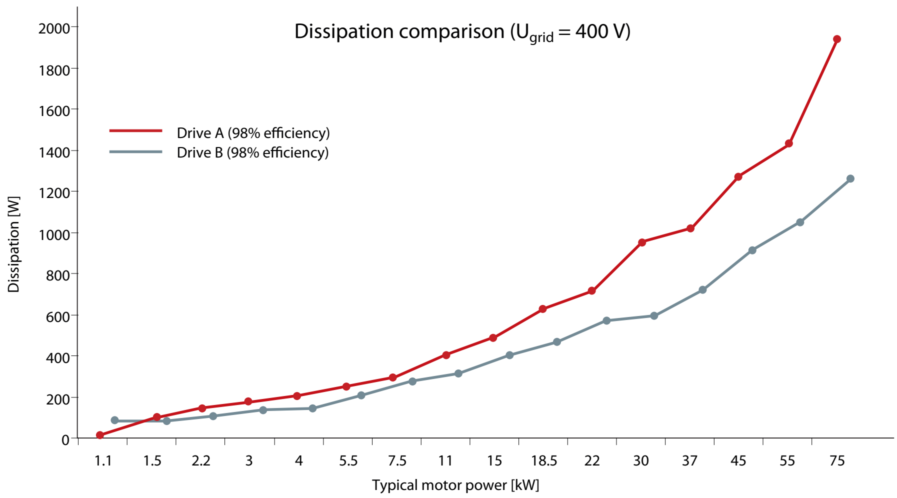
To be able to compare the efficiencies of different drives, the user must be aware of the conditions under which the manufacturer has determined those efficiencies. Drives are usually differentiated between normal overload (110%) and high overload (160%). The rated current of the device, as well as operation in the partial load range and measurement tolerances, are also taken into consideration in the determination of efficiency.

Information on the power dissipation of a device is much more useful. Of course, the operating mode and the rated current of the device are also important. However, the power dissipation can be regarded as relatively reliable because operators and plant engineers also use it to determine the air conditioning requirements for a cabinet or an electrical room.

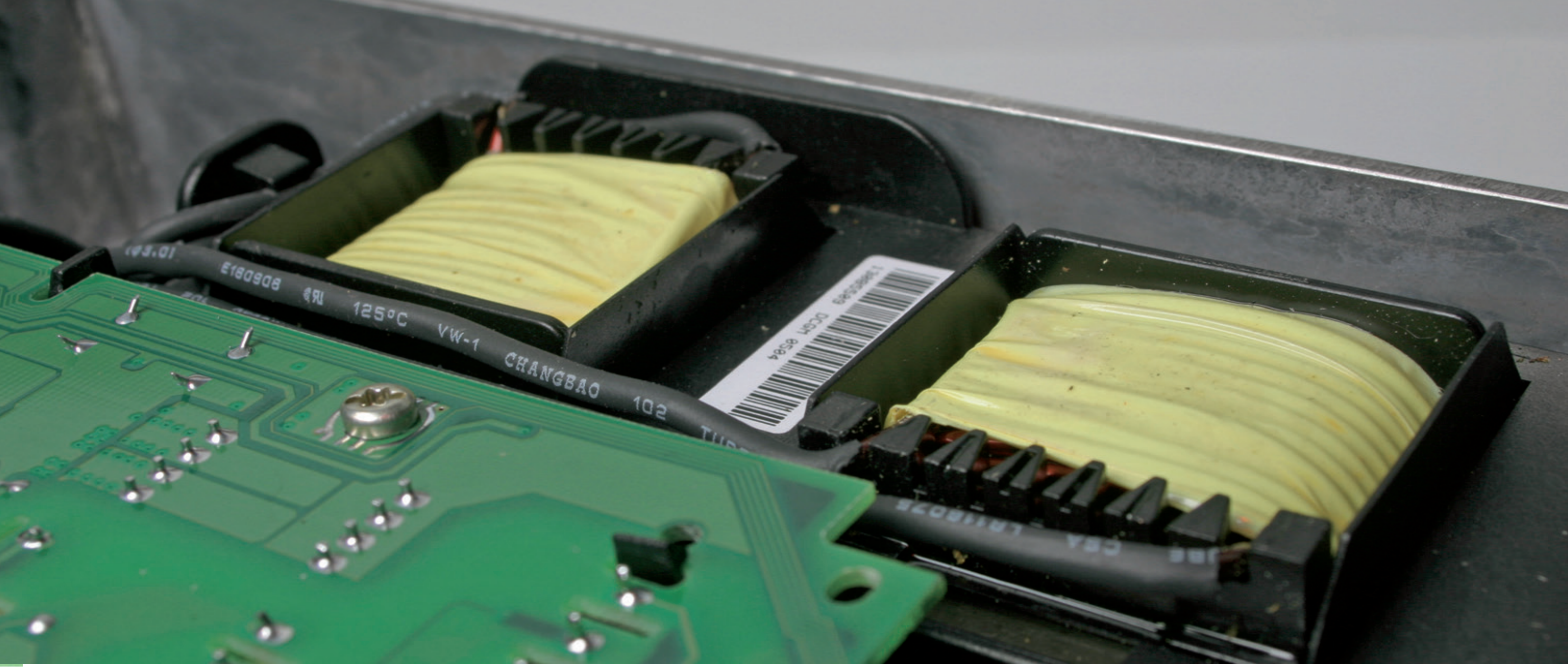
The following chart shows a comparison of the power dissipation of two different drives. The efficiency specifications for most of the power ratings are the same.

What does this mean over the lifetime of the device? Assuming a lifetime of 60,000 hours and a motor operation of 90%, this results in a total energy dissipation of 124,740 kWh or 66,528 kWh for the 75 kW drives in the chart.

Although both devices have the same efficiency specification, one consumes approximately 58,000 kWh more than the other. The difference is less in the partial load range.
The trend, however, is clear.



Direct comparison of different AC drives is very difficult due to different general data, such as rated currents and overload capacity. Power dissipation is a better option for comparison.



Consider filters for protection and efficiency

Due to their operating principle, AC drives generate electromagnetic interference. To limit this interference EMC filters are available for each AC drive. The filters may be directly integrated in the device or installed directly in front of the device. A combination of internal and external filters is also possible.

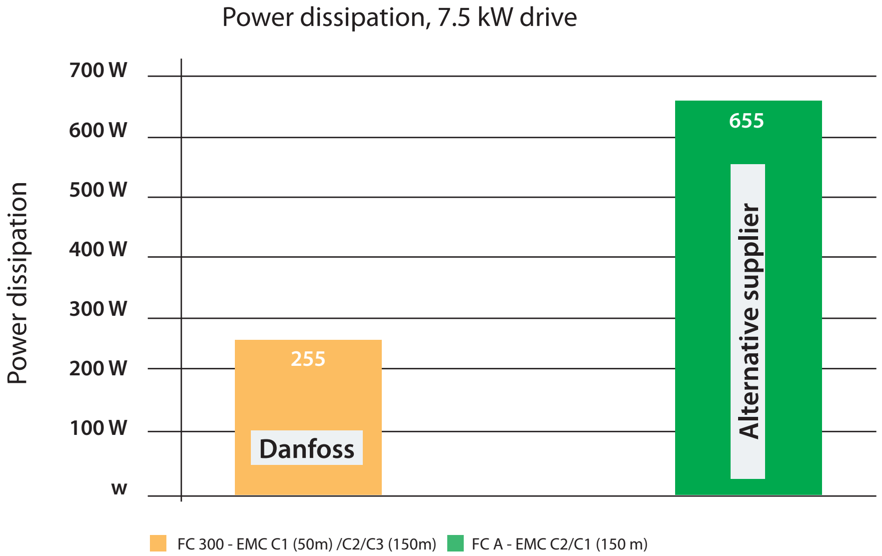
Influence of filters
Another aspect is sine wave, dU/dt filters or common-mode sine filters on the motor side. AC drives operate at a high switching frequency to generate an output voltage at the appropriate frequency.

As a result, the output voltage is no longer sinusoidal. Depending on the length of the motor cable and the motor insulation, this voltage can damage the insulation. This is particularly problematic with older motors. Motor-side filters protect the windings from flashovers by limiting the voltage slew rate at the motor insulation and the amplitude of the peak voltages.

The downside of external filters is the need for additional installation space. Moreover, all external filters always generate additional losses. This applies to EMC filters as well as motor-side dU/dt filters or sine wave filters. These additional losses must also be considered for the air conditioning of the cabinet which will also have an effect on the overall efficiency including the switchroom air conditioning. Losses for drives with integrated filters are usually already included in the specified power dissipation. Therefore, in order to compare the efficiencies of two AC drives, one must consider whether both already have the filters installed and whether they meet the same standards with respect to EMC filters, harmonic filter design, and AC/DC inductor design. If not, this leads to a degradation of the overall efficiency of the filter and drive, higher losses and higher energy costs for the drive without a filter.

Cost savings from installing lower-quality EMC filters or none at all and doing without the necessary motor filters may lead to high costs for retrofitting, additional dissipation and air conditioning or even damaging equipment.

Comparison of power loss with integrated RFI filter versus external RFI filter



External filters produce additional dissipation. In the project engineering of AC drives, it is therefore necessary to ensure that all necessary filters are integrated in the device.

Fundamentals

Variable speed control: great potential and quick implementation

Variable speed control of motors often results in energy advantages, which can be seen immediately on the electricity bill. The benefits of using variable speed control include:

Energy savings
Various levels of potential savings are possible, depending on the torque characteristic of the load. With a constant torque curve, the maximum savings are proportional to the reduction of the torque and the speed at the shaft; with a quadratic torque curve, the savings are proportional to the third power of the speed reduction.

Power factor (cos φ) correction
Many AC drives correct the power factor (cos φ) to nearly 1, reducing their inductive reactive power consumption. This also reduces the losses in the supply cable.

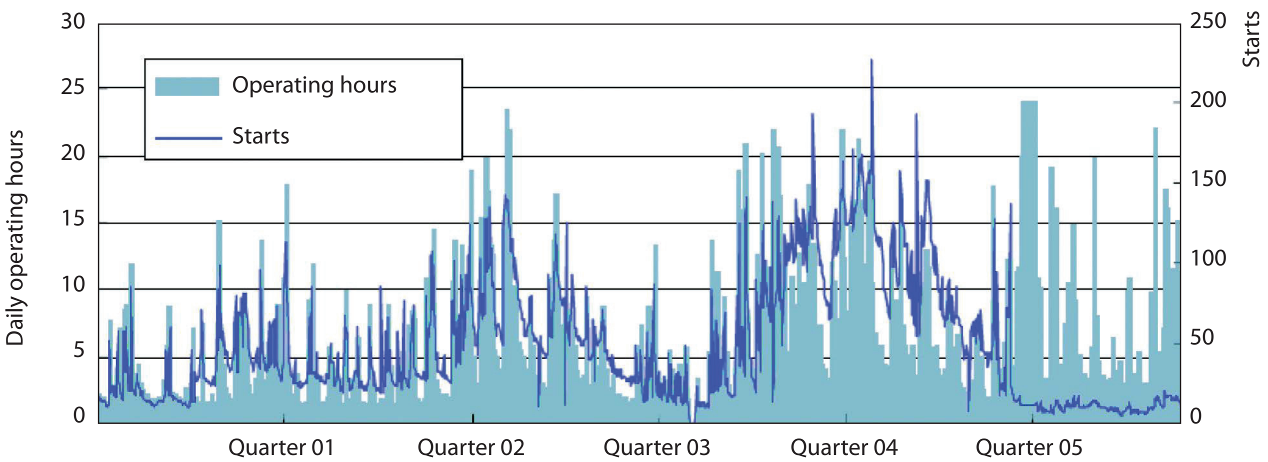
Optimized operation in the partial load range
Efficiencies are usually specified for three-phase motors only at the rated operating point. If a motor operates directly from the grid in the partial load range, its efficiency deteriorates considerably due to constant mechanical and electromagnetic losses. AC drive operation always ensures optimum magnetization of the motor, depending on the quality of the control algorithm.
The efficiency therefore does not decrease as much in the partial load range. Noticeable improvements are usually found with motors rated 11 kW and up.

Automatic energy optimization
For applications that do not involve fast load changes, the operator can use the automatic energy optimizing (AEO) functions. The drive then reduces the motor magnetization to a minimum. That saves energy. These functions have proven effective in all slow control systems, which are common with pumps and fans.

Fewer start cycles
Variable speed control can reduce the number of starts in many applications. Every uncontrolled start of an electric motor requires additional energy for motor startup and load re-acceleration. With pumps, the energy consumption for starting is normally 5-10% of the total energy consumption, but in some cases up to 40% of the total energy is used for starting. Peak currents and mechanical shock loads during startup are also reduced.

Variable speed control provides additional benefits due to reduction of the mechanical load on the system and its parts, as well as the integrated software functions provided by modern AC drives.

Practical example: With the introduction of variable speed drives in Q4, the number of starts, and therefore the mechanical load on the system, was significantly reduced during Q5.



Cost reduction over the entire life cycle

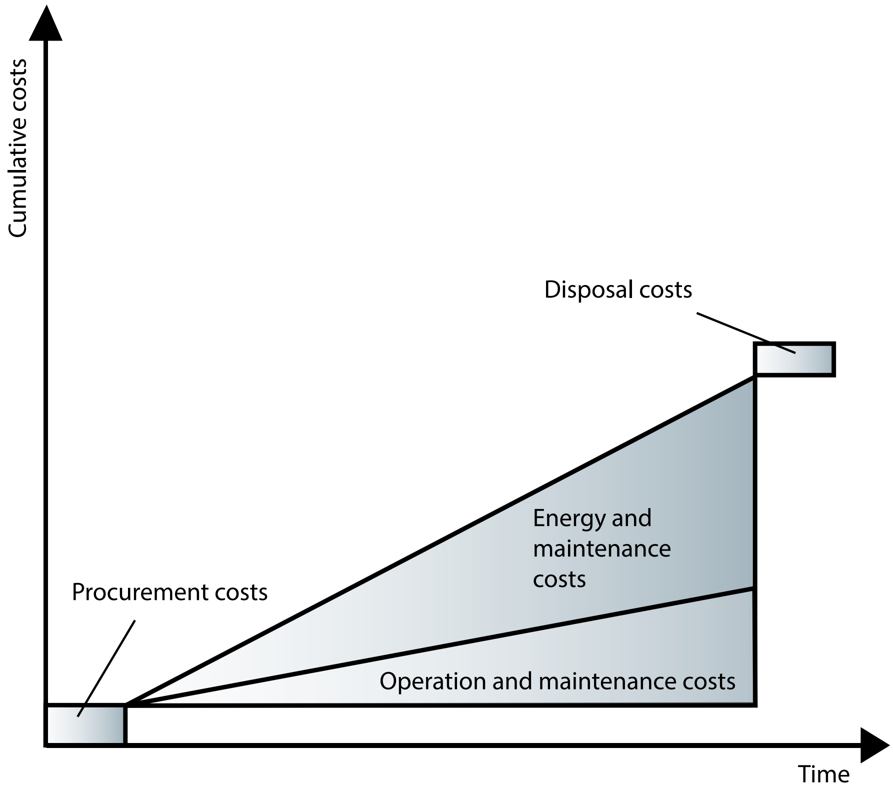
The use of AC drives is becoming more common as their advantages are undeniable. Note: To avoid uneconomical and counterproductive measures, it is necessary to check technical, commercial and logistical aspects before making an investment decision. According to the latest research, the cost of acquisition only accounts for approximately 10% of the total life cycle cost. Operating costs such as energy, maintenance and service costs account for 90% of the costs incurred. The acquisition costs for air conditioning, inductors and line filters are also significant.

Known methods for an overall analysis of all costs are LCC (Life Cycle Costs), which means costs during the life cycle) or TCO (Total Cost of Ownership), which is the total cost over the period of use. They consider not only the acquisition costs, but also the energy, repair and maintenance costs. A device with a higher purchase price may turn out to be less costly over its total lifetime than a cheaper device.

In this sort of analysis, other factors may also be considered, such as product availability. If a device breaks down while being used, this will entail costs, for example due to downtime in production. To avoid this situation, the operator requires storage space for one or several replacement devices. The size of the storage space required depends on factors such as how quickly the product manufacturer can deliver new devices when needed.

Gentle system operation
Modern AC drives also offer a multitude of functions that reduce the need for external components and their complex wiring. At the same time, the inherent soft start reduces stress on motors and system components, increasing their lifetime and reducing maintenance and service costs.

Predictive maintenance for lower costs and greater availability
Extensive protection functions for the motor and system always show the current status of the drives and the system. They protect the components and can extend maintenance intervals by early indication of wear, thereby increasing the availability of the system.



As a rule, acquisition costs account for only about 10% of the life cycle costs of the system. The higher acquisition cost of an energy-saving device is often offset by payback within a very short time.

Part 2: Project engineering

Implementing available savings

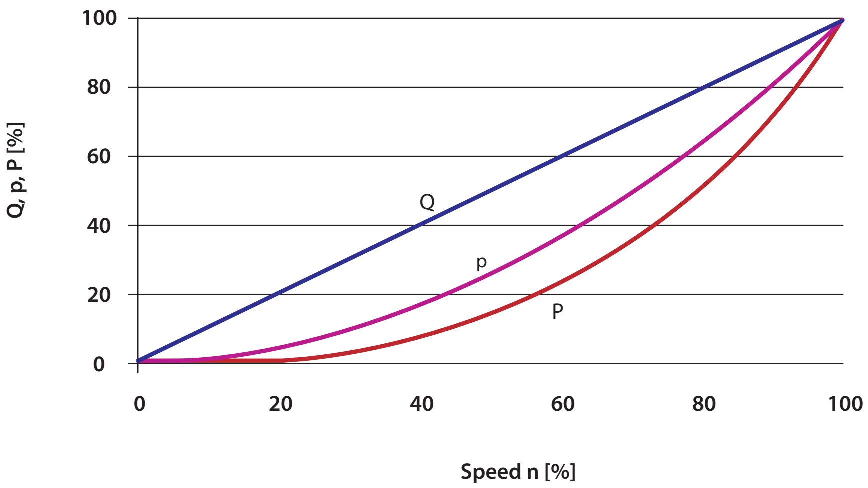
In the previous versions of the Engineering Guide for the chemical industry, the primary focus was on the fundamentals and the potential savings in plants in the chemical and pharmaceutical industries.
They provided more information about life cycle costs, energy savings, and maintenance and service costs. Now it is time to put these potential savings into practice by means of sound and accurate planning.

Accordingly, the next part guides you through the planning process in four steps.
In the sections

- Mains supply
- Ambient and environmental conditions
- Motor and cable
- AC drive

you will find all the information on the parameters and data that you need for safe operation of the system, as well as selection and dimensioning. Where more in-depth knowledge is advantageous, you will find not only the basic information in this guide but also references to other documents.

Systematically answering all the questions and aspects listed below creates the optimal conditions for an energy-efficient and safe system.



Mains supply

Recognizing the existing network configuration

A variety of network configurations are available for supplying power to electric drives. All have a more or less significant influence on the EMC properties of a system. The best initial situation is with a five-conductor TN-S network, while the worst is with an isolated IT network.

TN networks

There are two versions of this network configuration: TN-S and TN-C.

TN-S

This system is a five-conductor network with separate neutral (N) and protective (PE) conductors. It therefore offers the best EMC properties and avoids transmitting interference.

TN-C

This system is a four-conductor network in which the neutral conductor and the protective conductor are combined into one conductor throughout the system.

The TN-C network does not provide good EMC properties due to the combined neutral and protective conductors.

TT networks

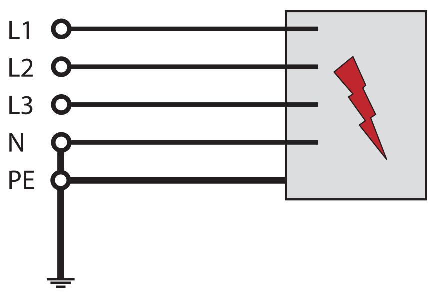
This system is a four-conductor network with a grounded neutral conductor – usually grounded near the electrical feed point – and individual grounding of the drives. This system provides good EMC properties when grounding is clean.

IT networks

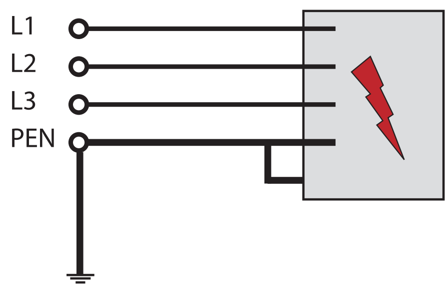
This system is an isolated four-conductor network in which the neutral conductor is either ungrounded or grounded through a high impedance.

Note: In IT systems, RFI filters must be disabled.

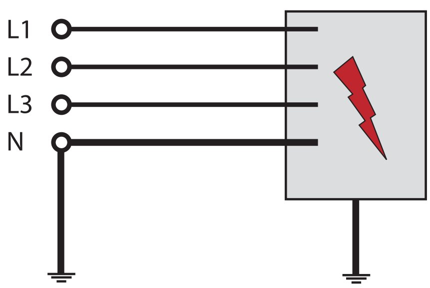
TN-S system Neutral conductor and protective conductor separated



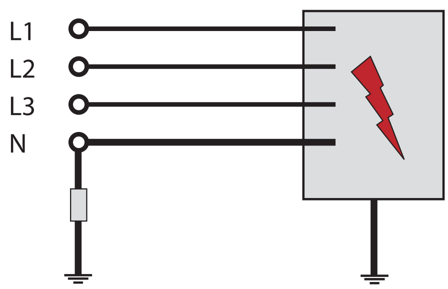
TN-C system Neutral and protective conductors combined into one conductor throughout the entire system



TT system Grounded neutral conductor and individual grounding of the equipment



IT system Isolated grid, neutral conductor can be ungrounded or grounded through an impedance



Network configurations for power distribution systems according to EN 50310 / HD 384.3

Industrial DC Backup technology

Maximum uptime is a key factor in complex industrial production lines, rendering them vulnerable to sudden power loss
When the national grid is unreliable, this is where industrial DC backup technology form Danfoss can ensure a stable power supply for the process. Industrial DC backup solutions from Danfoss ensure continuous running or controlled ramp down where required in certain applications. In addition, they ensure

- Constant DC link voltage is maintained, ensuring that over- and under-voltage do not occur
- Utilization of energy storage as the redundant power source
- Generators run at full efficiency, not at partial load
- Reduced generator size
- Battery power to supply peak demands

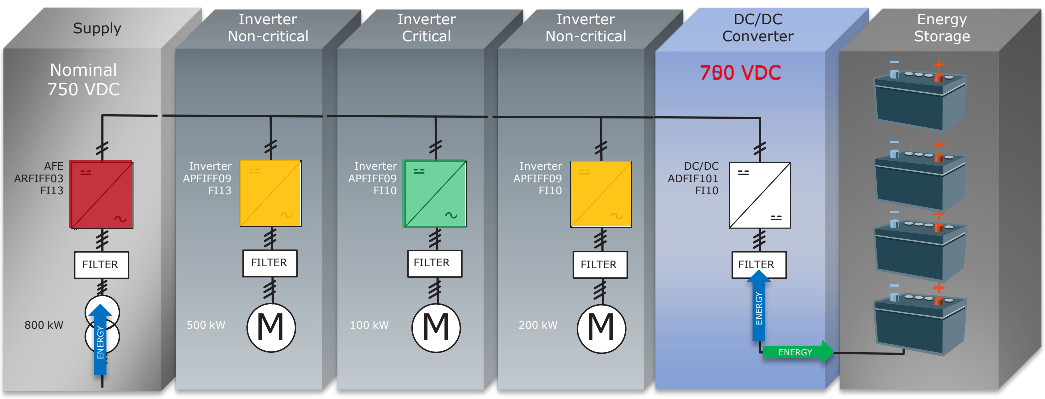
Use cases for industrial DC backup include

Peak shaving
Optimizing energy supply between the incoming grid and the energy storage medium to meet spikes in demand. The excess energy can then be stored when the demand and costs are low.

Time shifting
Storing energy during times when energy costs from the grid are low, and supplying energy from the storage medium when energy costs from the grid are high

Back-up power
Energy storage can be used to provide back-up power during downtime maintinain the ability to operate for a period of time.

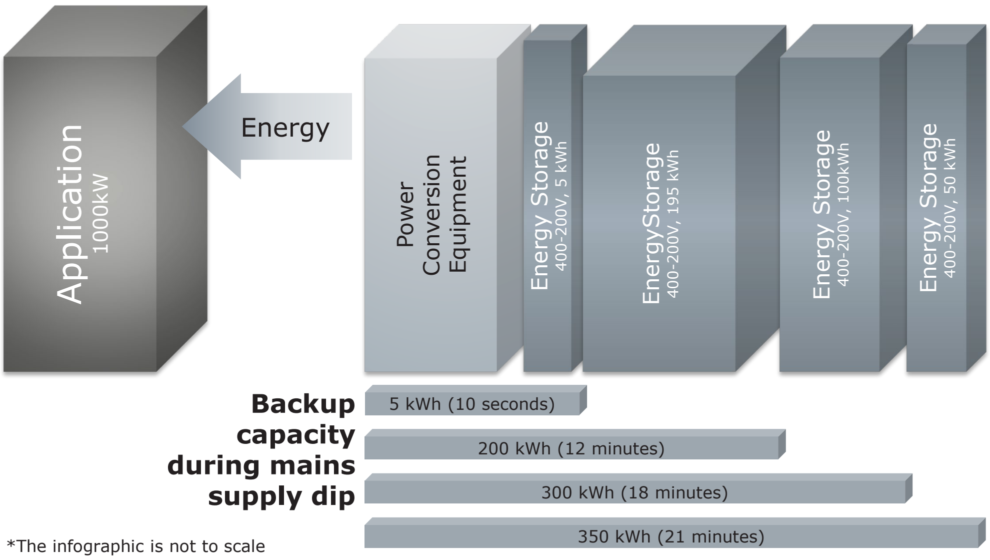
Industrial DC backup with VACON® NXP DC/DC Converter



Integrated DC-link backup:

- Power according to actual need (critical loads)
- No external control system needed
- Can provide backup for:
  - Common DC Bus systems
  - Standalone drives

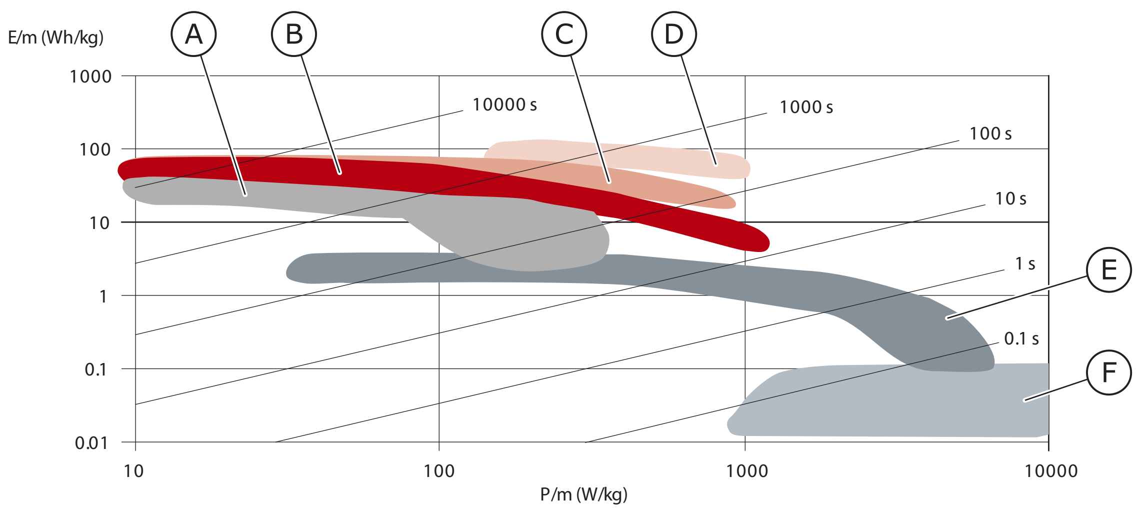
Basic principle



Use one converter per technology

- Battery technologies A-F
- Super capacitor
- Ultra capacitor
- Kinetic energy storage (?)

Combine energy storage technologies



A – Pb batteries

B – NiCd batteries

C – NiMH batteries

D – Li - ion batteries

E – Double - layer batteries

F – Electrolytic capacitors

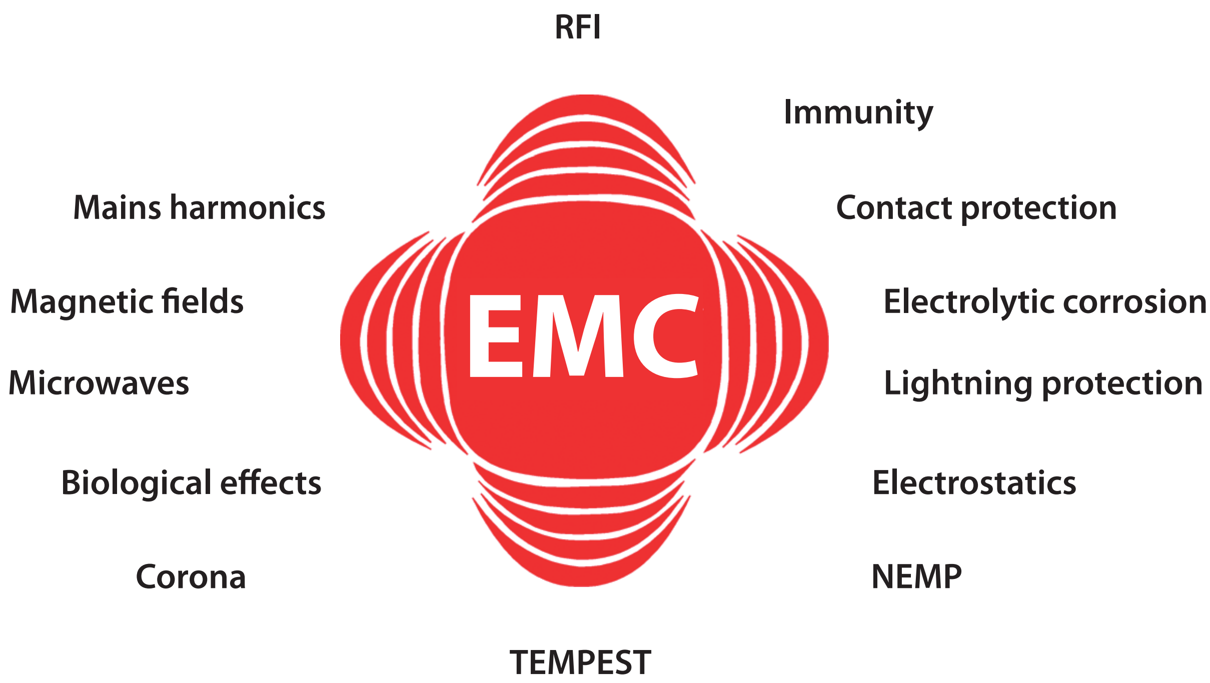
Electromagnetic compatibility (EMC)

Every electrical device influences its immediate environment to a greater or lesser degree through electrical and magnetic fields. The size and effect of these influences are dependent on the power and construction of the device. With electrical machinery and equipment, interactions between electrical or electronic assemblies can impair or prevent safe, trouble-free operation. Therefore, it is important for operators as well as designers and plant engineers to understand the mechanisms of interaction.
Only then can they take appropriate and cost-effective countermeasures during the planning phase. Because: *The later you respond, the more expensive the measures become.*

Electromagnetic influences work in both directions
The components in a system have a reciprocal influence on each other: Not only does each device emit interference, but it is subjected to interference as well. Therefore, in addition to the nature of the interference and the scope of interference emission, the assembly concerned is also characterized by its degree of immunity to interference from adjacent assemblies.

The responsibility lies with the operator
The EN 61800-3 standard for the application of variable speed drives gives responsibility for compliance with legal guidelines to the end user or operator of the system.
Manufacturers only need to offer solutions for use in compliance with the standards. Elimination of any interference that may arise, which means the application of these solutions, is the responsibility of the operator. This also applies to the resulting costs.

Two approaches for reducing interference
Operators or plant engineers can use two approaches to ensuring electromagnetic compatibility.
The first is to suppress interference at the source by minimizing or eliminating interference emissions. The second is to increase the interference immunity of the device or system by preventing or significantly reducing the received interferences.



Electromagnetic compatibility (EMC) encompasses a wide range of phenomena. With drives technology, the main considerations are mains harmonics, radio frequency interference (RFI) and interference immunity.

Distinguishing between interference sources and interference sinks

Basically, there are always interactions between multiple systems. Experts distinguish between interference sources and interference sinks, which in practice often take the form of devices that emit or receive interference.
All types of electrical and magnetic phenomena that cause undesired effects can be regarded as interference. This may take the form of mains harmonics, electrostatic discharges, rapid voltage fluctuations or radio frequency interference.
Mains harmonics are often referred to in practice as mains distortion or simply harmonics.

Coupling mechanisms between electrical circuits

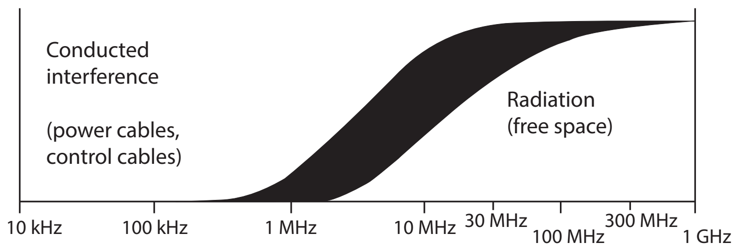
How is the interference energy transmitted? Transmission can take place electromagnetically via conductors, electrical fields or electromagnetic waves. Experts speak of galvanic, capacitive and/or inductive coupling as well as radiation coupling, which is an interaction between the various circuits, in which electromagnetic energy flows from one circuit to the other.

- Galvanic coupling occurs when two or more circuits share a common electrically conductive connection (for example, an equipotential bonding cable).
- Capacitive coupling arises due to a difference in voltage potentials between the circuits.
- Inductive coupling occurs between two current-carrying conductors.
- Radiation coupling occurs when the interference sink is in the far field of radiated energy from an interference source.

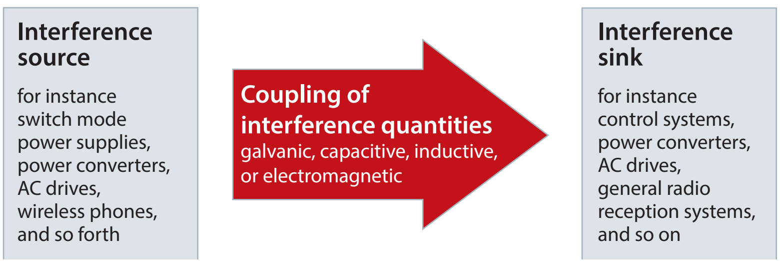
The transition from the (electromagnetic) view of conductor-based coupling to radiation coupling is at 30 MHz according to the standard. This corresponds to a wavelength of 10 meters.

Below this frequency, electromagnetic interference propagates predominantly via conductors or via coupling of electrical or magnetic fields. Above 30 MHz, wires and cables act as antennas and emit electromagnetic waves.

Interference propagation paths



Electromagnetic interference occurs across the entire frequency range. However, the type and the propagation path differ.



Overview of coupling paths for electromagnetic interference and typical examples

EMC in connection with AC drives

Low-frequency interference (conducted) → Mains harmonics

High-frequency interference (radiated) → Radio frequency interference (electromagnetic field emission)

High frequency radio frequency interference

Radio frequency interference

AC drives generate variable three-phase frequencies at corresponding motor voltages by means of rectangular voltage pulses with variable width. The steep pulse edges contain high-frequency components. Motor cables and AC drives radiate them and feed them to the grid via the mains cable. To reduce this type of interference at the grid feed, manufacturers use radio frequency interference suppression filters (also called RFI filters, line filters or EMC filters). They protect devices against conducted high-frequency interference (immunity) and reduce the high-frequency interference emissions from devices, either conducted or radiated by the power cable. The filters should limit these interference emissions to a prescribed legal level, which means they should be installed in the devices from the outset if possible. As with line reactors, the quality of the radio frequency interference suppression filters to be used must also be clearly defined. The product standard EN 61800-3 and the environment standard EN 55011 define specific limits for interference levels.

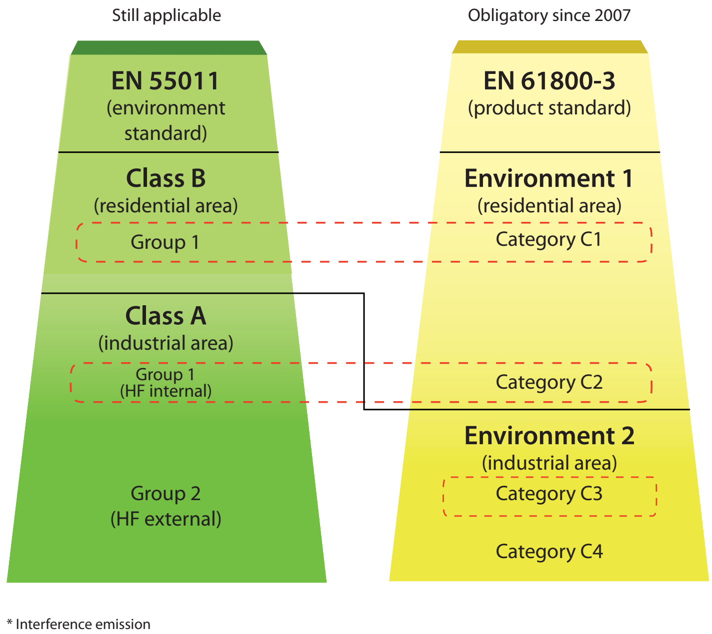
Standards and directives define limits

For a comprehensive assessment of high-frequency radio interference, two standards must be considered. The environment standard EN 55011 defines the limits as a function of the underlying industrial environments or residential environment. The standard EN 61800-3 for electrical power drive systems, defines categories for device application areas.

Although these are comparable to the previous classes in terms of limits, they allow extended application within the scope of the product standard.

Note:
EN 55011 and EN 61800-3: Must be observed by the drive manufacturer.

Comparison of the limits*



**Comparison of the product standard EN 61800-3 and the environment standard EN 55011.*

The operating site is the deciding factor - first and second environment

The limits for each environment are specified by the corresponding standards. But how can you determine the appropriate environment? The EN 55011 and EN 61800-3 standards for electrical power drive systems and components provide information on this as well:

1st environment /class B:

residential environment

All locations that are directly connected to the public low-voltage grid are considered residential, commercial or small business environments.
They do not have their own high-voltage or medium-voltage distribution transformers for a separate supply.
The environment areas apply to both inside and outside buildings.
Examples of this include business premises, residential buildings or residential areas, catering and entertainment establishments, parking lots, amusement parks and sports facilities.

2nd environment / class A:

industrial environment

Industrial environments are operating sites that are not connected directly to the public low-voltage power grid, but instead have their own high-voltage or medium-voltage distribution transformers. In addition, they are defined as such in the land register and characterized by special electromagnetic conditions:

- Presence of scientific, medical, or industrial devices.
- Switching of large inductive and capacitive loads.
- Occurrence of strong magnetic fields (for example, due to strong currents).

The environment areas apply to both inside and outside buildings.

Special environments

In these cases, the users decide on the environmental classification their system will be assigned to.
The prerequisite is a separate medium-voltage transformer and a clear demarcation between other environments. Within their own area, they must independently ensure the necessary electromagnetic compatibility which guarantees the faultless functioning of all devices under specific conditions. Examples of this include technical environments in shopping centers, supermarkets, gas stations, office buildings or warehouses.

Responsibility

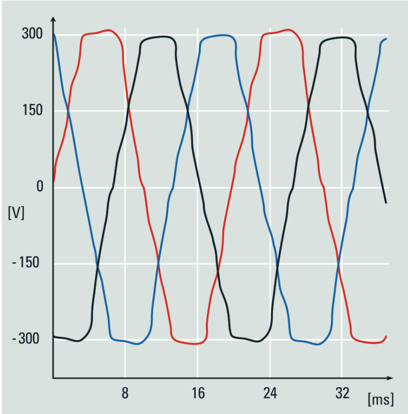
In the event of interference, experts troubleshoot in accordance with the use environment. The operator bears the costs for elimination of EMC interference. Ultimately, the users themselves are responsible for the appropriate assignment of the classes in these two standards.

Power quality

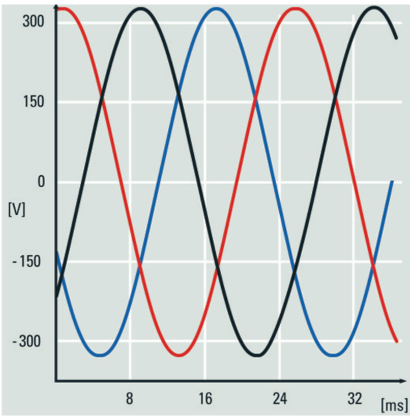
Low-frequency mains harmonics

Supply networks at risk
The mains voltage supplied by the power companies for households, trade and industry should be a uniform sinusoidal voltage with constant amplitude and frequency. This ideal situation is no longer present in public grids today. This is partly due to loads, such as PCs, television sets, switch mode power supplies, energy-efficient lamps or AC drives, that draw non-sinusoidal load currents from the grid. The mains voltage quality will continue to decline in the future due to the trans-European power grid, higher grid utilization and lower investments. Deviations from the ideal sinusoidal shape are therefore inevitable and are acceptable within certain limits. Planners and operators have an obligation to keep this load on the grid at a low level. But what are these limits and who sets them?

Legal basis ensures quality
Standards, guidelines and regulations help in the discussion of clean, qualitatively good mains voltage.
In Europe, the basis for an objective evaluation of mains voltage quality is the Electromagnetic Compatibility of Devices Act (EMVG). The European standards EN 61000-2-2, EN 61000-2-4 and EN 50160 define the limits to be observed for the mains voltage in public and industrial grids. The EN 61000-3-2 and EN 61000-3-12, and other standards such as IEEE 519 define specifications regarding the mains harmonics of connected devices. The fundamental assumption is that all devices and systems in electrical supply networks will function correctly without interference when these levels are maintained.



Measurements show significant non-sinusoidal distortion of the mains voltage due to the harmonics of non-linear loads.



In our grids, the ideal case of a sinusoidal mains voltage is virtually non-existent.

How mains harmonics arise
In technical terms, this distortion of the sinusoidal waveform of the supply network resulting from the pulsating power consumption of connected loads is called low-frequency harmonics or simply harmonics. Based on Fourier analysis, this is also called the harmonic distortion of the grid, which is assessed up to 2.5 kHz, corresponding to the 50th harmonic.

The input rectifiers of AC drives generate this typical form of harmonic load on the grid. With AC drives in 50 Hz grids, this involves mainly the fifth harmonic (250 Hz) or seventh harmonic (350 Hz). The effects are strongest at this point.

Effects of mains harmonics

System perturbation such as harmonics or voltage fluctuations have a different appearance at their point of origin than that at any other load connection point in the grid.
The combination of grid infeed, grid expansion and loads must be taken into account as a whole when assessing mains harmonics.
The effects of increased harmonic levels are:

Undervoltage warnings
- Due to the distortion of the grid sinewave, the voltage is not measured correctly.
- Lower capacity of the supply network.

Higher losses
- Harmonics additionally require a share of real power, apparent power and reactive power.
- Shortened lifetime of devices and components, for example due to additional heating resulting from resonances.
- Malfunctioning and damage to electrical and electronic loads, for instance as audible hum in other devices. In the worst case scenario, it could even lead to destruction.
- Incorrect measurement results, as only true RMS meters and measuring systems take harmonic components into account.

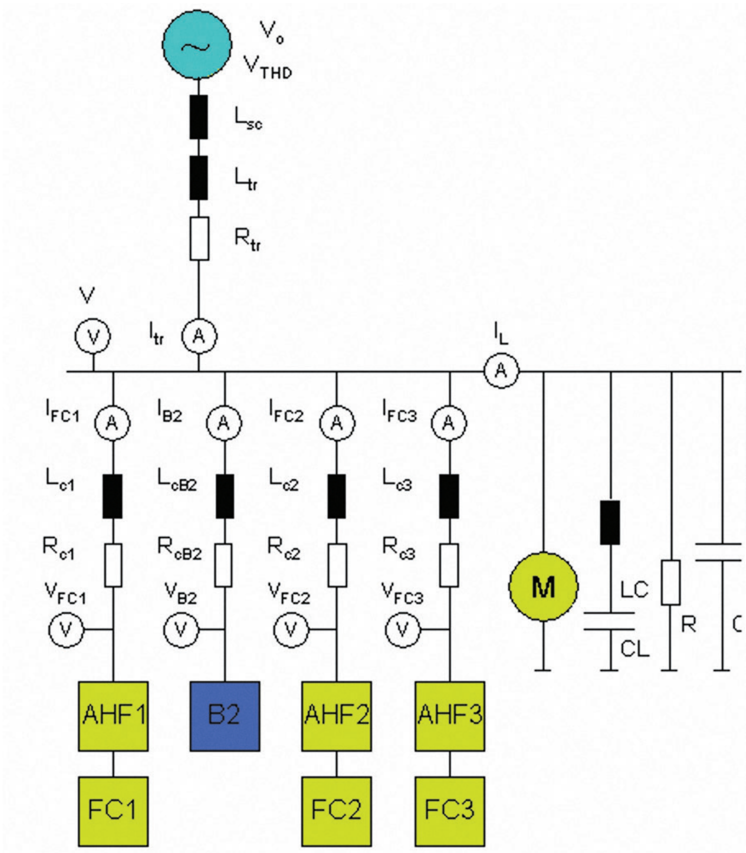
Are there any harmonic-free AC drives?
Every AC drive generates mains harmonics. However, the current standard only considers the frequency range up to 2 kHz. Therefore, some manufacturers shift harmonics into the range above 2 kHz not defined by the standard (see also ***Slim DC link***) and advertise them as harmonic-free devices. Limits for this range are currently being considered.

Note: *Excessively high harmonic components strain reactive power compensation systems and can lead to their destruction. A choked version of these should therefore be used.*

Calculating mains harmonics

To prevent overburdening of mains voltage quality, various methods for reduction, avoidance or compensation must be used with systems and devices that produce harmonic currents.
Harmonic analysis programs, such as HCS (Harmonic Calculation Software) or MyDrive® Harmonics, facilitate the calculation of systems as early as the planning stage. They allow operators to test and consider countermeasures in advance and ensure the availability of the systems.

Note: Danfoss is very skilled in the area of EMC and has many years of experience in this field. We pass this experience on to our customers in the form of training courses, seminars, workshops, or in daily practice in the form of EMC analyses with detailed evaluation or harmonic analysis.



Example of a system illustrated in Danfoss harmonics mitigation software, showing advanced harmonic filters (AHF) installed to mitigate harmonics on the three AC drives (FC)

Reduction of mains harmonics

Options for reducing mains harmonics

The mains harmonics of electronic power controls can generally be reduced by limiting the amplitude of the pulsed currents. This reduction improves the power factor λ (lambda). To prevent overburdening of the mains voltage quality, various methods for reduction, avoidance or compensation must be used with systems and devices that produce harmonic currents:

- Inductors at the input or in the DC link of AC drives
- 12-, 18- or 24-pulse rectifiers
- Passive filters
- Active filters
- Active Front End
- Low-harmonic drives

Inductors at the input or in the DC link
Even simple inductors effectively reduce the harmonics that rectifier circuits feed back into the supply network. Manufacturers of AC drives usually offer these as additional or retrofit options. The inductors can be located in front of the AC drive on the feed side or in the DC link after the rectifier. Because the inductance produces the same effect at each point, the attenuation of the mains harmonics is independent of the installation location. Both variants offer advantages and disadvantages. Line-side inductors are more expensive, are larger, need additional installation space and wiring effort, cause a voltage drop which reduce available torque at the motor shaft and have higher dissipation than DC inductors. Their advantage is that they also protect the rectifier inside the AC drive against electrical transients. DC inductors are located in the DC link and are mounted inside the AC drive. They are more effective, but usually cannot be retrofitted. With inductors such as these, the harmonic distortion of a B6 rectifier can be reduced from an unchoked THDi of 80% to a level of approximately 40%. In practice, inductors with a short-circuit voltage of 4% have proven effective for AC drives. Additional reduction can be achieved only with specifically adapted filters.

Note: *Danfoss VLT® drives are equipped with a DC inductor as standard, which reduces the mains harmonics to a THDi of maximum 48%.*

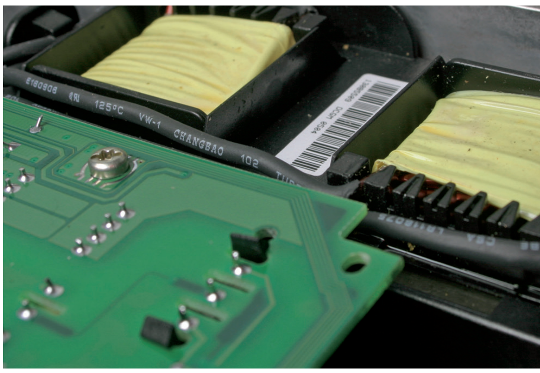
Rectifiers with 12, 18 or 24 pulses
Rectifier circuits with higher pulse counts (12, 18 or 24) produce lower harmonics. In the past, they were often used in the higher power range. However, a special transformer is required to supply the rectifier groups with the total required power in several phase-shifted secondary windings. Disadvantages of this method are complexity and space requirements for the special transformer and higher capital expenditure for the transformer and the AC drive.

Passive filters
Optionally, passive harmonic filters are available for situations with high requirements for the absence of harmonics. These filters consist of passive components such as coils and capacitors. LC series resonant circuits connected in parallel to the load and specifically tuned to the individual harmonics reduce the THDi harmonic distortion at the grid feed to 10% or 5%. A filter module is suitable for both individual AC drives and groups of AC drives. In order for the harmonic filter to provide optimum performance, it must be adapted to the input current actually required by the AC drive. Passive harmonic filters are used in front of an AC drive or a group of AC drives.

Advantages of passive filters
This type of filter offers a good price/performance ratio. At a relatively low cost, the operator obtains a reduction in harmonics, as is possible with 12- or 18-pulse rectifiers, usually a reduction in harmonic current distortion to a THDi of 5%. Moreover, passive filters do not produce any interference in the frequency range above 2 kHz. Because they are composed entirely of passive components, there is no wear, and this solution is insensitive to electrical interference and mechanical stress.

Disadvantages of passive filters
Passive filters are less compact than active filter solutions due to their design.
Filters in this category work very effectively in the load range of 80-100%. However, the capacitive reactive power consumption increases with decreasing load, and disconnecting filter capacitors during no-load operation is recommended - a feature available in Danfoss drives.
Advanced harmonic filters from Danfoss are compact, wall-mountable, and compatible with Danfoss drives platforms.

Active filters
If the requirements with regard to mains harmonics are even more demanding, active electronic filters are used. Active filters are electronic absorption circuits that operators connect in parallel to harmonic generators. They analyze the harmonic current generated by non-linear loads and supply a compensating counter-phase current. This completely neutralizes the corresponding harmonic currents at the connection point. The degree of compensation is adjustable. Thus, harmonics can be almost completely compensated as desired, or only to the necessary extent for complying with legal limits (for example for economic reasons).



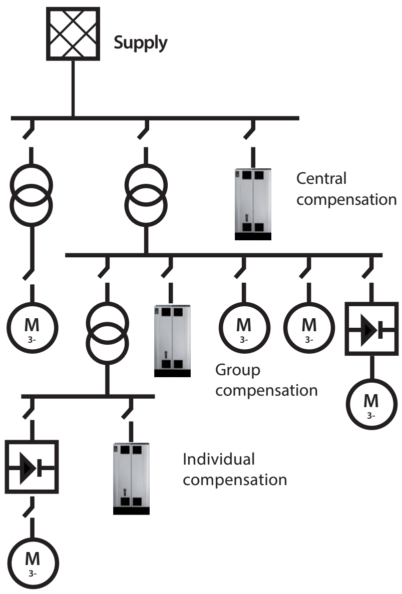
Built-in inductors, such as the DC inductors in this case, effectively reduce harmonics.

Active filters reduce harmonics

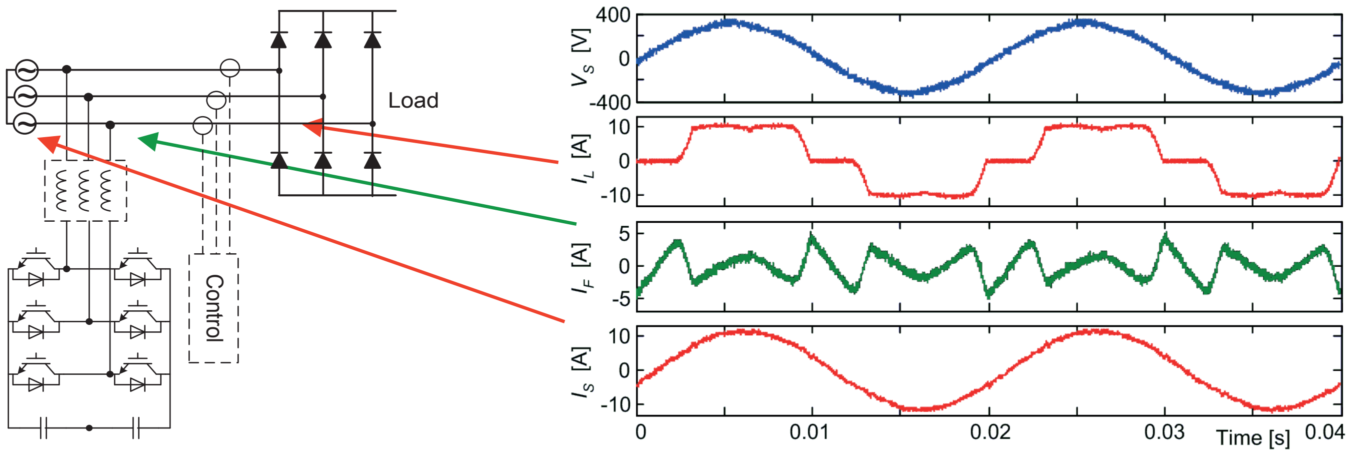
It should be noted that these filters operate with a switching frequency and burden the mains voltage in the range from 4 to 10 kHz.

Advantages of active filters
Operators can insert active filters as a key measure at any desired point in the grid, depending on whether they want to compensate individual drives, entire groups or even entire grids. A separate filter is not required for each AC drive. The harmonic current distortion drops to a THDi value of ≤2%.

Disadvantages of active filters
With active filters, the effects these filters produce above 2 kHz must also be taken into account. They require additional measures to keep the grid clean.



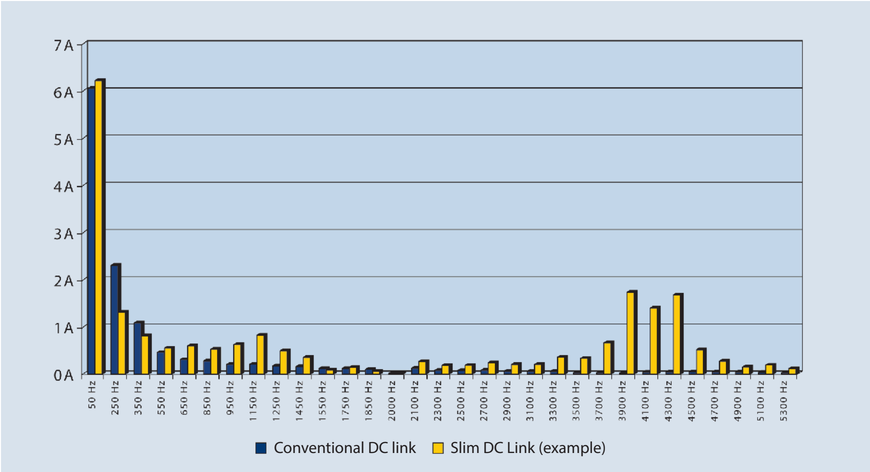
Active filters can be added at any desired point in the grid, depending on whether they are intended to compensate individual drives, entire groups or even entire grids.



Operation Principle of an Active Filter

Harmonic mitigation technology overview

Disadvantages of slim DC link
AC drives with slim DC links have increasingly come onto the market. With this method, manufacturers greatly reduce the capacitance of the DC link capacitors. Even without an inductor, this limits the lower-order harmonics to standard specifications. However, harmonics that would otherwise not occur are generated in the upper frequency range.
The broad frequency spectrum of devices with slim DC links increases the risk of resonance with other components in the grid, such as fluorescent lamps or transformers. The design of suitable measures is therefore time-consuming and very difficult.



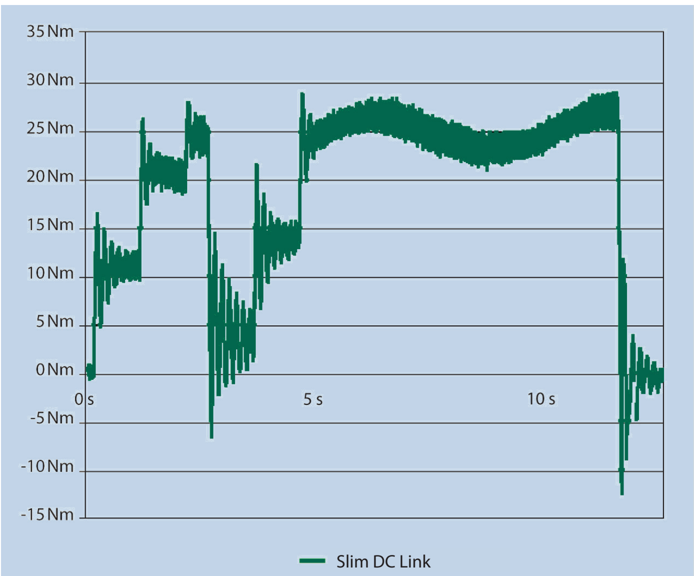
Increased harmonics occur in drives with slim DC links, particularly in the higher frequency ranges.

In addition, drives with slim DC links have weaknesses on the load side. With these drives, there are significantly higher voltage changes when the load varies. They therefore tend to oscillate when the load on the motor shaft changes. Load shedding is also problematic. During load shedding, the motor generates regenerative energy with high peak voltages. To protect themselves against destruction due to an overload or overvoltage, devices with slim DC links react and shut down faster than conventional devices.

Due to the small or absent capacitors, drives with slim DC links have poor ride-through capability for voltage dropouts. As a rule of thumb, a slim DC link has approximately 10 times less capacitance than a conventional DC link.

In addition to the mains harmonics caused by the current consumption, drives with slim DC links also burden the grid with the switching frequency of the motor-side inverter. Due to the missing or minimal capacitance in the DC link, this is clearly visible on the grid side.

Active Front End and low-harmonic drive
Active Front End (AFE) and low-harmonic drive (LHD) for AC drives or power factor correction (PFC) for power supplies are electronic input circuits that replace conventional rectifiers. With very fast-switching semiconductors, these circuits force an almost sinusoidal current by being very effective in attenuating low-frequency mains harmonics. Like AC drives with slim DC links, they produce mains harmonics in the upper frequency range.
An active front end device is the most expensive way to reduce mains harmonics, since it has an additional, fully-fledged frequency converter that is able to feed energy back into the supply network.
A low harmonic drive does not offer this regenerative capability and is therefore somewhat less expensive.



In devices with slim DC links, there is a greater tendency to oscillate with relatively large load changes.

Advantages of AFE/LHD
The harmonic current distortion drops to a THDi value of almost 0% in the range of the 3rd to 50th harmonics. Four-quadrant operation is possible with AFE devices, which means they can feed braking energy from the motor back into the supply network.

Disadvantages of AFE/LHD
The devices have considerable technical complexity, which leads to a higher initial purchase costs compared to a passive solution. Conventional AFE devices basically consist of two frequency converters, one working toward the motor and the other toward the grid.
The additional circuit complexity reduces the efficiency of the AC drive when supplying power to the motor. The power dissipation can be 40-50% greater than with AC drives with uncontrolled rectifiers. For trouble-free operation, an AFE always requires a higher DC-link voltage. This higher voltage is often transfered directly to the motor, which increases the stress on the motor insulation. If the DC links of the AFE devices are not separated, failure of the filter also means failure of the entire device. Another disadvantage is the switching frequency the devices use to correct the input current. It is in the 4-20 kHz range. Good and more technically sophisticated devices filter this switching frequency out before it reaches the grid. The currently applicable standards and laws do not yet cover this frequency range. Current harmonic analyzers usually do not detect this frequency range, so usually the effects can not be measured.

However, they can be seen in all devices operating on this grid, for example as increased current consumption in power supplies. For this reason, users should specifically ask the manufacturer for emission values and countermeasures in the interest of the operational reliability of their own system.

Note: EN 61000-3-12 does not specify that devices within themselves must comply with the limits as standard. It may well be that a drive complies with the limits only with the addition of a filter.

The devices are available for various power sizes and voltage ranges and in different enclosures according to IP and NEMA classifications.

Active Front End and Matrix converter

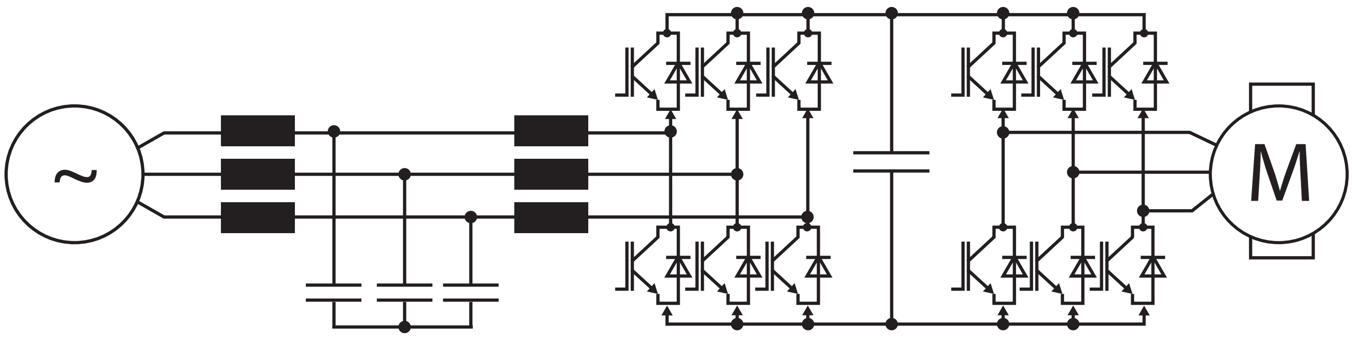
An Active Front End (AFE) is used to transfer power bidirectionally between the AC input and intermediate DC circuit. An AFE is typically used in cyclic applications, like separators, decanters, and centrifuges, to eliminate the need for brake resistors and cabling. This in turn reduces cooling and space requirements. Since an AFE drive uses an active infeed section the overall losses are higher than losses for a standard AC drive with 6- or 12-pulse rectifier.

General AFE features

- Low mains current harmonics in the range of 3rd to 50th harmonics. For higher-order harmonics, special high-frequency filters may be needed to protect other equipment
- Direct active and reactive current control
- Automatic line synchronization
- Bidirectional power flow
- Regeneration of energy back to the grid improves system efficiency

Different Active Front End technologies
AFE drive with DC bus capacitors:

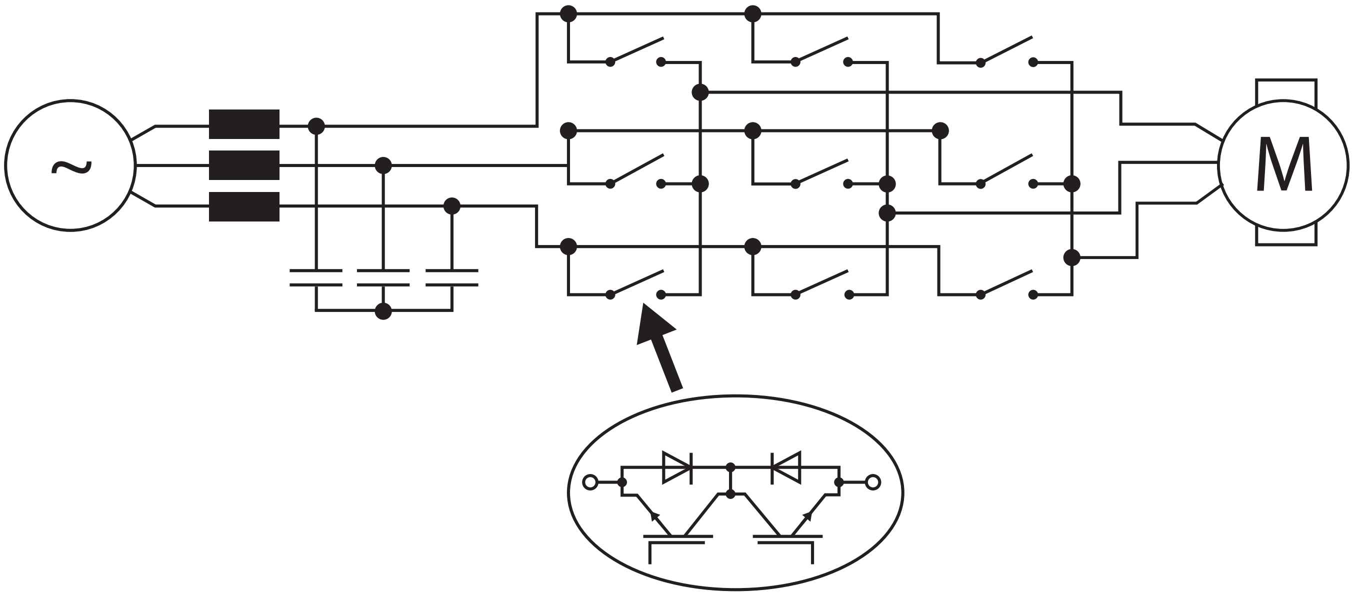
- Full output voltage with the possibility to boost the output voltage even to a higher level
- Full harmonics mitigation performance up to 50th harmonics
- Full power factor control
- Full power loss ride-through capacity
- LCL filter at mains input



Control principle AFE drive with DC bus capacitors, incl. LCL filter

Matrix converter, AFE drive without DC bus capacitors:

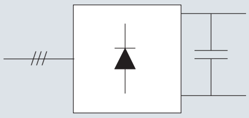
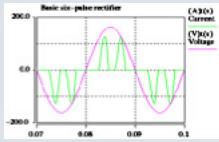
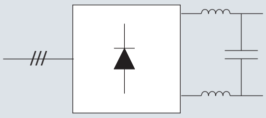
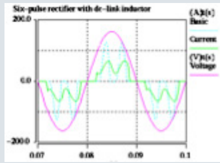
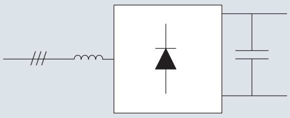
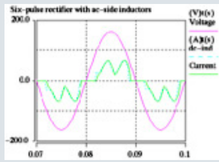
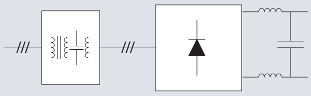
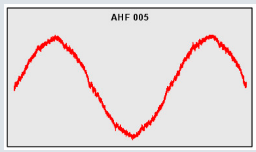
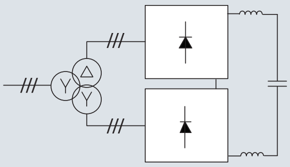
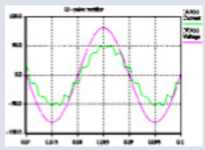
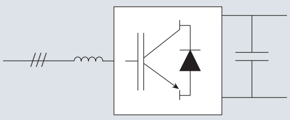
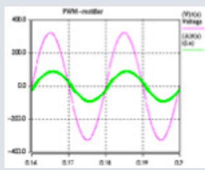
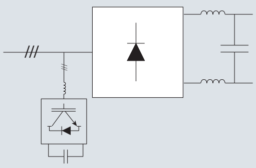
- Lower output voltage, means less motor torque and higher motor temperature (oversizing of motor might be required)
- Lower and less stable harmonic mitigation performance
- Limitations on power factor control
- Limitations on power loss ride-through
- Output voltage drop during voltage sag on grid
- Greater number of IGBTs for more complex control
- Overvoltage sensitive
- LC-filter at mains input



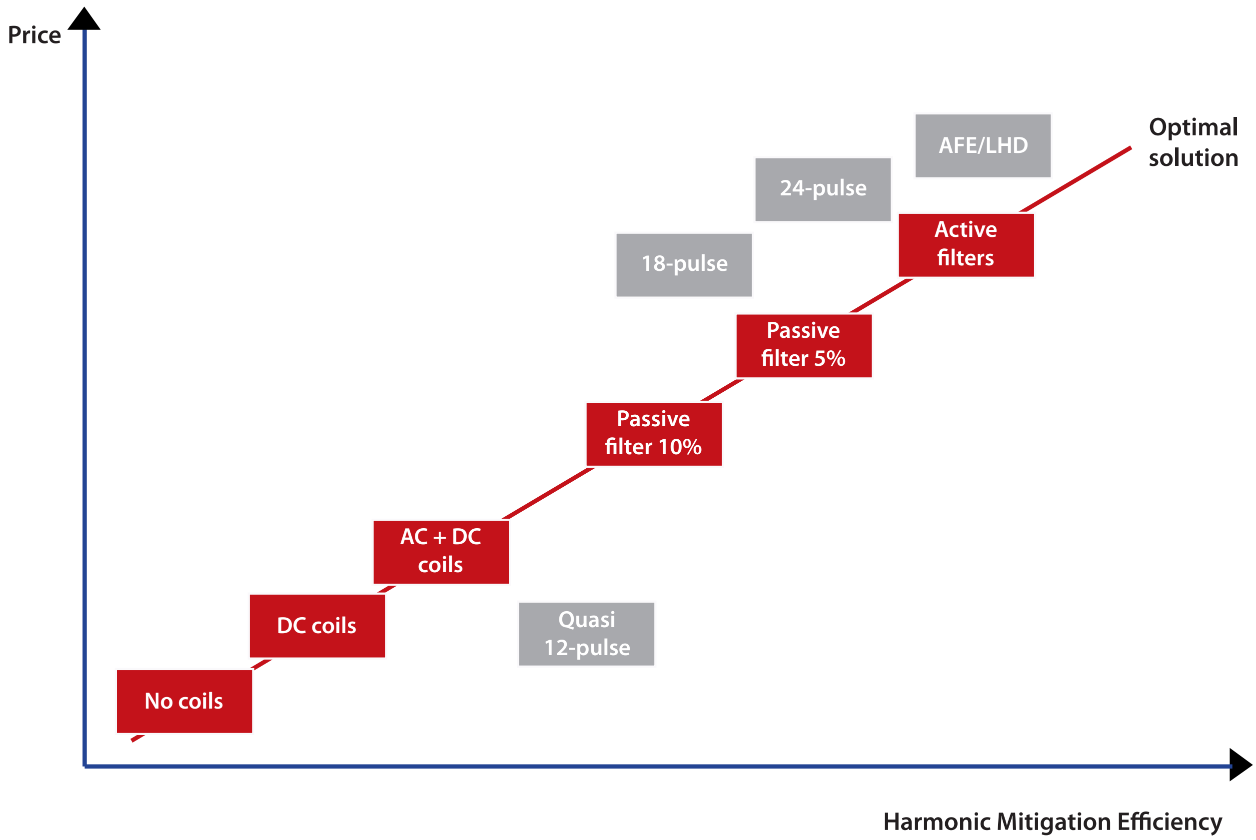
Control principle AFE drive without DC bus capacitors (matrix converter), incl. LC filter

Both AFE technologies can mitigate mains harmonics, but with different performance levels. Engineers designing applications for chemical and/or pharmaceutical plants should be aware about these crucial differences before deciding on a concept.

Harmonic mitigation solutions

Typical THD achievable, by mitigation method	Circuit diagram	Typical current waveform
No mitigation THD > 80%		
DC inductors THD < 40%		
AC inductors THD < 40%		
Passive harmonic filter THD < 10%		
Multi-pulse rectifier (12/18) THD < 10%		
Active front end THD < 5%		
Active filter THD < 5%		Waveform similar to AFE

Harmonic Mitigation Methods



Overview of measures for reduction of harmonics.

Common DC bus systems

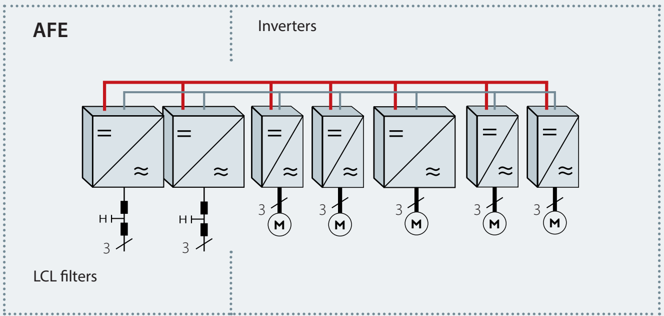
Common DC bus systems typically consist of one or more infeed sections which could be rectifier-based with Non-regenerative Front End (NFE) or IGBT-based Active Front End (AFE) feeding a DC bus connected to several motor inverters.

■ **Energy savings**
A motor running in regenerative mode can supply other motor inverters which are connected to the same DC bus and that are running in motoring mode. Brake resistors could be completely avoided, or the amount of brake resistors can be reduced with this solution, resulting in an overall efficiency improvement.

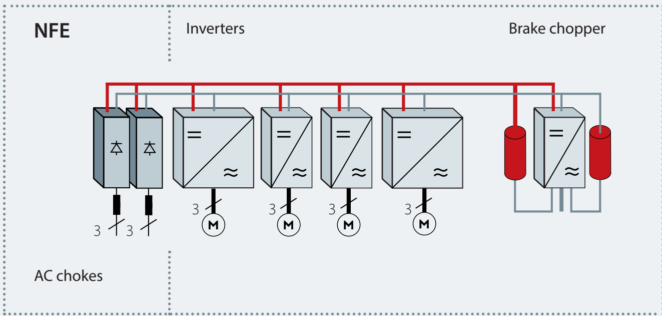
■ **Fewer parts**
Supplying several motor inverters from a common DC bus can reduce the number of infeed sections, resulting in a more compact drive system design.

■ **Power back-up**
Possibility to connect a DC backup system.
Read more in the section Industrial DC Backup technology

A regenerative common DC bus system



A non-regenerative common DC bus system

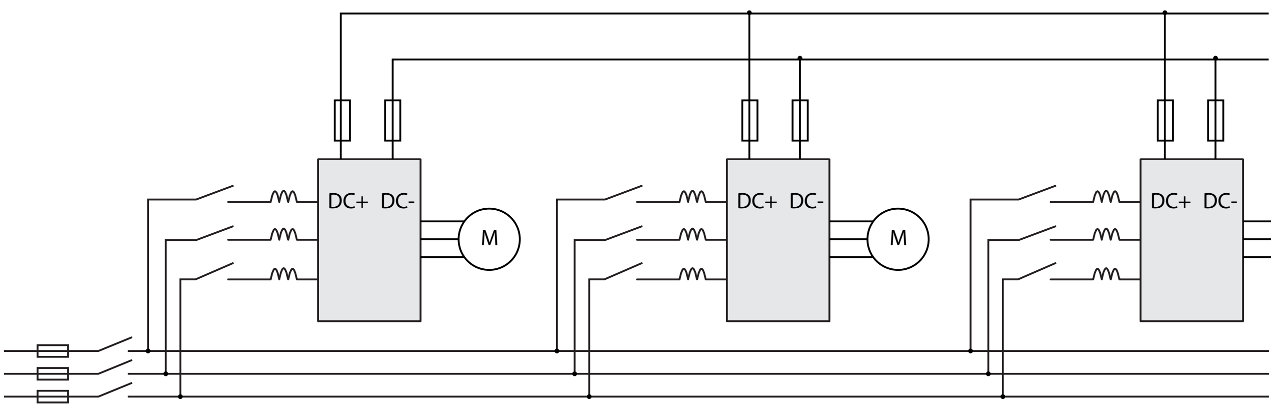


A common DC bus system consists of one or more front-end modules and inverter modules connected together by a DC bus.

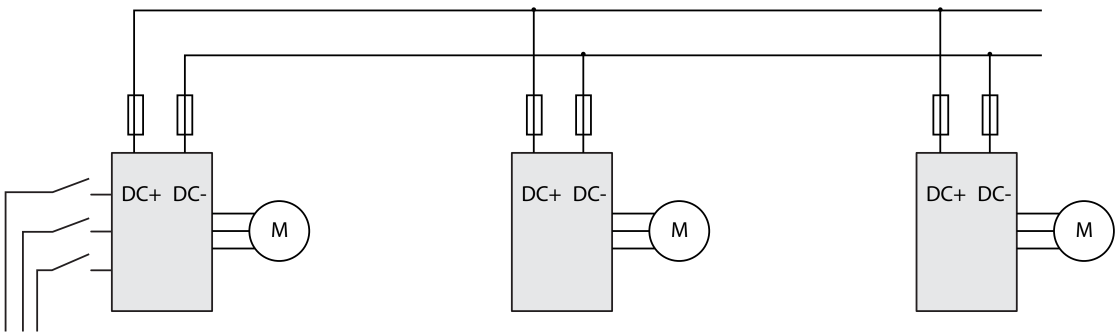
Load sharing

It is also possible to connect several standard AC drives in the common DC bus.

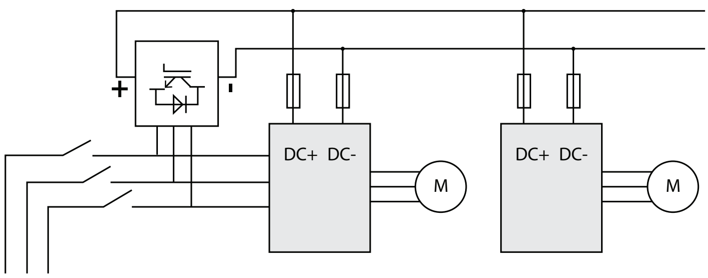
In one configuration, the DC bus terminals of multiple AC drives are used to tie them together to a common DC bus. This configuration allows one AC drive in regenerative mode to share its excess bus voltage with another AC drive in motoring mode. In this configuration, one or several AC drives are connected to the mains supply. A connection of the common DC bus to an external regen unit could also be an alternative which reduces the need for external dynamic brake resistors while also saving energy. Any number of AC drives can be connected in this way, as long they are of the same type and the same voltage rating. In such a configuration, it may be necessary to install AC and/or DC reactors and DC fuses at each drive. Different AC drives series and different power sizes can have different inrush circuits which must be considered as well. We highly recommend that you contact your AC drive supplier for further details, before considering such a solution.



Load sharing configuration: All AC drives are connected to the mains supply using AC chokes. DC bus connection with DC fuses at each AC drive.

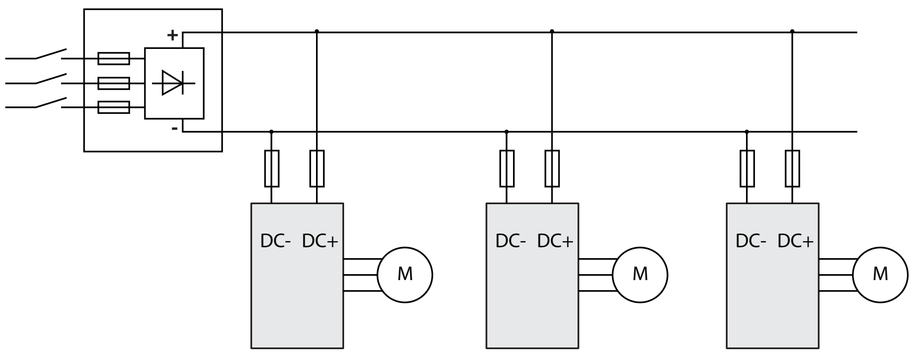


Load sharing configuration: Only one AC drives is connected to the mains supply. DC bus connection with DC fuses at each AC drive.



Load sharing configuration with external regen unit: Only one AC drives is connected to the mains supply. DC bus connection with DC fuses at each AC drive.

In the second configuration, the DC-bus-connected AC drives are exclusively powered from an external DC source. This DC source needs to maintain the pre-charging procedure of all connected AC drives. We recommended installing DC fuses in front of each AC drive.



Load sharing configuration with power supply from an external DC source. None of the AC drives are connected to the mains supply.
DC bus connection with DC fuses at each AC drive.

Grid protection measures

Reactive power compensation

Reactive power compensation systems are used to compensate the phase angle φ between voltage and current. This is necessary when many inductive loads (motors, ballasts for lamps and so on) are used in a supply network.

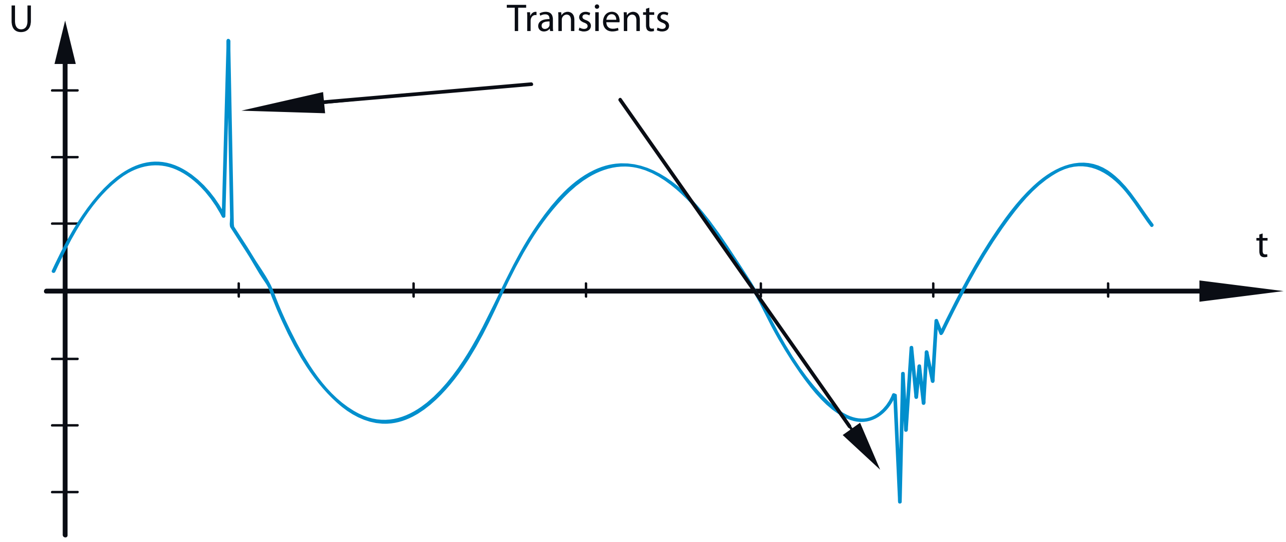
Depending on the design of the DC link, AC drives do not draw any reactive current from the supply network and do not generate any phase shift.
Cos φ is approximately 1.
For this reason, users do not need to take variable speed motors into account when dimensioning any reactive power compensation system. However, because AC drives generate harmonics, the current consumption of the reactive power compensation system increases.

The load on the capacitors increases with the number of harmonic generators, and they heat up to a greater degree. Therefore, operators must implement choked reactive power compensation systems.
Choking also prevents resonances from occurring between the inductances of the loads and the capacitance of the compensation system.

Electrical transients

Transients are short-term voltage overshoots in the range of a few thousand volts. They can occur in all supply networks, be it in industry or in residential areas.
Lightning strikes are a frequent cause of transients. However, they are also caused by switching of heavy loads in the supply network or, for example, switching of reactive power compensation systems.
Short circuits, tripping of protective devices in the supply network, and magnetic inductive coupling between parallel cables can also cause transients.
The Technical Report EN 61000-4-1 describes the forms of these transients and the energy contained in them.

The extent of the damage they cause can be limited by various methods.
For high-energy transients, gas arresters or spark gaps are used as coarse protection. Electronic devices usually use voltage-dependent resistors (varistors) for attenuation as fine protection. AC drives also rely on this solution.



Lightning strikes are among the most frequent causes of electrical transients in HVAC and air conditioning systems.

Operation from a transformer or generator

Maximum transformer load

Operators can use variable speed drives up to several MW in low-voltage grids (400 V, 500 V, 690 V). The necessary voltage is converted from the medium-voltage grid by means of a transformer. In the public supply network (first environment: residential environment), the power company handles this task. In industrial grids (second environment: industrial environment; usually 500 V, 690 V), the transformer is located on the premises of the end user, who is also responsible for power feed to their own system.

Transformer load
With transformers that supply power to AC drives, it should be noted that the use of AC drives and other rectifier loads creates harmonics that burden the transformer additionally with reactive power. This results in higher losses and additional heating. In the worst case, the transformer may be damaged. Smart vector groups (interconnection of several transformers) may eliminate harmonics.

Power quality
To ensure the quality of the mains voltage in accordance with the applicable standards, the following question must be considered:
How much AC drive load can the transformer handle?

Harmonic analysis programs, such as the HCS software and MyDrive® Harmonics *https://suite.mydrive.danfoss.com/content/tools*, provide an accurate indication of how much AC drive load a transformer can supply in a given system.

Operation from a standby generator

Operators always use back-up power systems when loads must continue to operate even if the mains voltage fails, for example in processing systems. They are also used when the existing grid connection does not provide the required power. Operation parallel to the public grid is also possible in order to achieve greater line power. This is often done when there is a simultaneous need for heat output from co-generation units. They make use of the high efficiency that can be achieved with this energy conversion. When a generator provides back-up power, the grid impedance is usually higher than with operation on the public grid. This leads to increasing harmonic distortion. If correctly designed, generators can operate in a grid containing harmonic sources. In practical terms, this means:

- When switching from AC line operation to generator feed, a higher harmonic load can usually be expected.
- Planners and operators should calculate or measure the increase in harmonic load to ensure proper voltage and prevent malfunctions and failures.
- Asymmetrical loading of the generator must be avoided, as increased losses may occur and the harmonic distortion may increase.
- A 5/6 interleave of the generator winding attenuates the fifth and seventh harmonics but increases the third harmonic. A 2/3 interleave reduces the third harmonic.
- If possible, the operator should switch off reactive power compensation systems, since resonances can occur in the grid.
- Inductors or active absorption filters can attenuate harmonics. Resistive loads operated in parallel also have an attenuating effect, while capacitors operated in parallel cause an additional load due to unpredictable resonance effects.

Taking these types of behavior into account, a generator-fed grid can handle a certain number of AC drives while still maintaining the specified power quality. More precise calculation is possible with harmonic analysis software, such as HCS (Harmonic Calculation Software).
https://suite.mydrive.danfoss.com/content/tools

When operating with harmonic sources, the limits are as follows:

B2 and B6 rectifiers	→	max. 20% generator load
Choked B6 rectifier	→	max. 20-35% of the generator load, depending on the design
Controlled B6 bridges	→	max. 10% generator load

The above-mentioned maximum loads are recommended empirical values for trouble-free system operation.

Ambient and environmental conditions

The right installation site

A high degree of availability and long service life of AC drives in use can be achieved only with correct cooling and clean air. The selection of an installation site and installation conditions therefore has a decisive influence on the lifetime of these devices.

Cabinet mounting or wall mounting?

The question of whether AC drives should be mounted centrally in a cabinet or decentrally on a wall has no right or wrong answer.
Each variant offers both advantages and disadvantages.

The cabinet option has the advantage of grouping all electrical and electronic components close together and protecting them in a single enclosure. The cabinet comes ready equipped as a complete unit for installation in the system.

A disadvantage is that components can influence one another due to their close proximity inside cabinet. which makes EMC-compliant layout of the cabinet especially important. In addition, there are higher capital costs for shielded motor cables because the cabinet and the drive are usually much further apart than with a decentralized solution.

Wall mounting is easier to handle from an EMC perspective due to the close proximity of the AC drive to the drive system, and therefore entails significantly lower costs for shielded motor cables. The slight additional price for an AC drive with IP54/NEMA 12 protection rating is negligible.

Note:
Danfoss AC drives are available with three different protection ratings:

- *IP00/20/NEMA Type 1 protection rating for installation in cabinets*
- *IP54/55/NEMA Type 12 protection rating for decentralized mounting*
- *IP66 NEMA Type 3R protection rating for critical ambient conditions, such as extremely high (air) humidity or high levels of dust or aggressive gases.*

AC drives can be installed centrally in cabinets or decentrally near the drive system. Both concepts have their advantages and disadvantages.

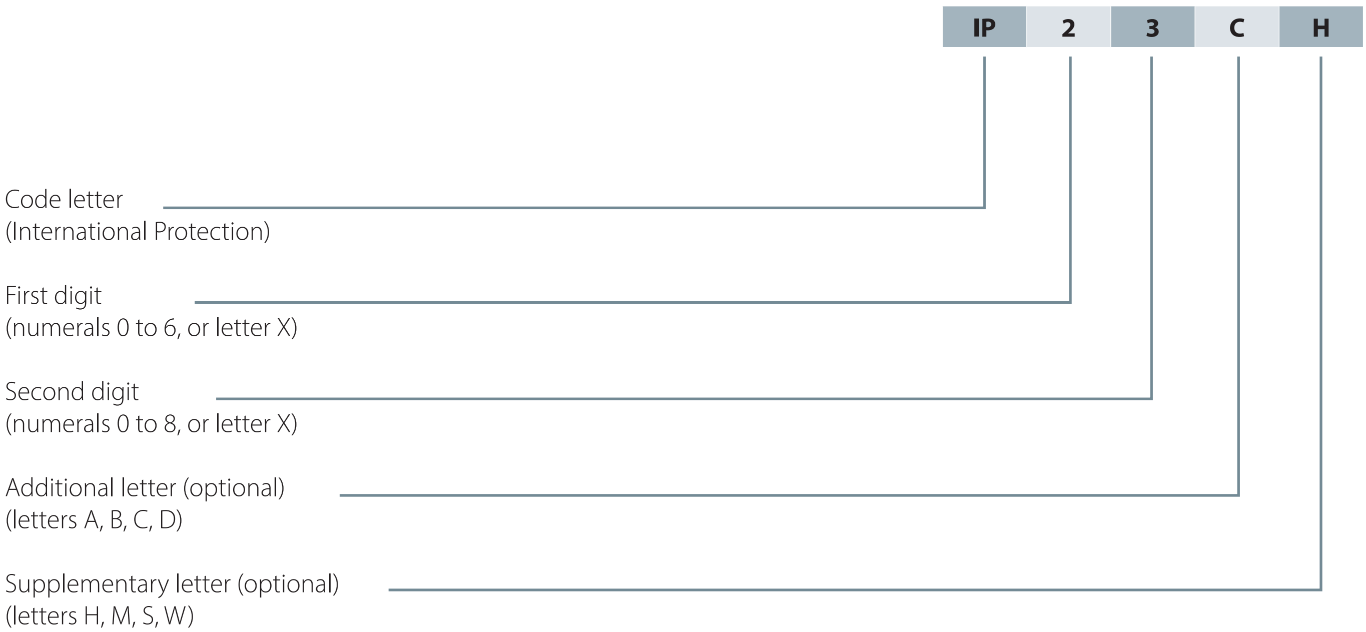
IP and NEMA protection ratings

Structure of IP protection ratings according to IEC 60529

The ingress protection (IP) rating system defined in the standard IEC 60529 indicates the degree of protection provided by an enclosure against access to hazardous parts, ingress of solid foreign objects, ingress of water and to give additional information in connection with such protection.

The IP rating indicates the degree of protection provided by enclosures of electrical equipment, comprising:
- Protection of persons against access to hazardous parts inside the enclosure
- Protection of the equipment inside the enclosure against ingress of solid foreign objects
- Protection of the equipment inside the enclosure against harmful effects due to the ingress of water

Arrangement of the IP Code:



Where a characteristic numeral is not required to be specified, it shall be replaced by the letter "X" ("XX" both numerals are omitted. Additional letters and/or supplementary letters may be omitted without replacement. Where more than one supplementary letter is used, the alphabetic sequence shall apply.

Touch-safe drives with IP20 and IP21 protection ratings (right) are designed for installation in cabinets. Splash-proof AC drives with IP54 and IP55 protection rating (left) are designed for mounting on walls or frames.

Degrees of protection against solid foreign objects and water

First digit	Degree of protection against solid foreign objects		Second digit	Degree of protection against water
	Brief description	Against access to hazardous parts		Brief description
0	not protected	not protected	0	not protected
1	≥50mm diameter	With the back of a hand	1	Vertical dripping
2	≥12,5mm diameter	With a finger	2	Dripping (15° angle)
3	≥2,5mm diameter	With a tool	3	Spraying water
4	≥1mm diameter	With a wire	4	Splashing water
5	Dust protected	With a wire	5	Water jets
6	Dust-tight	With a wire	6	Powerful water jets
-	-	-	7	Short-term immersion
-	-	-	8	Long-term immersion

Degrees of protection against access to hazardous parts indicted by the additional letter

Additional letter	Degree of protection
A	Protected against access with the back of the hand
B	Protected against access with a finger
C	Protected against access with a tool
D	Protected against access with a wire

Supplementary letters

Letter	Significance
H	High voltage device
M	Device moving during water test
S	Device stationary during water test
W	Specified weather conditions

VACON® NXP in different IP ratings

Structure of NEMA enclosure types according to NEMA EN P1-2020

NEMA 250-2018
Comparison of Specific Applications of Enclosures for Indoor Locations

Provides a Degree of Protection against the following conditions	Type of Enclosure									
	1	2	4	4X	5	6	6P	12	12K	13
Access to hazardous parts	■	■	■	■	■	■	■	■	■	■
Ingress of solid foreign objects (falling dirt)	■	■	■	■	■	■	■	■	■	■
Ingress of water (dripping and light splashing)		■	■	■	■	■	■	■	■	■
Ingress of solid foreign objects (circulating dust, lint, fibers, and flyings **)			■	■		■	■	■	■	■
Ingress of solid foreign objects (settling dust, lint, fibers, and flyings **)			■	■	■	■	■	■	■	■
Ingress of water (hosedown and splashing water)			■	■		■	■			
Oil and coolant								■	■	■
Oil or coolant spraying and splashing										■
Corrosive agents				■			■			
Ingress of water (occasional temporary submersion)						■	■			
Ingress of water (occasional prolonged submersion)							■			

NEMA 250-2018
Comparison of Specific Applications of Enclosures for Indoor & Outdoor Locations

Provides a Degree of Protection against the following conditions	Type of Enclosure									
	3	3X	3R	3RX	3S	3SX	4	4X	6	6P
Access to hazardous parts	■	■	■	■	■	■	■	■	■	■
Ingress of solid foreign objects (falling dirt)	■	■	■	■	■	■	■	■	■	■
Ingress of water (dripping and light splashing)	■	■	■	■	■	■	■	■	■	■
Ingress of water (rain, snow, and sleet**)	■	■	■	■	■	■	■	■	■	■
Sleet***					■	■				
Ingress of solid foreign objects (windblown dust, lint, fibers, and flyings****)	■	■			■	■	■	■	■	■
Ingress of water (hosedown and splashing water)							■	■	■	■
Corrosive agents		■		■		■		■		■
Ingress of water (occasional temporary submersion)									■	■
Ingress of water (occasional prolonged submersion)										■

** External operating mechanisms are not required to be operable when the enclosure is ice covered.
*** External operating mechanisms are operable when the enclosure is ice covered. See subsection 5.6 of NEMA 250-2018.
**** These fibers and flyings are not considered Class III type ignitable fibers or combustible flyings. For Class III type ignitable fibers or flyings see the NEC, Article 500.5(D).

Cooling concept

The external climatic conditions and environmental factors have a decisive influence on the cooling of all electrical and electronic components in a control room or cabinet.

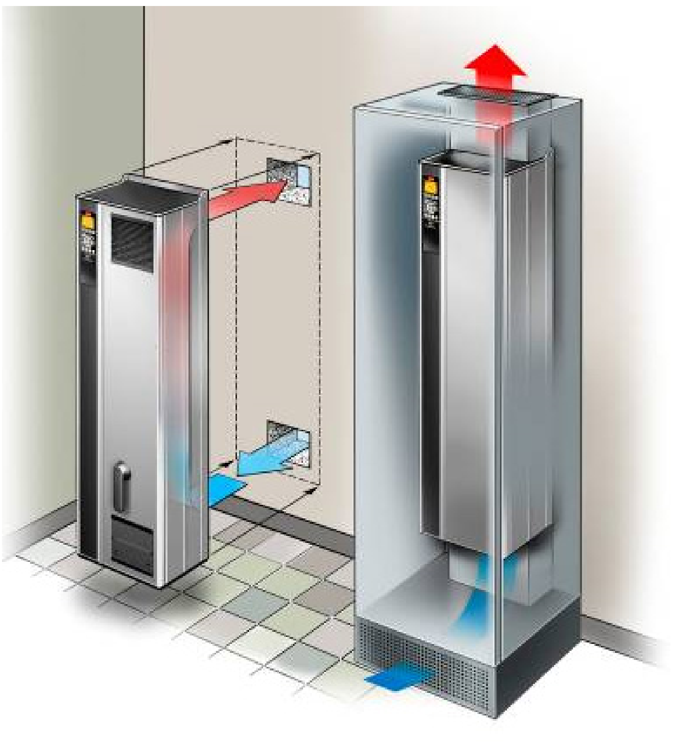
Ambient temperature compliance
The minimum and maximum ambient temperature limits are specified for all AC drives. These limits are usually specified based on the electronic components. For example, the ambient temperature for the electrolytic capacitors installed in the DC link can not fall below a certain limit due to the temperature dependence of the capacitance. Although AC drives can still operate at temperatures as low as -10°C [14°F], manufacturers only guarantee operation with rated power at temperatures above 0°C [32°F]. Avoid use in areas prone to frost (for example non-insulated equipment rooms).

At certain conditions AC drives can work also down to -25°C [-13°F]. The maximum temperature should not be exceeded either. Electronic components are sensitive to heat. According to the Arrhenius equation, the lifetime of an electronic component operated at 10°C [50°F] above its design temperature is reduced by half. This applies not only to devices that are installed in cabinets. Even when using devices with IP54, IP55/ NEMA 12 or IP66/NEMA 3R protection rating, the ambient temperature must remain within the range specified in the manuals. This may necessitate air conditioning of installation sites or cabinets. Avoiding extreme ambient temperatures increases the lifetime of AC drives and thus the overall availability of the system.

Cooling
AC drives dissipate power in the form of heat. The amount of power dissipation in watts is specified in the technical data of the AC drives. Operators should take suitable measures to remove the heat dissipated by the AC drives from the cabinet, for instance by means of cabinet fans. The required air volumes are specified in the manufacturer's documentation. AC drives must be mounted in such a way that the cooling air can flow unimpeded through the device's cooling ribs. Particularly with IP20/NEMA 1 devices in the cabinet, there is a risk that the airflow cannot circulate freely due to the components being mounted too closely together, resulting in hot spots. The correct installation distances are specified in the manuals and must be strictly followed.

Relative humidity
Although some AC drives still function at relatively high humidities (up to 95% humidity with Danfoss AC drives), condensation must always be prevented. There is a particular danger of this if the AC drive or parts of it are colder than the ambient air which has as high level of humidity. The humidity can then condense on the electronics. If this happens, the water droplets can lead to a short circuit in the electronics when the device is switched on again. Condensation normally forms only in AC drives that are switched off. It is therefore advisable to provide cabinet heating where condensation cannot be ruled out due to the ambient conditions. Alternatively, standby operation of the AC drive (AC drive constantly connected to the grid) helps reduce the risk of condensation. Check whether the heat from power dissipation is sufficient to keep the electronics in the AC drive dry.

Note: Some manufacturers of AC drives prescribe minimum distances above and below the devices as well as lateral distances to adjacent devices.



The smart cooling concept of the VLT® drives removes up to 90% of the power dissipation from the device housing via cooling channels.

Liquid-cooled drive technology
Liquid cooling enables you to place the drive system in factory areas where clean cooling air is not available.
Save space thanks to the compact enclosure size. Heat can be trasferred relatively easily where it can be dissipated. There is no need for air ducts which may be difficult to place afterwards in factory buildings.
This also makes it possible to place the drive close to the driven machines and motors avoiding long motor cabling.
Use the principles of sector coupling: utilizing heat energy contained in the drive's cooling liquid you can improve the total system efficiency.

Typical applications for chemical industries:
- Compressors
- Extruders
- Pumps and fans
- Production lines
- Crushers
- Conveyors

Advantages of cooling technology

Up to **25%** savings in total life cycle costs compared to air cooled solutions

20dBA less noise than air cooled drive

25% smaller unit can deliver the same or better performance

Heat exchangers

Due to the nature of the liquid-cooled drives, the heat energy in the cooling liquid needs to be removed. For that purpose, dedicated heat exchangers are required. Select the right heat exchanger for the application, from several alternatives:
- Liquid-to-liquid heat exchanger where heat energy is exchanged from the primary cooling loop of the drive to a secondary loop. This is the most typical solution
- Liquid-to-air, where the secondary loop consists of natural cooling air circulation
- Chiller solution, where the secondary cooling loop is built on a active chiller

Read the selection guide here

Special requirements

Aggressive air or gases

Aggressive gases such as hydrogen sulfide, chlorine or ammonia often occur in industrial plants. Contamination of the cooling air can lead to corrosion of the electronic components and circuit board tracks of AC drives in the long term. This affects all electronic devices in the electrical installation or in the cabinet. If such contamination of the ambient air is present, operators or plant engineers should either install the AC drives in places where contamination is reliably prevented (for instance other buildings, a closed cabinet with heat exchanger, or other) or order devices whose PCAs are coated with a special protective coating that resists the aggressive components in the air.

A clear sign of aggressive ambient air is corrosion of copper. If copper turns black, blisters or even disintegrates within a short time, PCAs or devices with an additional coating should be used. The international standard IEC 60721-3-3 describes the media and concentrations that a specific coating is able to withstand.

Note: *Where the air for cooling electrical installations comes from should already be considered in the planning and project engineering phase.*
Note: *As standard, the VLT® AutomationDrive comes with class 3C2 coating. Class 3C3 coating is also available on request.*

Classification: according to IEC 60721-3-3, average values are expected long-term values. Maximum values are short-term peak values that do not occur longer than 30 minutes per day.

Environmental parameters	Unit	Class				
		3C1	3C2		3C3	
			Average value	Max. value	Average value	Max. value
Sea salt	mg/m^3	No	Salt mist		Salt mist	
Sulfur oxide	mg/m^3	0.1	0.3	1.0	5.0	10
Hydrogen sulfide	mg/m^3	0.01	0.1	0.5	3.0	10
Chlorine	mg/m^3	0.01	0.01	0.3	0.3	1.0
Hydrogen chloride	mg/m^3	0.01	0.1	0.5	1.0	5.0
Hydrogen fluoride	mg/m^3	0.003	0.01	0.3	0.1	3.0
Ammonia	mg/m^3	0.3	1.0	3.0	10	35
Ozone	mg/m^3	0.01	0.05	0.1	0.1	0.3
Nitrogen	mg/m^3	0.1	0.5	1.0	3.0	9.0

Dust burden

The installation of AC drives in high-dust environments is often unavoidable in practice. Dust penetrates even the smallest of cracks and settles everywhere.
It affects not only decentralized AC drives with IP55 (NEMA Typ 12) or IP66 (NEMA Type 4X)protection rating that are mounted on walls or frames, but also devices with IP20 or IP21 (NEMA Type 1) protection rating that are mounted in a cabinet. If AC drives are used in high-dust environments, there are three things that must be considered:

- **Reduced cooling**
  Dust is deposited on the surfaces of the devices as well as inside the devices on the PCAs and the electronic components. It then acts as an insulating layer. The components are less able to release heat into the surrounding air. This reduces the cooling capacity. The components heat up more intensely. As a result, electronic components age faster, and the lifetime of the affected AC drive decreases. The same happens when the heat sink on the back of an AC drive becomes dusty.

- **Cooling fan**
  The airflow for cooling AC drives is generated by cooling fans, which are usually located at the rear of the devices. The rotors in the fans have small bearings into which the dust penetrates and acts as an abrasive. This results in fan failure due to damaged bearings.

- **Filter mats**
  High-power AC drives are equipped with cooling fans which expel warm air from the inside of the unit to the outside. These cooling fans are equipped with filter mats that prevent dust above a certain size from entering the device. When used in very dusty environments, these filter mats clog very quickly, which also results in reduced cooling. The cooling fans can no longer properly cool the components in the AC drive.

Note: *It is advisable to clean the air cooled AC drives at regular maintenance intervals under the above-mentioned conditions: Blow dust out of the heat sink and clean the filter mats regularly. In environments with very high levels of dust, liquid cooled drives have advantages.*

Explosion hazard area

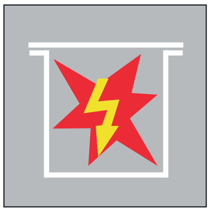
Explosion hazard areas

Power drive systems often operate in explosion hazard areas. If AC drives are used for variable speed control of these motors and pumps, the systems must comply with special provisions. EU Directive 2014/34/EU, also known as the ATEX Directive, forms the basis for this. It describes the use and operation of equipment and protective devices in potentially explosive atmospheres. The directive standardizes the rules and requirements throughout the EU for the operation of electrical and electronic devices in potentially hazardous environments caused, for example, by dust or gases.
In addition, the user should adhere to NAMUR recommendation NE 38 when installing AC drives.

If AC drives are used to control motors in explosion hazard areas, these motors must be equipped with a temperature monitoring system with thermistor sensors. Motors in ignition protection classes "d" and "e" are available for selection. The difference between the protection classes is how the ignition of an explosive medium is prevented. In practice, protection class "e" motors have very rarely been used with AC drives. A combination such as this must be formally approved together as a unit in a complex and expensive type test. As an alternative, the PTB in Braunschweig/Germany has developed an approval procedure that will make the use of variable speed control of Ex e motors much easier.

Protection class Ex d motors must be approved for variable speed drive operation. These motors are then given a second nameplate with data for variable speed drive operation.

Flameproof enclosure "d" according to EN 60079-1, ISA 60079-1, and IEC 60079-1

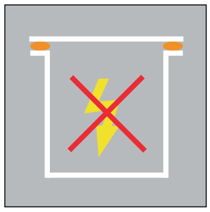


Parts which can ignite an explosive atmosphere are housed in an enclosure which, in the event of an explosion of an explosive mixture inside the enclosure, can withstand the pressure and prevent the explosion from being transmitted to the atmosphere surrounding the enclosure (source: EN 60079-1 standard).

Then it is no longer necessary to obtain separate approval for a system composed of an AC drive and a flameproof motor approved for AC drive operation.

The most widespread are "de" motors. The motor is designed for ignition protection class "d," while the terminal compartment is designed for ignition protection class "e." The limitation of the "e" terminal compartment is the maximum voltage level. The modulation of the output voltage can result in voltage overshoots at the drive output that exceed the permissible limits in the Ex e terminal compartment. In practice, the use of sine wave filters at AC drive outputs, which among other things attenuate the high peak voltages, has proven to be satisfactory.

Improved safety "e" according to EN 60079-7; ISA 60079-7, and IEC 60079-7



Here, additional measures have been taken to prevent, with an increased degree of safety, the possibility of unacceptably high temperatures and the occurrence of sparks and arcs inside or on external parts of electrical equipment that would not occur during normal operation.

Note: *Never install AC drives directly in explosion hazard areas. They must be installed outside this zone in a cabinet or in a dedicated electrical switch room. The use of sine wave filters at the AC drive output is also recommended, because they attenuate the voltage slew rate dv/dt and the peak voltage Upeak. The length of the connected motor cable must be kept as short as possible due to the voltage drop on the cable and the sine wave filter.*

Note: *With the MCB 112, the AC drives of the VLT® AutomationDrive series are equipped with a certified motor thermistor evaluation for explosion hazard areas. When using VLT® drives with output sine wave filters, shielded motor cables are not required.*

Note: *With OPT-AF option board, the AC drives of the Vacon® NX series are equipped with certified motor thermistor evaluation for explosion hazard areas according ATEX directive 94/9/EC, category (2) in the G area (area in which potentially explosive gas, vapor, mist or air mixtures are present) and D area (area with combustible dust).*

ATEX motor design

During the production, storage, and transport of chemical or petrochemical products, gases, vapors, mists or dusts can arise which, in certain mixing ratios, can be explosive with air. Ignition occurs when the mixing ratio is in the range of the upper and lower explosion limit, and when the ignition temperature or the minimum ignition energy is exceeded. Explosion-proof electrical equipment must be used in areas that are at risk of explosion from such gases, vapors, mists or dusts. Dust explosion protection must be provided for all areas in which dust or dust deposits can occur.

Electric motors for explosion-hazard areas (ATEX design) conform to the 2014/34/EU (ATEX) directive and are designed to avoid explosion hazards. Electric motors with explosion-proof design can be used safely in chemical and petrochemical industries, gas plants and gas supply companies, filling stations, coking plants, mills, sewage treatment plants, in oil and natural gas extraction, in the wood industry and in almost all industrial areas that are exposed to risk of explosion.

Zone classification		
Gas	Zone 0*	This is an area in which a potentially explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapor or mist is continuously present for long periods or frequently.
	Zone 1*	This is an area in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapor or mist may occur occasionally during normal operation.
	Zone 2*	This is an area in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapor or mist is not likely to occur during normal operation or will exist for a short period only.
Dust	Zone 20*	This is an area in which a dangerous explosive atmosphere in the form of a cloud of combustible dust in the air is present continuously, for long periods or frequently.
	Zone 21*	This is an area in which an explosive atmosphere in the form of a cloud of combustible dust in the air may occur occasionally during normal operation.
	Zone 22*	This is an area in which a dangerous explosive atmosphere in the form of a cloud of combustible dust in the air is not likely to occur during normal operation or will exist for a short period only.

** Definitions from the German Industrial Safety Regulation (BetrSichV)*

The table above describes how the ATEX zone classifications are defined. The zones provide information on the frequency and duration of occurrence of an explosive atmosphere. It should be noted that components selected for use in the explosion hazard area must at least correspond to the prevailing zone in their category. Additional criteria are the temperature classes and the explosion groups. For example, it is generally not possible to use an electric motor in zone 0. It is essential that the approval of a deployed device according to the intended use matches the type of potentially explosive atmosphere: dust (code D) or gas (code G). Additional requirements also apply, for example in mining for firedamp protection.

Explosion-protected motors

The following table shows the possible explosion protection categories for motors, and the related zones:

Design	Option	Use
2G	Motors according to Directive 2014/34/EU, category 2 (gas)	Can be used in zones 1 and 2
2D	Motors according to Directive 2014/34/EU, category 2 (dust)	Can be used in zones 21 and 22
2GD	Motors according to Directive 2014/34/EU, category 2 (gas/dust)	Can be used in zones 1 and 2, as well as in zones 21 and 22
3G	Motors according to Directive 2014/34/EU, category 3 (gas)	Can be used in zone 2
3D	Motors according to Directive 2014/34/EU, category 3 (dust)	Can be used in zone 22
3GD	Motors according to Directive 2014/34/EU, category 3 (gas/dust)	Can be used in zones 2 and 22

Insulation stress at electrical machines supplied by AC drives
The insulation of a motor is subjected to higher dielectric stress when supplied by an AC drive than in the case of a pure sinusoidal source. An AC drive generates rectangular pulses of fixed amplitude voltage that have varying width and frequency.

The amplitude voltage of the pulses at the output of the AC drive is determined by the DC link voltage. Modern low voltage AC drives have an output voltage rise time which is in the ns range to minimize switching losses in the output section of the drive. Due to this fact AC drives can generate repetitive voltage overshoots (Upeak) with a high voltage slew rate (dv/dt) at the terminals of the AC motor, which can reduce the lifetime of the motor insulation. Depending on the rise time of the voltage pulse (dv/dt) at the AC drive output, the motor cable length, the grounding system and the impedance of the motor, the pulses generate peak voltages at the motor terminals which can be higher than twice the DC link voltage of the AC drive (phase-to-phase and phase-to-ground). If the motor cable is short (a few meters), the rise time and peak voltage are lower. If the motor cable is long (100 m or more), the rise time and peak voltage are higher. It is noted here that the DC link voltage of an AC drive with active infeed converter (AFE) is higher compared to an AC drive with three-phase diode rectifier.

For motor rated at voltages ≤ 500 V AC the insulation system should typically give satisfactory life when subjected to peak voltages of a modern AC drive. For motors rated over 500V AC up to 690V AC an enhanced or reinforced insulation system and/or filters at the AC drive output designed to limit the rise time and/or peak voltages may be required.

It is recommended that the system integrator of the AC drive and the motor takes these facts into consideration.

Nominal motor voltage	Motor insulation
Un ≤ 420V	Standard U_{LL} ~ 1300V
420V < Un ≤ 500V	Reinforced U_{LL} ~ 1600V
500V < Un ≤ 600V	Reinforced U_{LL} ~ 1800V
600V < Un ≤ 690V	Reinforced U_{LL} ~ 2000V

Typical motor insulation ratings

No measures for limiting the cause of the peak voltages generated by AC drives are specified in the standards for explosion-protected electrical machinery. Nevertheless, from the perspective of motor manufacturers and in the interest of increased operational reliability it is urgently advisable to apply measures to the AC drive system to reduce the additional insulation stress, such as using a moderate switching frequency, avoiding extremely short voltage rise times (very high dv/dt) and high Upeak values by installing an additional output filter on the output side of an AC drive. These measures are also recommended in IEC 60034-25, and in IEC 60034-18-41. Specific requirements from the different motor manufacturers must be considered. Always observe the operating instructions of the motor, the gear and the AC drive!

Project planning is an important factor to avoid overtemperatures and increase the lifetime of a motor.

The performance characteristics and operating data for AC drives with converter-fed induction motors are influenced by the complete system, comprising supply system, AC drive, in- and output filter, motor, cables, grounding system and control system.

Any values quoted in this document are thus indicative only!

In explosion hazard areas, however, it is primarily about the voltage at the motor terminal box and the surface temperatures at the motor. This shows which type of Ex-motor may be used in which zone in order to exclude a source of ignition.
In general, the system manufacturer and the system operator are responsible. An explosion hazard area specialist is allowed to define the zone classification and the selection of the equipment and is generally liable.

These specialists should adhere to the applicable regional installation recommendations and the NAMUR NE 38 (Frequency Converter Design, Voltage Stress Limits of Motors on Impulse Converters) and NE 47 (3-phase Asynchronous Motors, Technical Requirements) recommendations, which define limits.

Extract from NE 38:
Filters should generally be provided at the converter output to reduce voltage stress and harmonics and for EMC suppression. The following may be considered as suitable limits:
For 400V and 500V motors:
ULL < 1000V and du/dt < 500V/µs

For 690V motors:
ULL < 1350V and du/dt < 500V/µs

The last mentioned values form the basis for all new motors in VIK Recommendation VE1 (NAMUR Recommendation NE 47) as of 05.2011.

Safety functions in drives

Explosion hazard areas

Variable speed drives are found in the chemical and pharmaceutical industry in strongly growing numbers. With increasing cost pressure, operators are therefore looking for new solutions to reduce costs, increase availability in plants and energy efficiency and improve safety. One possibility is to relocate safety functions that were previously built with discrete components to the drives. This lowers the cost of space, installation and wiring, as well as troubleshooting and maintenance. Modern AC drives offer a wide range of options for this purpose.

Motor sole protection

A drive solution that reduces the required component count, wiring, interfaces, planning effort and installation times for motor sole protection offers considerable savings potential.

In addition to the task of adjusting the motor speed, AC drives can also integrate the functions relevant for explosion protection. The basic motor monitoring function in the explosion hazard area is ensured by ATEX-certified PTC electronic evaluation in conjunction with a likewise certified and safe way of switching off the power to the motor. If a fieldbus connection is added to this functionality and PTC monitoring is available as an internal, evaluable signal of the AC drive, the expense for signal cables, installation and interface planning is noticeably reduced. Danfoss, for example, offers such solutions with its VLT® AutomationDrive and Vacon® NX series with Fieldbus and PTC-option modules.

Due to assured interruption of the power supply to the motor by means of redundant internal shutdown of the IGBT trigger stage supply and simultaneous trigger pulse blocking, it is no longer necessary to use a main contactor, a coupling relay or control voltage protective devices on the feed panel.

Using a fieldbus communication interface, which is widely available in the chemical industry, opens up additional savings potential. The VLT® AutomationDrive and Vacon® NX series with Fieldbus and PTC modules helps to utilize this and reduces planning and installation costs as well as the need for modules in the process control system. In the event of a fault, troubleshooting is greatly simplified, and downtime and repair times are reduced to a minimum.

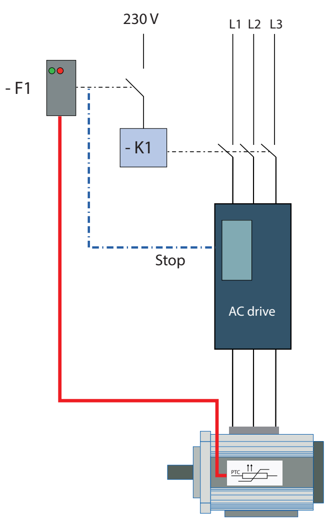
Explosion protection concept for variable speed drives with "increased safety" ignition protection

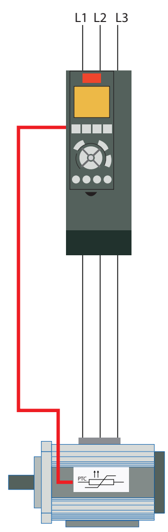
The previous approval procedure for motors with "increased safety" ignition protection class (Ex e) in combination with variable speed drives was very inflexible and complicated. For applications in potentially explosive atmospheres, operators therefore often resorted to significantly more expensive motors with flameproof enclosures (Ex d). In the meantime, there is a new approval procedure in place that makes the use of variable speed control with Ex e motors much more attractive.

Like all other options of the VLT® AutomationDrive FC 302, the PTC thermistor card MCB 112 can be quickly and cost-effectively retrofitted on site as a plug & play module.

The OPT-AF option board provides the NXP product with an ATEX thermistor input for protection against motor overtemperature, where the motor is located in an ATEX environment.

The new concept only require for the approval of the motor itself, but with specific requirements for thermal monitoring defined in its EC type test certificate. In addition to the usual certified thermistor evaluation, speed-dependent current limiting is also required to take account of the reduced cooling of self-ventilated motors with variable speed control.



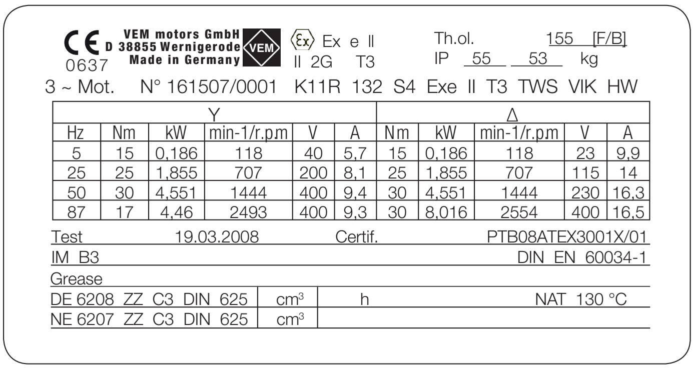


Permissible protection concept for operation on an AC drive

Monitoring of the motor PTC thermistor by a monitoring device for protecting explosion-protected motors is mandatory, for example as described in Directive 2014/34/EU.
An additional nameplate with permitted continuous currents depending on different frequencies must be mounted on the motor.
The maximum and minimum frequencies indicated on the motor nameplate may not exceed or fall below these specifications. The rated current of the AC drive must not exceed twice the rated current of the motor.

The data stamped on the nameplate is part of the approval for the motor. Do not change the AC drive parameter settings from the motor nameplate data.

All motors must be protected from impermissible heating according to ATEX Directive 2014/34/EU. Safety equipment required for safe operation is affected by this Directive and must be certified for this reason.

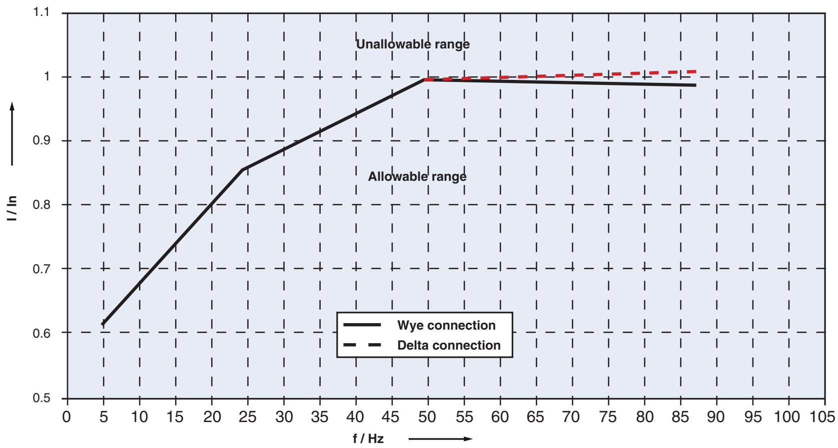


CE 0637 D 38855 Wernigerode VEM motors GmbH Made in Germany
Ex e II II 2G T3
Th.ol. 155 [F/B]
IP 55 53 kg
3 ~ Mot. N° 161507/0001 K11R 132 S4 Exe II T3 TWS VIK HW

Y						Δ				
Hz	Nm	kW	min-1/r.p.m	V	A	Nm	kW	min-1/r.p.m	V	A
5	15	0,186	118	40	5,7	15	0,186	118	23	9,9
25	25	1,855	707	200	8,1	25	1,855	707	115	14
50	30	4,551	1444	400	9,4	30	4,551	1444	230	16,3
87	17	4,46	2493	400	9,3	30	8,016	2554	400	16,5

Test 19.03.2008 Certif. PTB08ATEX3001X/01
IM B3 DIN EN 60034-1
Grease
DE 6208 ZZ C3 DIN 625 cm³ h NAT 130 °C
NE 6207 ZZ C3 DIN 625 cm³

The speed-dependent data for the evaluation function is shown on the nameplate (above) and can be entered during commissioning. The evaluation function (below chart) then monitors the self-ventilated motor during variable speed operation according to the specifications.



A low-cost, flexible alternative

The new method opens up interesting potential to save energy in the future through the more favorable use of variable speed control, particularly for pumps and fan drives that have not been retrofitted due to high conversion costs.

Simple
Flexible use of variable speed control for motors of the "increased safety" ignition protection class.

Compact
Significantly smaller frame size, weight and cost compared to variable speed control of motors with flameproof enclosures.

Flexible
Easy to combine, reducing stock diversity of motors and AC drives.

Safe
Future-proof operation of Ex e/Ex-n motors (can also be combined with successor series).

Economical
Lower capital expenditures enable earlier return on investment when speed control is used to reduce energy costs.

Universal
Integrated solution in the power range of 400 W and higher at 400/500/690 V.

Special functions for applications in the chemical industry

Optional safety functions for VLT® AutomationDrive and Vacon® NX series. Danfoss has developed certified modules for the sole protection of an explosion-proof motor suitable for use with an AC drive. This saves on external components, expensive cabinet space and wiring costs.
The module is suitable for PTC connection and monitoring according to DIN 44081 and DIN 44082. Sensor circuit monitoring for short circuit and open circuit is of course integrated.
By using the STO- function integrated as standard in the VLT® FC302 AutomationDrive at performance level d according to EN ISO 13849-1 or SIL 2 according to EN 61508, grid disconnection by means of a contactor can be dispensed with.

ATEX certification for Ex e motors
VLT® AutomationDrives and Vacon® NX series can also be used to control ATEX-certified motors from any manufacturer for variable speed operation in zones 1 and 2 (gas) or zones 21 and 22 (dust). With the MCB 112 PTC option for the VLT series or the OPT-AF option for the Vacon® NX series, users can now implement the required ATEX-certified temperature monitoring directly in the AC drive.
Evaluation function for Ex e motors
In addition, the VLT® AutomationDrive offers a special evaluation function that facilitates the operation of ATEX-certified Ex e motors that are compatible with AC drives.
The information required for the evaluation function is available on the nameplate of corresponding Ex e motors and users can easily enter it during commissioning via the control panel or the MCT 10 programming software.

Terminal designation according to NAMUR NE 37. In conjunction with the MCB 113 expansion module, the VLT® AutomationDrive FC 302 can provide the control terminal strip functionality according to NAMUR recommendation NE37 without additional external peripherals.
This makes it possible to integrate high functionality and safety into the system with minimum space requirements.

NAMUR is an international user association of automation technology and digitalization in process industries. The organization represents their interests concerning automation technology.

The organization provides publications, recommendations (NE) and worksheets (NA) related to a broad range of technical topics related to the process industry. Some of those recommendations targeting AC drives and AC motors and are important for the pharmaceutical and chemical industries. E.g. NE 37 (Realization of Frequency Converters – Standard Terminal Strip for Variable-speed Drives), NE 38 (Frequency Converter Design – Voltage Stress Limits of Motors on Impulse Converters) and NE 47 (3-Phase Asynchronous Motors; Technical Requirements), just to mention a few.

Functional safety

Functional safety defines protection against hazards caused by incorrect functioning of components or systems. For chemical industries in Europe, functional safety falls under the Machinery Directive 2006/42/EC and the Serveso Directive 2012/18/EU.

Here, the safety instrumentation in big installations (not classified as machines) is normally approved using the standard IEC 61511 that requires IEC 61508 certification for safety-related sub-elements such as STO in the drive. The Machinery Directive describes the purpose of functional safety as follows:

"Machinery must be designed and constructed so that it is fitted for its function, and can be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the conditions foreseen but also taking into account any reasonably foreseeable misuse thereof."

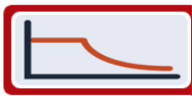
Depending on which application standard must be fulfilled, the system must fulfil a defined safety level. This safety level is defined through the risk assessment. The Machinery Directive refers to different standards, according to the safety level required.

Safety Level	Abbreviation	Standard
Performance Level	PL	EN ISO 13849-1
Safety Integrity Level	SIL	IEC 61508, IEC 62061

Safety functions in AC drives

By using options, you can extend the safety functions available in Danfoss drives. Some examples for safety functions.

Stop Functions:



Safe Torque Off (STO)
Power that can cause rotation is not applied to the motor. The PDS will not provide energy to the motor which can generate torque.

Safe Stop 1 (SS1)
Initiates and monitors the motor deceleration rate within set limits to stop the motor and initiates the STO function when the motor speed is below a specified limit; or after specified time.

Safe Stop 2 (SS2)
Initiates and monitors the motor deceleration rate within set limits to stop the motor and initiates the Safe Operating Stop function when the motor speed is still energized, when the motor speed is below a specified limit or after specified time.

Safe Quick Stop (SQS)
Independent set of functions in combination with STO, SS1 or SS2 functions. The functions utilize independent ramp definitions from the standard SS1 and SS2 functions.

Safe Brake Control (SBC)
Provides a safe output signal(s) to control an external brakes(s). Integrated to STO function.

Speed Functions:

Safely-limited Speed (SLS)
Prevents the motor from exceeding the specified speed limit.

Safe Speed Monitor (SSM)
Provides a safe output signal to indicate whether the motor speed is below a specified limit.

Safe Speed Range (SSR)
Prevents the motor from exceeding the specified speed limit.

Safely Acceleration Range (SAR)
Keeps the motor acceleration and/or deceleration within specified limits.

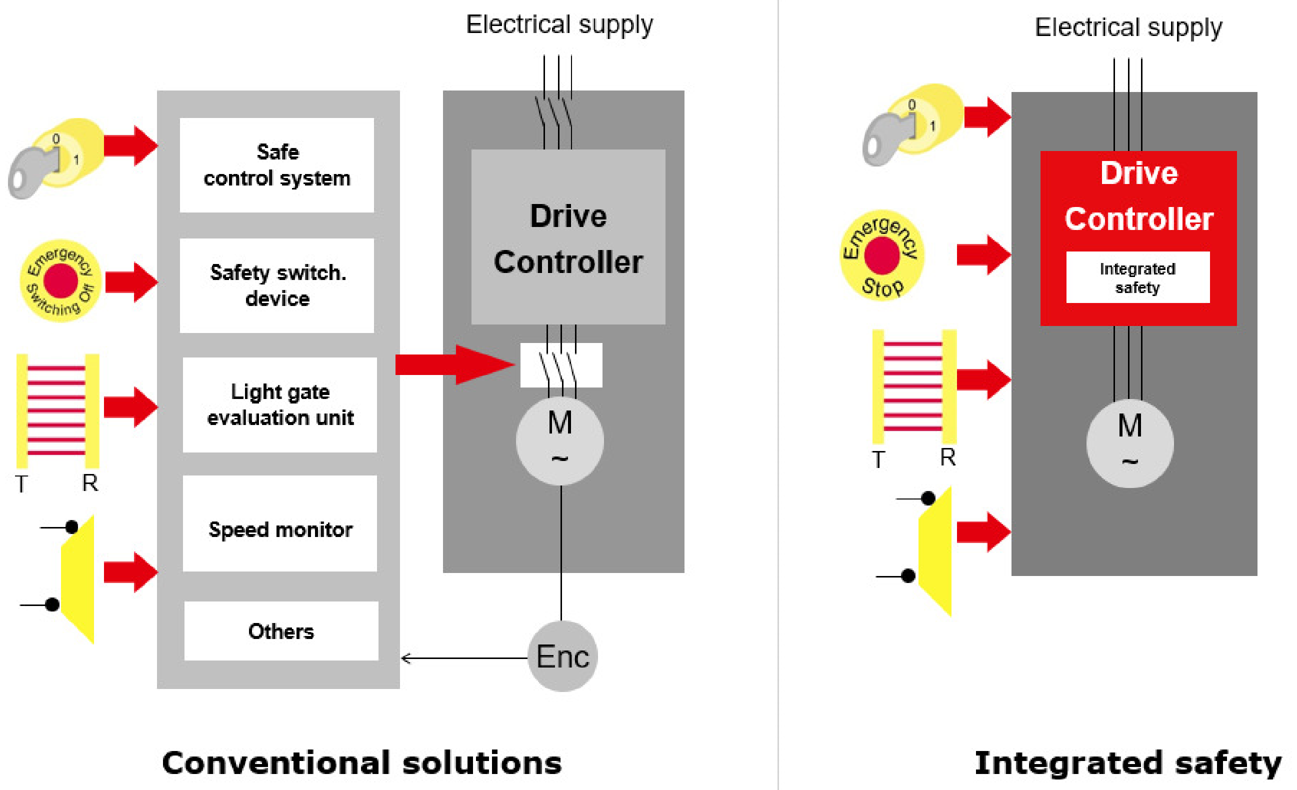
Safe Direction (SDI)
Prevents the motor shaft from moving in an unintended direction.

Safe Maximum Speed (SMS)
Prevents the motor exceeding the maximum specified limit.

General benefits using AC drives with integrated functional safety:

- Integrated functional safety replaces external safety equipment and additional contactors to save costs
- Reduced wiring effort and space requirements inside electrical cabinets
- Easier and faster fault tracking by sending status messages via fieldbus
- Password and logging function
- Increasing productivity through innovative safety concepts
- Easing machinery/plant design by providing certified safety components
- Easier machine certification thanks to pre-compliance with international standards
- Easier and faster control, since there is no need to power down the AC drive when a functional safety event occurs

***Note:** The VLT® and VACON® Safety Options expand the functional safety features of both drive series. Even speed safety functions can be realized without installing an encoder at the application (Open Loop functional safety). When the VLT® Safety Option MCB 151 is combined with the built-in VLT® Sensorless Safety MCB 159 option, an external sensor is no longer required for safe speed monitoring.*

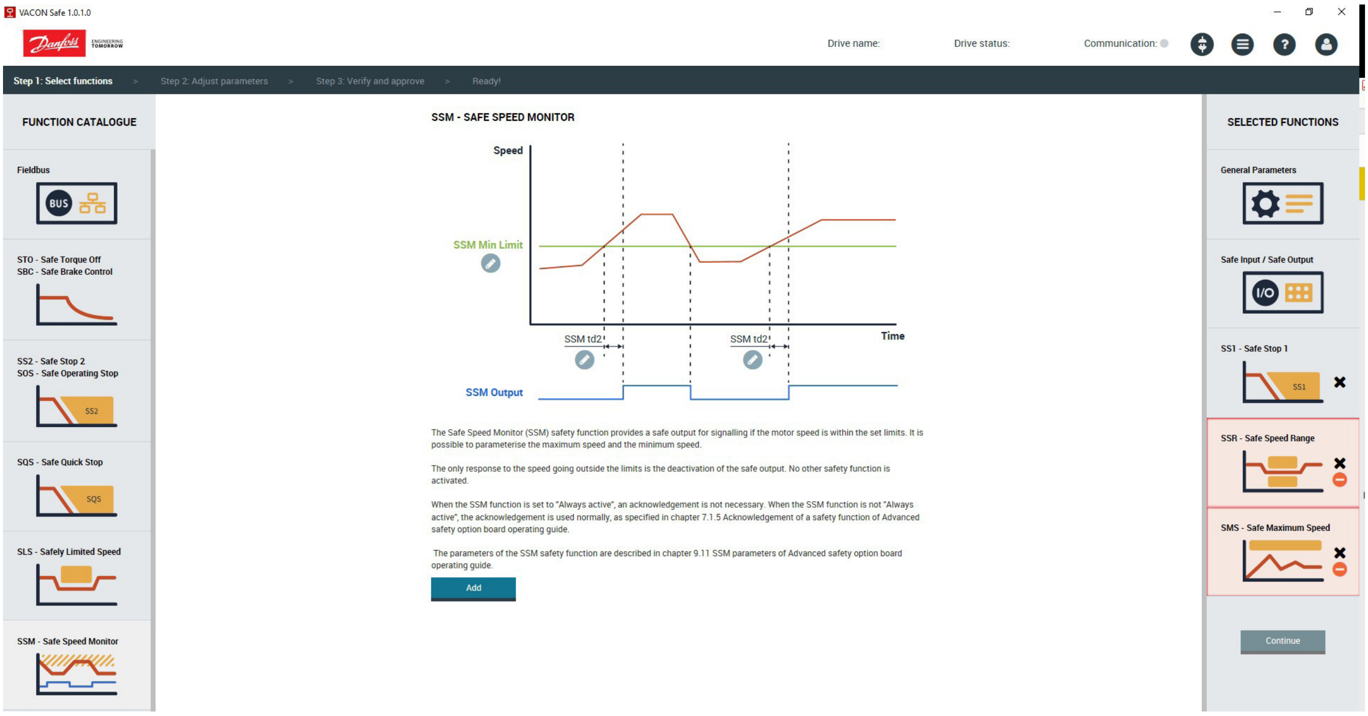


With modern AC drives it is possible to use flexible speed control in combination with dedicated functional safety features. The user can connect input devices – such as guard locking switches, light curtains and emergency stops – directly to the module and eliminate the need for a separate, dedicated safety controller.

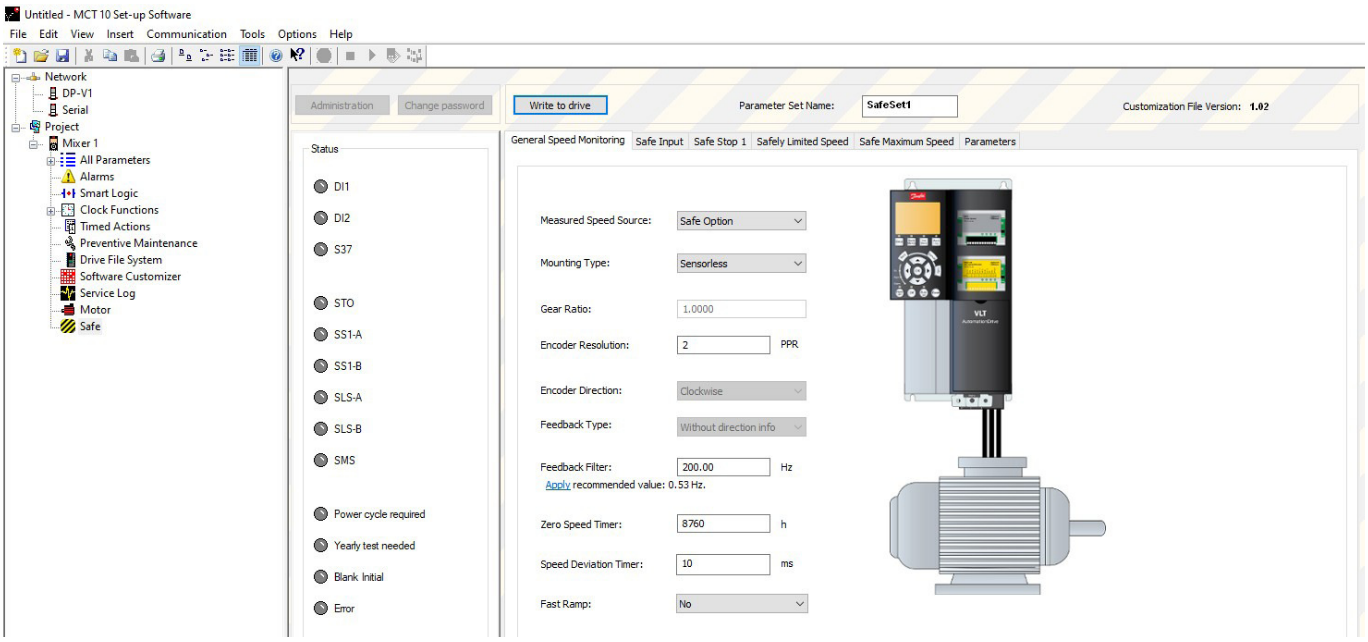
For commissioning and documentation purposes, many AC drives manufacturers provide dedicated PC tools for the users. It is worth to check for the user if these tools are available free of charge or if they are coming with some license costs.

***Note:** Danfoss Drives providing these tools (VLT® MCT 10 Safe-Plugin for MCT10 and VACON® Safe PC tool) free of charge. They can be downloaded from: https://suite.mydrive.danfoss.com/content/tools*

VACON® Safe



VLT® MCT 10 Safe-Plugin for MCT10



Available Functional safety Options for Danfoss Drives:

- VLT® AutomationDrive Safety Options: MCB108, MCB112, MCB150, MCB151, MCB152, MCB159 according SIL2, PLd, Cat. 3
- Vacon® Advanced Safety Options: OPT-AF, OPT-BL/BM/BN according SIL3, PLd, Cat. 3
- PROFIsafe through PROFIBUS and/or PROFINET

***Note:** Integrated functional safety reduces overall system cost, improves flexibility and increases productivity by enabling operators to perform maintenance safely, even while the machine is still in motion.*

Suitability of motors for AC drive operation

Selection criteria

The following aspects must be considered with regard to motor control with an AC drive:

- Insulation stress
- Bearing stress
- Thermal stress

Insulation stress

Operation of a motor with an AC drive stresses the motor windings more than with pure AC line operation.
This is mainly due to the high voltage slew rate dU/dt, as well as the motor cable depending on for instance the length, type, and installation.
The high voltage slew rate is caused by the fast switching semiconductors in the inverter of the AC drive. These switch at a high frequency in the range of 2-20 kHz with very short switching times to simulate a sinusoidal current waveform.

The voltage slew rate at the motor in conjunction with the motor cable is responsible for the following things:

- High pulse voltages ÛLL at the motor terminal increase the stress on the phase insulation.
- Higher pulse voltages ÛLE between the windings and the lamination stack increase the stress on the slot insulation.
- The higher voltage stress between the windings Ûwdg places a much greater stress on the wire insulator of the windings.

Bearing stress

Under unfavorable conditions, variable speed motors may fail due to bearing damage caused by bearing currents.
A bearing current flows when a voltage that is high enough to penetrate the lubricant insulation is present at the bearing lubrication gap. If this occurs, increasing bearing noise signals imminent failure. The types of bearing currents include high-frequency loop currents, ground currents and EDM currents (spark erosion).
Which of these currents lead to bearing damage depends on the following parameters:

- Mains voltage at the AC drive input
- Voltage slew rate dU/dt
- Type of motor cable
- Electrical shielding
- Grounding of the system
- Frame size of the motor
- Grounding system for motor housing and motor shaft

Bearing currents can be reduced by taking the following measures, for example:

- Using output filters (output inductors, dU/dt filters, sine wave filters and common mode filters)
- Using insulated bearings
- Good grounding connection of all metal parts of the system with low impedance
- Shielded motor cable

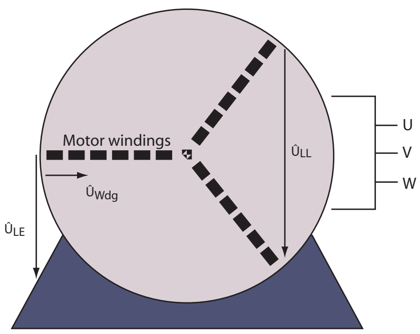
Note: *Ask the motor manufacturer to confirm that the motor is designed for operation with an AC drive; and the speed range in which it can be operated (min./max. speed).*
Note: Bearing currents arise from the overall system consisting of AC drive, motor, cable and grounding. IEC 60034-25 recommends that measures be taken at shaft heights of 315 mm (approximately 132 kW) and above.

Thermal stress

If the drive is not able to generate the full mains voltage at the rated line frequency, we recommend that the motor insulation be designed in thermal class F. The motor temperature increases by up to 10 K at lower motor voltages compared to pure AC line operation.

Overmodulation can increase the maximum output voltage of the AC drive, for example to compensate for voltage drops due to sine wave filters or to increase the torque of the motor at speeds above the rated speed. Heating of standard motors (up to frame size 315) is then within the range of additional heating due to grid tolerances and is therefore negligible. With transnorm motors (frame size 355 and up), however, manufacturers sometimes specify a derating.

Overmodulation leads to small torque ripples on the motor shaft. These can lead to undesirable mechanical vibrations. In ventilation systems, for example, system-related mechanical resonances can occur. Users should test the system during commissioning. Particularly with critical applications, the manufacturers should be consulted before long-term use.



Pulse voltages occur in the motor at the motor terminals ÛLL and between the windings and the lamination stack ÛLE. There is also a voltage stress between each wire Ûwdg of the motor winding.

Output filters

Sine wave filter, All-mode filter or dU/dt filter

Output filters include sine wave filters dU/dt filters and All-mode filters. In contrast to sine wave filters, dU/dt filters only have the task of reducing the voltage slew rate.
They have a smaller footprint, a simpler design than sine wave filters (lower L and C values) and are therefore lower priced.
Sine wave filters, also known as motor filters or LC filters, work optionally on the output side of AC drives.
They smooth out the rectangular voltage pulses at the output to an almost sinusoidal output voltage.

Functions and tasks of sine wave filters
Sine wave filters are designed to let only low frequencies pass. High frequencies are thus filtered out, and the current and voltage become almost sinusoidal. With the sinusoidal waveforms, it is no longer necessary to use special AC drive motors with reinforced insulation. Acoustic switching noise is also attentuated. The sine wave filter reduces the stress on the motor insulation and bearing currents in the motor. This extends motor life and maintenance intervals. As the filter does not act between the motor phases and ground, it does not reduce the leakage currents in the cables. The motor cable length is therefore not extended.

- Reduces the voltage slew rate dU/dt at the motor terminals
- Reduces the peak voltages ÛII
- Acoustic swithcing noise from the motor
- Reduces motor dissipation
- Reduces electromagnetic emissions from motor cables by reducing high frequency harmonics in the cable

Sine wave filters are used in the following applications:

- Applications where acoustic switching noise from the motor must be reduced
- Retrofitting in systems with old motors with inadequate insulation
- The causes of bearing currents are manifold; effective countermeasures include sine wave filters that reduce loop currents
- Applications in which the motor is installed in an aggressive environment or runs at high temperatures
- Applications with motor cables up to 150 meters/492 feet long (with shielded cables) and up to 300 meter /984 feet long (with unshielded cables) The use of motor cables longer than 300 meters/984 feet depends on the application. For longer motor cables use All-mode sine wave filter.
- Applications in which the maintenance interval of the motor must be extended
- Always when non-inverter rated motor is used (consult the motor manufacturer)
- Applications with regenerative braking to limit high peak voltage

Subsequent installation/retrofitting
If an operator converts a system with older motors that previously ran directly from the AC line to variable speed control and retrofits them with an AC drive, using a sine wave filter is generally recommended unless it is certain from the motor data sheet that the winding is designed for AC drive operation.

As part of the conversion measures, it often makes sense to replace old, low-efficiency motors with new, energy-efficient motors suitable for AC drives. In these cases, an additional sine wave filter is not required. The new motor usually pays for itself very quickly, due to the lower energy costs.

Reducing bearing currents
Bearing currents reduce the lifetime of motor bearings. In order to reduce bearing currents, IEC 60034-25 recommends taking measures.
Sine wave filters reduce loop currents (bearing to bearing currents); common mode filters reduce high-frequency common mode interference against ground. Loop currents (bearing to bearing currents) are slightly reduced by dU/dt filters; high-frequency common mode ground noise can be reduced by common mode filters.
In addition to using the mentioned filters, a faultless EMC installation is absolutely necessary.

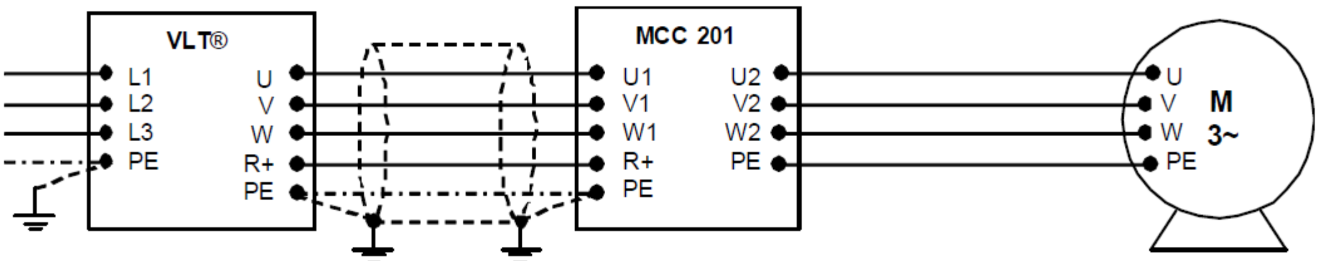
All-mode filter

All-mode sine wave filters, also known as all-mode filters, are dual-mode low-pass sine-wave filters operating in differential mode and common mode. These filters suppress the switching frequency component from the AC drive and smooth out both the phase-to-phase and phase-to-ground output voltages to become sinusoidal. This technology uses reduction of differential mode and common mode interference at the AC drive output to make extremely long motor cable lengths possible. This filter also supports the use of unshielded motor cables.

Through the connection to the intermediate circuit of the AC drive, the common-mode currents return to the source of the AC drive. This configuration is highly effective at preventing this high-frequency interference current from spreading across the electrical installation. Inverter-based bearing currents in the motor may be caused by the common-mode voltage from the AC drive IGBT output stage. All-mode filters provide a real solution to those effects, for all practical purposes eliminating the common mode distortions, which considerably extends motor lifetime. To connect a common-mode filter the AC drive requires a DC-link connection for common-mode feedback.

Advantages:

- Enables the use of longer cable lengths than otherwise limited by the AC drive and the integrated EMC filter, with up to 1000 meter / 3280 feet unscreened motor cable
- Enables use of unshielded motor cables, still observing AC drive radiated emission class
- Reduces acoustical switching noise from motor
- Improves conducted emissions
- Reduces motor bearing currents
- Reduces motor insulation stress
- Extends motor service lifetime
- Terminals for motor cable connections can accommodate increased cable cross sections, reducing voltage drop for long cable operation



Connection diagram and wiring of an All-mode sine wave filter

> ***Note:*** *The VLT® All-mode sine wave filter MCC 201 program is designed for the VLT® AutomationDrive as a supplement to the existing VLT® program of motor protection filters, the sine-wave filters, the du/dt filters and the common-mode filters. All-mode sine-wave filters are available in the current range 6-65 A nominal current at 380-440 V and 5.5-62 A nominal current at 441-500 V.*

dU/dt filter

dU/dt filters have lower L and C values and are therefore less expensive and smaller than sine wave filters. With a dU/dt filter, the voltage waveform is still pulse-shaped but the current is sinusoidal. dU/dt filters reduce the voltage slew rate of the pulses at the motor terminals, typically to approximately 500 V/µs.

Danfoss recommends using dU/dt filters for the following applications:

- Applications with frequent regenerative braking
- Motors that are not designed for AC drive operation
- Motors that are installed in aggressive environments or are operated at high temperatures
- Applications with flashover hazard
- Systems with old motors (retrofitting) or universal motors
- Applications with short motor cables (less than 15 m), as the rise time is short, resulting in high dU/dt values. These can cause a damagingly high potential difference between the windings in the motor, which can lead to insulation breakdown and flashover.
- 690 V applications

Output filters IP20 (left) or IP00 (right) reduce the peak voltage Upeak and the voltage slew rate dU/dt of modern AC drives to protect the insulation of the motor.

Common mode filter

Common-mode filters reduce electromagnetic interference and reduce motor bearing damage by electrical discharge. Installed around the three motor phases (U, V, W), they reduce high-frequency common-mode currents. As a result, high-frequency electromagnetic interference from the motor cable is reduced. However, common-mode filters should not be used as the sole mitigation measure, and even when the common-mode filters are used, the EMC installation rules must be followed. The most important function is to reduce high-frequency currents associated with electrical discharges in the motor currents.

These discharges contribute to the premature wear-out and failure of motor bearings. By reducing or even eliminating discharges, bearing wear is reduced and their lifetime extended. Thus, maintenance costs and downtime are reduced.

Install common-mode filters at the AC drive output terminals (U, V, W) or in the motor terminal box. When installed at the AC drive terminals, use the HF-CM kit to reduce bearing stress and high-frequency electromagnetic interference from the motor cable. The number of cores typically depends on motor cable length and AC drive voltage.

Note: *VLT® Common Mode Filters MCC 105 (HF-CM) cores are special nanocrystalline magnetic cores which have superior filtering performance compared to regular ferrite cores. They act like a common-mode inductor (between phases and ground), and are best suited to high-frequency content of the current.*

Common mode filter

Overview of output filters

	All-mode filter	dU/dt filter	Sine wave filter	Common mode filter
Stress on motor insulation	Reduce stress on motor insulation - Provides a sinusoidal phase-to-phase motor terminal voltage.	Reduced	Reduced - operation with long motor cables possible. Provides a sinusoidal phase-to-phase motor terminal voltage. Usually suited for general purpose motors with cables up to 500m (1km for VLT frame size D, E and F).	No reduction
Stress on motor bearings	Reduce common mode currents	Slightly reduced	Reduces loop currents, but not common mode currents	Reduces common mode currents
Electromagnetic compatibility	Reduce overshoot in motor cables. Secure AC drive EMC classification even with very long unshielded motor cables	No change in EMC classification	No change in EMC classification	Reduces high-frequency emissions (above 1 MHz). No change in EMC classification.
Max. motor cable length EMC-compliant		Manufacturer-dependent.	Manufacturer-dependent. FC 302: max. 150 m/492feet shielded With guaranteed EMC performance: 150m screened and 300m unscreened. Without guaranteed EMC performance: up to 500m (1km for VLT frame size D, E and F)	Manufacturer-dependent. FC 302: max. 150 m/492feet shielded motor cable
Max. motor cable length not EMC-compliant	Manufacturer-dependent. FC 302: up to 1000 m/3280 feet unshielded motor cable	Manufacturer-dependent. FC 302: max. 150 m/492feet unshielded motor cable	Manufacturer-dependent. FC 302: max. 300 m/984 feet unshielded motor cable	Manufacturer-dependent. FC 302: max. 300 m /984feet unshielded motor cable
Switching noise at the motor	Reduced	No influence	Reduced	No influence
Relative to drive size	100%	15-50% (power-dependent)	100%	5-15%
Voltage drop	4-10%	0.5%	4-10%	None

Motor efficiency

Minimum efficiency performance standards (MEPS) for motors

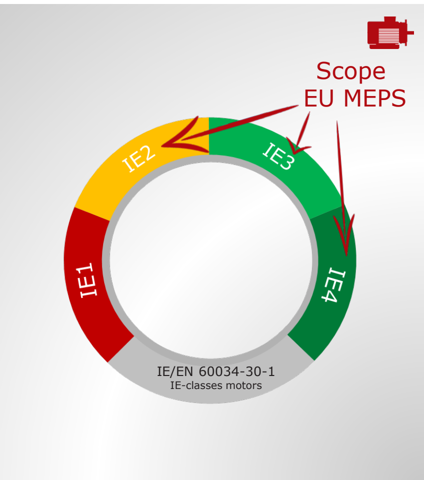
Mandatory minimum efficiencies
For greater energy efficiency in plants, the EU has developed a number of new regulations that also encompass the efficiency of the deployed motors.

Mandatory minimum efficiency performance standards (MEPS) for three-phase induction motors have been in force in the EU since the summer of 2011. EU legislation provides for a gradual increase in motor efficiency performance standards by 2023. The minimum efficiency performance standards (MEPS) are based on the internationally recognized International Efficiency (IE) classes defined in IEC 60034-30.

Affected three-phase motors
Compliance with MEPS is mandatory for the following three-phase induction motors:

- Operating mode S1 (continuous operation) or S3/S6 (intermittent operation) with a duty cycle (ED) above 80%
- Pole number 2 to 6 (8 pole from 2021)
- Power range 750 W to 375 kW (0,12 kW to 1000 kW from 2021)
- Rated voltage up to 1000 V

The introduction of MEPS is intended to contribute to energy savings. However, in rare cases the solution may also consume more energy. For this reason, EU Regulation No. 640/2009 includes technically reasonable exceptions for various application areas. Among these are:



- Motors in explosion-protected areas (within the meaning of ATEX Directive 2014/34/EU) and brake motors. Ex eb motors will be included from 2023.
- Special motors intended for one of the following operating conditions:
  – Ambient temperatures above 60°C [140°F]
  – Ambient temperatures below 15°C [59°F] (air-cooled motors 0°C [32°F])
  – Operating temperatures above 400°C [752°F]
  – Cooling water temperatures lower than 5°C [41°F] or higher than 25°C [77°F]
  – Operation over 4000 m [13123 feet] above sea level.
- Motors that are completely integrated into a product, such as gearboxes, pumps or fans, or that are operated completely in a liquid medium, such as submersible pumps

With geared motors in Europe, the motor is not considered an integral part and is measured separately.
The procedure for special motors is similar. The base motor is measured, and the efficiency class is assigned to variants of the motor.

Alternatives to required IE3 motors
As an alternative to the planned IE3 classes, users can also use IE2 motors powered by an AC drive. The user must ensure compliance with the IE3 class or the alternative IE2 class with the AC drive at the point of putting into service. From 2021 the MEPS alternative will be omitted. From this point in time motors has to comply with MEPS according the table below.

Motor compatibility
The new high efficiency classes can lead to a larger frame size for IE2 , IE3 and IE4 motors. This can be particularly problematic when replacing older motors if there is not enough space available to use existing mounting points.

Geared motors
The use of energy-efficient electric motors for the operation of gearboxes is standard today. Depending on the manufacturer, users can choose from several efficiency classes for their drive motor. However, the efficiency class of the motor relates only to the motor and not to the combination of gearbox and motor.

Selection of the gearbox type offers a considerable potential. Spur gears and bevel gears are generally significantly more efficient than worm gears. If the operator chooses compact bevel gears instead of worm gears, the initial capital expenditure is higher. However, the payback time is usually short due to the higher efficiency and reduced flank wear.

Geared motors in particular are ideal for operation with AC drives.
On the one hand, the drive optimizes the operation of the electric motor, and on the other hand, it allows the operator to omit mechanical multi-speed gearboxes.

Ecodesign for motors
Regulation (EG) 2019/1781 define MEPS for electrical motors based on IEC/EN 60034-30-1

The requirements apply to most induction motors fulfilling these criteria:

- Nominal frequency 50 Hz, 60 Hz or 50/60 Hz
- Operation at sinusoidal voltage
- Power range 0.12 – 1000 kW
- Nominal voltage up to 1000 V (1~ und 3~)
- Duty type S1, S3 or S6 (ED >=80%)
- 2 to 8 poles
- Altitude up to 4000 m
- Ambient temperature limits up to 60°C
- Ambient temperature -30°C or 0°C for water-cooled motors

IE classification of motors

Advantage of PM motors – higher energy efficiency
As it is becoming increasingly difficult to achieve ever higher efficiencies with three-phase induction motors, permanent magnet synchronous motors (PM motors) will gain in importance in the future.

PM motors are synchronous motors with permanent magnets, usually attached to the rotor. These types of motors have been used for quite some time in mechanical engineering, particularly in highly dynamic applications in the form of servo drives. Compared to induction motors with similar efficiencies (e.g. IE 3 or IE4), PM motors are often more compact. Falling prices for the permanent magnets used in PM motors make them attractive, even for applications with less dynamic requirements.

However, with the PM motors now emerging for industrial applications, another aspect is at the forefront – energy savings. Their greater efficiency compared to induction motors ensures higher energy efficiency in the system. In addition, they offer several advantages such as (in many cases) a smaller frame size with the same power, lower dissipation, lower inertia, a large torque range and a large speed range.

To facilitate the use of this high efficiency in less dynamic applications such as fans or pumps, PM motors in standard IEC sizes are now entering the market. They are optimized for energy efficiency instead of high dynamic performance, and along with easy integration into new systems without complex new design, they often allow retrofitting in existing systems.

Read more about Ecodesign

MyDrive® ecoSmart™ calculation tool

Energy cost advantage of an IE motor to the next better IE class

Whether or not replacing three-phase induction motors with PM motors will pay off economically depends on many factors. In relevant analyses, the operator should of course consider maintenance and spare motor concepts in addition to procurement, conversion and energy costs.

Note: *EU Regulation No. 640/2009 can be downloaded free of charge from www.eur-lex.europa.eu.*

VLT® AutomationDrive: Optimum control of PM motors
Danfoss offer improved control algorithms for PM motors, because the rotor angle is required for control of PM motors. Danfoss has, for example, developed an open-loop solution for this in which the angular position of the rotor is determined during initialization. All things considered, commissioning a PM motor is no more complex than the well-known process for induction motors.

MEPS timeline

Year introduced	Minimum Efficiency Performance Standard in Europe			
	Motors [1], [2]		Drives	
	Class	Power range	Class	Power range
2017	IE3/IE2 and VSD[3]	3~ 0.75-375 kW	No requirement	0.12-1000 kW
2021	IE2	3~ 0.12-0.75 kW	IE2	0.12-1000 kW
	IE3	3-phase: 0.75-1000 kW		
2023	IE2	single-phase: ≥0.12 kW	IE2	0.12-1000 kW
	IE3	3-phase: 0.75-75 kW and 200-1000 kW		
	IE4	3~ 75-200 kW		

[1] For 3-phase motors (2/4/6 pole). Also 8-pole motors from 2021 onwards. Class IE2 will apply to single-phase and Ex eb motors from 2023. IE4 only for 2-, 4- and 6-pole motors.
[2] Part-load losses for AC drive operation must be provided from 1 July 2022 onward.
[3] IE2 + AC drive as an alternative to IE3 motors

Danfoss drives fulfill all requirements regarding IE2 classification for AC drives.

Good practice - motor cables

Rated voltage class
Peak voltages up to three times the DC-link voltage of the AC drive occur in the motor cable. These heavily stress the motor cable and the motor insulation. The stress is greater if no dU/dt or sine wave filters are installed at the output of the AC drive.

For this reason, motor cables should have a rated voltage class of at least U0/U = 0.6/1 kV. Cables of this class are usually high-voltage tested with a voltage of at least 3500 V AC (usually 4000 V AC) and have proven to have sufficient dielectric strength in practice.

Cable dimensioning
The required cross-sectional area of the motor cable depends on the output current of the AC drive, the ambient temperature and the type of cable routing. Overdimensioning of the cable cross-section due to harmonics is not necessary.

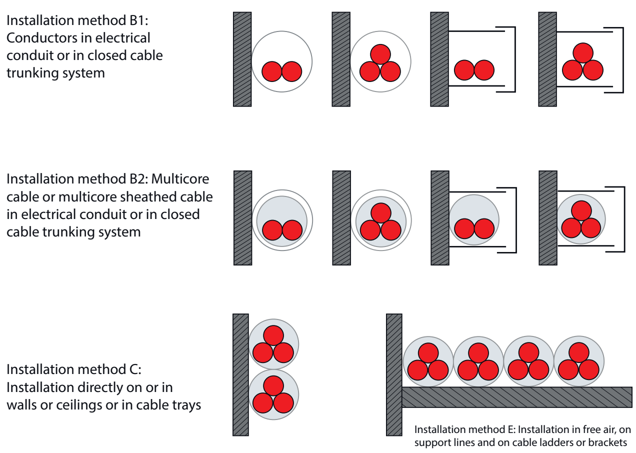
For selection and dimensioning of cables and conductors, EN 60204-1 / VDE 0113-1 provides current carrying capacity data for cable cross-sections up to a maximum of 120 mm^2. If larger cable cross-sections are required, useful information can be found in VDE 0298-4.

Motor cable length
Long motor cables are often found in chemical and pharmaceutical plants. Pumps and AC drives are often installed more than 100 m apart. The voltage drop over the length of the cable must be taken into account in project engineering. Plan the system so that the full output voltage reaches the motor even with long motor cables. The average motor cable length that can be connected to typical AC drives is between 50 and 100 meters (164-328 feet). Even then, the full output voltage is no longer available with units from some manufacturers. If users require cable lengths of more than 100 m / (328 feet), there are few manufacturers who meet this requirement as standard. Otherwise the user must provide additional motor inductors or output filters, which also increase the voltage drop.

Energy savings
The voltage drop and (heat) dissipation of a cable are approximately proportional to its length and are frequency dependent. Cable paths should therefore be kept as short as possible, and cable cross-sections should not be dimensioned larger than electrically necessary.

Cables with suitable shielding
Shielded cables should have a shield coverage of at least 80%. Examples of suitable cable types:
- Lapp Ölflex 100-CY
- Helu Y-CY-JB
- Helu Topflex-EMV-UV-2YSLCYK-J

Note: *Ask the AC drives manufacturer about the cable length that can be connected to the AC drive and the expected voltage drop.*
Note: *You can connect shielded cables up to 150 m / 492 feet and unshielded cables up to 300 m / 984 feet to the AC drives in the VLT® AutomationDrive series as standard, with full voltage at the motor.*



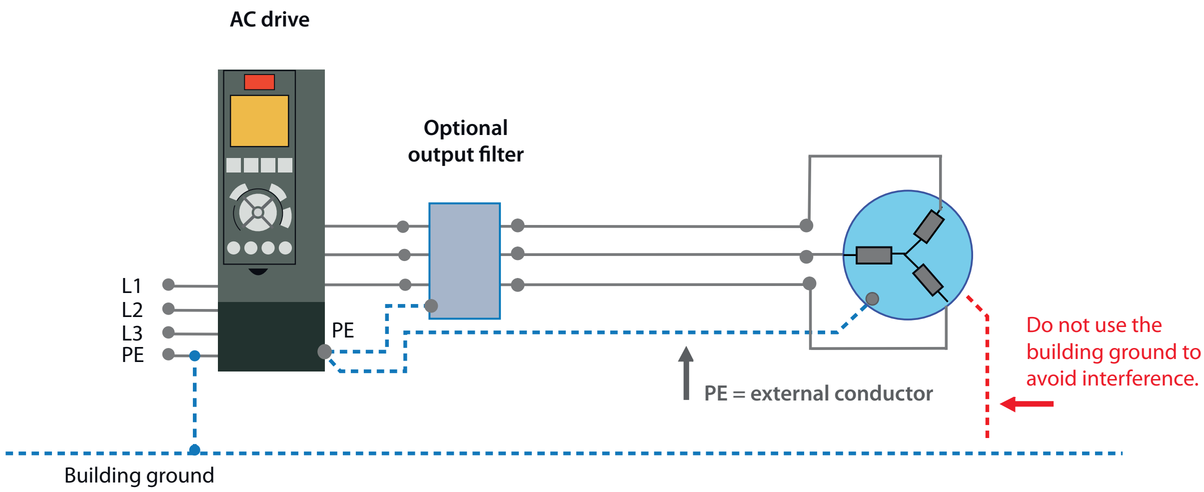
Current carrying capacity [A] at Tamb 40°C				
Installation method / mm^2	B1	B2	C	E
1	10.3	10.1	11.7	12.4
1.5	13.5	13.1	15.2	16.1
2	18.3	17.4	21.0	22.0
4	24.0	23.0	28.0	30.0
6	31	30.0	36.0	37.0
10	44.0	40.0	50.0	52.0
16	59.0	54.0	66.0	70.0
25	77.0	70.0	84.0	88.0

Excerpt from EN 60204-1, Current carrying capacity of cable cross-sections

Good practice - Grounding measures

Importance of grounding measures

Grounding measures are generally mandatory for compliance with the statutory regulations of the EMC and Low Voltage Directives. They are a prerequisite for the effective use of additional measures such as shielding or filters. Without good grounding, additional actions are useless. When retrofitting shielding and filters and for troubleshooting, EMC-compliant grounding should be checked and ensured first.



A grounding plan should always be drawn up for each system.

Conductive materials
Operators must ensure that metallic surfaces are connected to ground with low impedance. For EMC measures, what matters is not the cross-sectional area of the cable but instead the surface area, which is where the high-frequency currents flow due to the skin effect. The location with the smallest surface area limits the discharge capacity. Grounded surfaces provide shielding and reduce electromagnetic fields in the surrounding area.

Star-shaped grounding system
The motor should be grounded to the drive, which then is connected to the central grounding point, for example an equipotential bonding rail. This central grounding point must be clearly defined.

Contact points
Contact points must be connected over a large area that is free of paint and corrosion. Serrated washers are more suitable than plain washers. The use of tinned, or galvanized fittings is preferable to painted parts. Several contacts for shield connection must be provided in connectors.

Conductor surface
Large conductor surface areas for discharging high-frequency currents can be obtained with fine-stranded conductors, for example very flexible test lead wires or special grounding straps or cables. In practice, braided grounding straps are often used now instead of rigid conductors as in the past. These straps have a significantly larger surface area with the same cross-sectional area.

Note: *Grounding of a system has a significant influence on trouble-free and interference-free operation of the system. Ground loops must be avoided. Good equipotential bonding is an indispensable prerequisite. Generate a suitable grounding plan during the planning and project engineering phase.*
Note: *Additional information can be found in our guide for EMC installation measures for AC drives.*

Execution
To ensure adequate grounding, the grounding measures described here must be observed in practice.

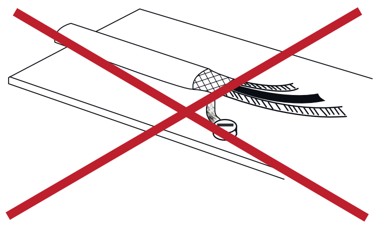
Shielding measures

Importance of shielding measures

Shielding measures serve to reduce the radiated interference energy (influencing neighboring systems and components) and improve the immunity of the device itself (immunity to external influences).

If implemented afterwards, it will be at a higher cost (for example cable replacement or additional enclosure). As a rule, manufacturers of AC drives provide information on compliance with legal limits, including information on additional measures required (for instance shielded cables). AC drives generate very steep-edged pulses at their outputs. These contain high-frequency components (up to the GHz range) which lead to undesirable radiation via the motor cable. Therefore, the motor cables must be shielded. The shield has the task of „trapping“ the high-frequency components and returning them to the source of the interference, in this case the AC drive.

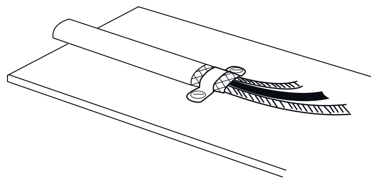
Shielded cables and conductors
Even good shielding that complies with the limits does not completely eliminate radiation. Electromagnetic fields, which components and equipment placed in the vicinity must withstand without functional impairment, are to be expected at close range.



Wrong

With regard to the permitted limits, the standard distinguishes between use in the first environment (residential) and the second environment (industrial). For details, see the "***Limits by location***" .

Shield connection
Effective cable shielding can only be achieved with all-round shield contact. For this purpose, EMC or grounding glands are used, as well as well as grounding clamps that completely enclose the shield and connect it to ground over a large area. The shield must be routed to the grounding point and clamped over a large area; it must be kept as short as possible at the cable ends.



Right

All other contact measures reduce the effectiveness of the shield.
Users often twist the cable shield together at the end (pigtails) and connect it to ground via a terminal. This type of connection presents a high contact impedance for the high-frequency components and not only returns interference to the source less effectively, but also emits it from the shield. This can reduce the shielding effect by up to 90%.

Shield gaps
Shield gaps, for instance at terminals, switches or contactors, must be bridged as much as possible with low impedance, large area conductors.

Shielding measures

Ground connection
The ground connection of a shield has a significant influence on its effectiveness. When mounting chassis, it is therefore necessary to use serrated washers or spring washers beneath screw heads and to scratch painted surfaces clean to the bare metal, in order to obtain a low transition impedance. Anodized aluminum chassis, for example, do not provide an adequate ground connection when plain washers are used under the mounting screws. Grounding cables should be made with the largest possible cross-sectional area, or even better, using braided grounding straps or Litz-wire conductors. If conductor cross-sections less than 10 mm² are used with low motor power, a separate PE conductor of at least 10 mm² must be routed from the drive to the motor.

Motor supply cable
To comply with the radio frequency interference limits, cables between the AC drive and the motor must be shielded according to the manufacturer's specifications, and the shield must be bonded at both ends.

Signal cable
The distance between motor cable and signal cable should be more than 20 cm / 8 inch. If possible, power and motor cables should not be routed next to each other. The level of interference decreases significantly with increasing distance. At relatively small distances, additional measures (for example partitions) are essential. Otherwise interference can be coupled in or transmitted.
Like motor cables, control cables should be bonded at both ends.
In practice, single-ended bonding could be an option in exceptional cases. However, this is not recommended.

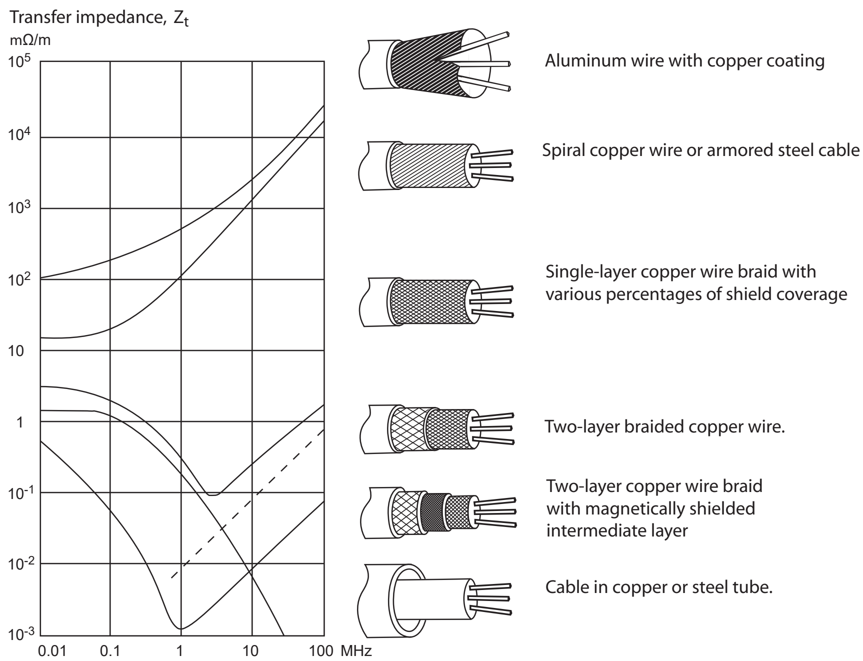
Shield types
Manufacturers of AC drives recommend shielded cables for shielding the conductors between the AC drive and the motor. Two criteria are important for selection: shield coverage and shield type.

The shield coverage, meaning the area of the cable covered by the shield, should be at least 80%.
A single-layer copper braid has proven to be an extremely effective type of shielding. It is important that the shield is braided. A shield made of wound copper wire (for example type NYCWY), by contrast, leaves long slits uncovered, from which HF components can escape unhindered. In addition, the surface area for the leakage current is significantly smaller.

Shield braid is available in bulk for retrofitting by pulling it over the cable. Alternatively, metal tubes or pipes can be used for short connections. Cable ducts can replace shielding only under certain conditions (radiation-tight duct, good grounding of lids and duct parts).

Double shielded cables further improve the attenuation of radiated and coupled-in interference.
The inner shield is connected at one end, and the outer shield at both ends. Twisted wires reduce magnetic fields. Cables with double shielding and twisted wires can be used for signal cables. The attenuation of magnetic fields increases from about 30 dB with single shielding to 60 dB with double shielding, and to about 75 dB with twisted wires in addition to shielding.

Shield as ground conductor?
Do not use the shield as a ground conductor.



There are many types of shielded cable. Not all are suitable for AC drive operation.

Implementing EMC measures

From theory to practice

All AC drives are broad-range disturbers, which means they transmit noise over a wide frequency range. System operators can reduce the noise radiation of AC drives by taking suitable measures. In this way, they can ensure trouble-free operation in the system by using RFI filters and line reactors or DC reactors. These are already installed in some AC drives. For others, the plant engineer must provide additional, scarce and valuable space in the cabinet. General information on EMC, low-frequency mains harmonics and radio frequency interference can be found in this guide.

Note: *High-quality AC drives are as standard equipped with high-quality measures for RFI suppression and reduction of mains harmonics. These measures account for approximately 15 to 20% of the price of an AC drive.*

Radio frequency interference

Practical recommendations
What matters in practice is stable running systems in which the components do not interfere with each other. Nevertheless, it often happens that sensitive measurements are no longer possible without interference and/or measurement signals are distorted after conversion tasks and the introduction of new components. It is precisely these cases that must be avoided. To achieve a high degree of interference immunity, it is therefore advisable to use AC drives with high-quality RFI suppression filters. This should comply with category C1 according to the product standard EN 61800-3 and thus take the limits of the generic standard EN 55011 according to class B into account. When using RFI filters which do not correspond to category C1, but only to categories C2/C3/C4, additional warning notices must be attached to the AC drives.

In the event of interference, the testing agency always uses the A1/2 and B limit values of the generic standard EN55011 corresponding to the operating environment as the basis for eliminating interference.
The cost of eliminating EMC interference is borne by the operator. Ultimately, the operator is directly responsible for the right assignment of the classes in these two standards.
Due to the cable transmission path, conducted interference can quickly spread to different areas of an installation if inadequate measures are taken. By contrast, EMC interference emitted through the air by the device and the cable is spatially bound.
The intensity decreases with every centimeter of distance from the interference source. EMC-compliant installation of a drive in a suitable cabinet, for example, is therefore usually sufficient to limit radiated interference. However, the operator should always provide a suitable filter for conducted interference.

In practice, there are two approaches for RFI filters. There are manufacturers who install RFI filters in the device as standard, and manufacturers who offer filters as an option. Not only do built-in filters save a lot of space in the cabinet, they also eliminate additional costs for installation, cabling and material. The main advantage, however, is the perfect EMC coordination and cabling of integrated filters.
External EMC filters installed as an option upstream of the AC drive present an additional voltage loss. In practical terms, this means that the full mains voltage is no longer applied to the AC drive, and overdimensioning may be necessary. Costs are incurred for installation, cabling and material. EMC coordination is not tested; the responsibility lies with the installer. The maximum connectable motor cable length with which the AC drive still complies with the EMC limits is also important. In practice, this ranges from 1 m/3 feet to 50 m /164feet. Increasing motor cable lengths require better RFI suppression filters.

Note: *An AC drive with a category C1 RFI filter is generally recommended for trouble-free operation of the power drive system.*
Note: *The VLT® AutomationDrive series is supplied with a built-in RFI filter as standard, which corresponds to category C1 (EN 61800-3) for 400 V grids and motor power up to 90 kW and to category C2 for 110 to 630 kW. The VLT® AutomationDrive complies with C1 (conducted) up to max. 50 m / 164 feet and C2 up to max. 150 m / 492 feet of shielded motor cable.*

Mains harmonics

The DC link influences mains harmonics
The increasing use of non-linear loads intensifies the occurrence of mains harmonics. These loads draw non-sinusoidal currents from the grid. Mains harmonics in AC drives are primarily caused by the charging currents for the DC link capacitors. The currents always flow only briefly near the peaks of the mains voltage. Due to the very strong current, the mains voltage collapses for a short time, and the sinusoidal shape of the mains voltage is lost. The requirements are described in the EN 61000-3-12 standard.
In applications where the operator must reduce the mains harmonics to THDi values below 10% or 5%, optional filters and active measures offer possibilities for almost fully attenuating mains harmonics.

Reduction measures
In order to limit mains harmonics, the system operator has various options at their disposal. They can be subdivided into passive and active measures and differ particularly in terms of project engineering.

Line reactors (AC or DC inductors)
The most common and cost-effective way to reduce mains harmonics is to install additional inductors, either in the DC link or at the input of the AC drive. A line reactor in the AC drive extends the current flow for charging the DC link capacitors, reduces the current amplitude and significantly reduces the distortion of the mains voltage (fewer mains harmonics). High-energy, transient voltage peaks are dampened. In the event of brief voltage drops, large charging currents can flow into the intermediate circuit capacitors of the AC drive. Line reactors limit these current surges. In addition, the current ripple in the intermediate circuit is reduced, which has a positive effect on the service life of the DC link capacitors. The magnitude of the distortion of the mains voltage also depends on the quality of the grid (transformer impedance and line impedances). The values in the table below apply as a rule of thumb for the connected AC drive load (or other three-phase rectifier loads) relative to the supply transformer power. If the maximum values are exceeded, consult the manufacturer of the AC drive.

In addition to reducing mains harmonics, the line reactor increases the lifetime of the DC link capacitors by limiting peak currents to provide gentler charging. In addition, line reactors improve the dielectric strength of the AC drive with respect to electrical transients. Due to the lower input current, the cable cross-sections and protective devices can be smaller. However, the inductor is an additional cost and takes up space.

Note: *In AC drives of the VLT® AutomationDrive series, the line reactor is designed as a DC inductor and is always integrated in the device. This reduces the THDi from 80% to 40% and thus meets the requirements of EN 61000-3-12.*
The effect is comparable to that of an external three-phase line reactor (UK 4%). The AC drive compensates for the voltage drop over the DC inductor. The full voltage (400 V) is thus available to the motor (see also ***Suitability of motors for AC drive operation****).*

Please refer also to chapter ***Inductors*** *at the input or in the DC link.*

Maximum 20% AC drive load on the transformer for AC drives without measures for mains harmonics; this means unchoked or slightly choked (for example with U_K 2%)

Maximum 40% AC drive load on the transformer for AC drives with measures for mains harmonics; this means choked with at least U_K 4%

The above-mentioned maximum load values are recommended guidelines based on experience with trouble-free system operation, if no other harmonic mitigation solutions, e.g. passive or active filters, are in use.

Passive filters
Passive harmonic filters consisting of an LC circuit can be used universally. Their efficiency is high, typically around 98.5% or more.
The technology is very solid and usually maintenance-free, except for any cooling fans that may be present.
The following must be observed with passive filters:
When operated without a load, they act as a capacitive reactive power source due to filter-related loop currents. Depending on the application, it makes sense to group the filters and, if necessary, to switch them on or off selectively.

Active filter, Active Front End and low-harmonic drive
A new way is the use of active electronic filter systems. Based on improved semiconductors and modern microprocessor technology, these systems constantly measure the power quality and feed a compensating current into the grid by means of an active current source. The net result is restoration of a sinusoidal current.

The structure of this new generation of filters is relatively complex and more expensive in comparison to the previously mentioned filters because fast, high-resolution data acquisition and high processing power are required.

12-,18- and 24-pulse rectifiers
In practice, AC drives with rectifier circuits with a higher pulse rate are more likely to be found in the larger power range. A special transformer is required for operation.

Recommendation
There is no basic recommendation for any of the above-mentioned measures for reducing mains harmonics.
During the planning and project engineering phase, it is important to set the right parameters for a power drive system with high availability and low mains harmonics and radio frequency interference. In principle, the following applies:
Before deciding which of the above reduction measures to use, the following factors must be carefully analyzed:

- Grid analysis
- Detailed overview of the grid topology
- Available space in the electrical equipment rooms
- Capabilities of the main distribution or sub-distribution panels

A low harmonic AC drive is a combination of an AC drive and a built-in filter acting toward the grid.

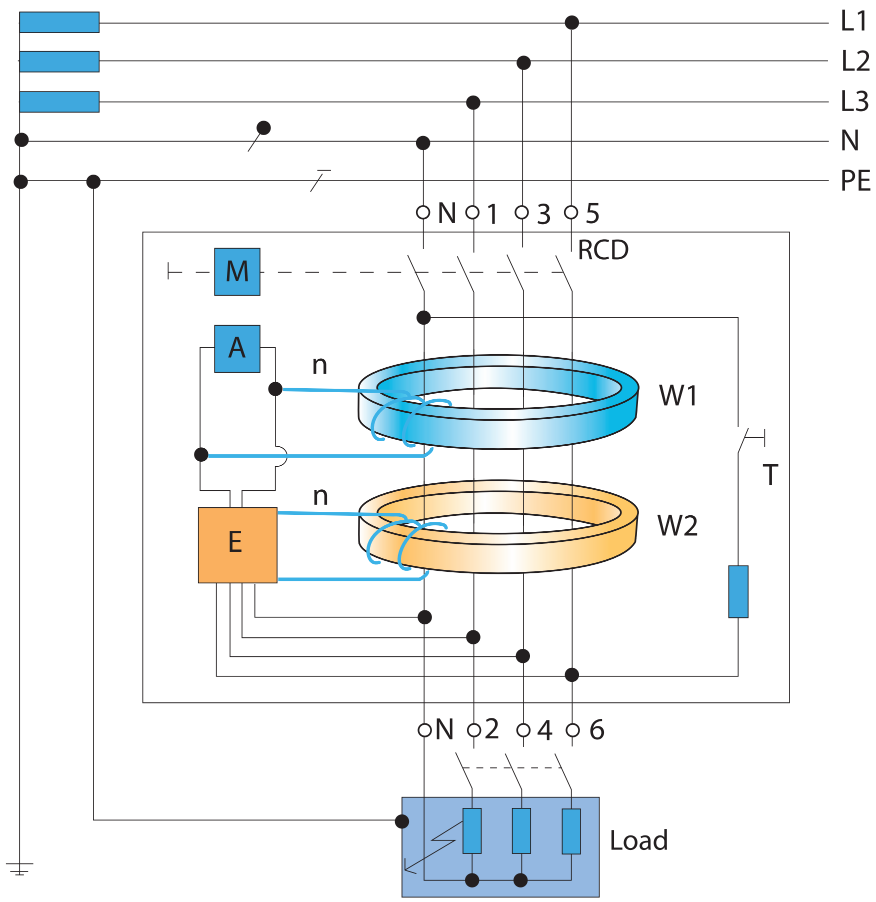
RCD

AC/DC-sensitive protective device

These devices are known as residual current operated circuit breakers (RCCBs). The generic term is residual current operated device (RCD) according to EN 61008-1.
RCDs with AC/DC sensitivity are required if devices that can generate a smooth direct current in the event of a fault are deployed in the area to be protected. This applies to all electrical equipment that uses a B6 rectifier bridge (for instance AC drives) on the three-phase grid.

According to IEC 60755, an AC/DC-sensitive RCD is designated as "Type B". Due to their design, AC drives produce ground leakage currents which the plant engineer and/or operator must take into account when selecting the rated residual current. Ask your AC drive manufacturer for a type of RCD suitable for your application.
The RCD must be installed directly between the supply network and the AC drive.

Magnitude of the leakage current
Various factors influence the magnitude of the leakage current.
As a general rule, the magnitude of the leakage currents in the AC drive and motor are a function which increases with the power.



AC/DC-sensitive RCDs have two separate monitoring circuits, one for pure DC and one for residual currents with an AC component.

Grounding and motor protection

Grounding measures in practice

The grounding measures are described in the "Motor and cabling" section. If the application requires external filters, these must be mounted as close to the AC drive as possible. The cable between the filter and the device should be a shielded cable, and the filter should be connected to the ground conductor on the grid and device sides. In addition, surface mounting of the filter is recommended, as well as a good conductive connection from the filter housing to ground.

RFI filters produce leakage currents that can rise considerably above the rated values in the event of a fault (phase fault or unbalanced load).

To avoid dangerous voltages, filters must therefore be grounded before power is switched on. AC drives generally generate leakage currents greater than 3.5 mA. According to EN 61800-5-1, if this limit is exceeded then:

- the protective conductor must be at least 10 mm²; or
- the protective conductor must be monitored for an open circuit; or
- PE wire should be part of a mains cable with an industrial connector; or
- an additional, second protective conductor must be installed.

Leakage currents are high-frequency interference. These require grounding measures with low impedance, large-area bonding and the shortest possible path to the ground potential.

Note: *Even the best measures with regard to mains harmonics and radio frequency interference are useless if the installer does not address EMC aspects during installation. In that case, interference is unavoidable.*

Note: *Due to the generated leakage currents exceeding 3.5 mA, EN 61800-5-1 prescribes special grounding measures.*

Motor protection and motor thermistor

AC drives provide motor protection against overcurrent. Thermistor sensors or thermal contacts in the motor winding are used for the best possible thermal motor protection. According to DIN 44081 or DIN 44082, thermistors are designed so that their resistance is within a specific range when their standard response temperature (SRT) is reached (SRT - 5°C [41°F] < 550 Ω; SRT + 5°C > 1330 Ω). Many drives have suitable functions for evaluating these thermocouples. For motors operated in explosion-hazard areas, thermistor evaluation is only permitted with certified triggering devices.

The device protection function of motor circuit breakers is limited to direct AC line operation. In systems with AC drives, they would only be able to provide motor protection in an emergency situation if the AC drive is equipped with a bypass circuit. The actual motor protection function of the switch is lost with AC drive operation. Nevertheless, if correctly dimensioned as a three-phase circuit breaker with a pure conductor protection function, it can also be reasonably used for motors operating from AC drives.

Note: *Many AC drives have a supplementary function: the thermal motor model. The motor temperature is calculated on the basis of the motor data and the power transferred to the motor. This function is usually very conservative and triggers too early rather than too late. The current ambient temperature at the start of the calculation is usually not taken into account. However, if no additional motor protection is available, this function is a simple way of providing basic protection for the motor.*

Note:
With the VLT® AutomationDrive, terminals 50 and 54 are provided as standard for the connection of thermistors. The connection is suitable for motor temperature monitoring with 3 to 6 PTCs.

Special case: multiple-motor operation

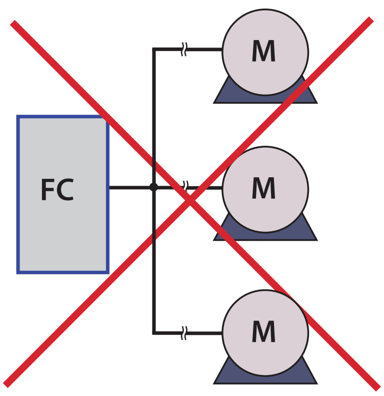
Design
If the operator intends to operate several motors simultaneously in parallel from one AC drive, the following applies to the design:

- The rated currents and powers of the individual motors must be added together.
- Selection of a suitable AC drive is based on the total power and total current.
- For motor protection, the operator must daisy-chain the motor thermistors and the AC drive evaluates this daisy-chained signal.
- The connected motors operate at the same rated speed. This means that the AC drive controls them all with the same frequency and voltage.
- Check the maximum motor cable length of all motors in parallel.
- Use a sine wave filter at the drive output.

***Note:** Due to the additive cold resistance of the winding thermistors connected in series, it is not advisable to use the thermistor evaluation function of the AC drive as a motor protection function for more than two motors operated in parallel.*
*Also observe the instructions on **motor protection***

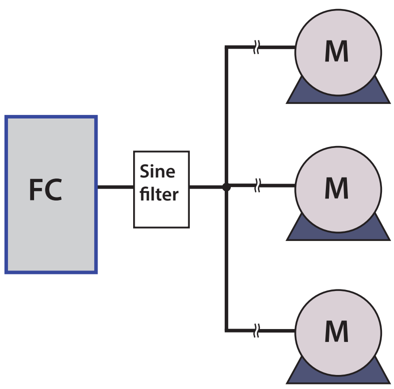
Cable routing

Avoid



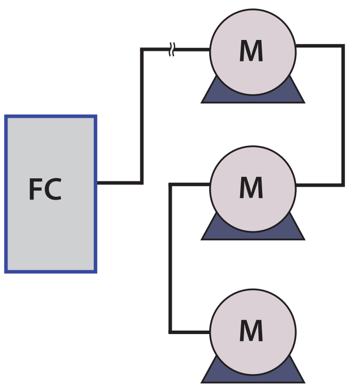
Avoid with multiple-motor operation: Parallel cables generate additional capacitance. The user should therefore always avoid this sort of connection.

Recommendation



The cable charge currents between phases are lower because an LC filter removes the switching frequencies. This allows parallel connection of motors, also with a longer parallel motor cable if necessary.

Recommendation



Recommended for multiple-motor operation: daisy-chain the motor cable from one motor to the next.

Design of AC drives

Basic design

In practice, planners and operators always design AC drives exclusively according to the power in kW. However, selection must be made on the basis of the respective rated motor current Inom at the highest load on the system. This selection criterion is safer because the motor power does not relate to the electrical power input, but instead to the mechanical shaft output. This means the motor efficiency is not taken into account. The kW specification of an AC drive, on the other hand, relates to the rated motor power Pnom of four-pole motors.
Motors also have different rated currents for the same power class, depending on the motor manufacturer and the efficiency class. For example, they range from 19.8 A to 22.5 A for an 11 kW motor.

Note: *An 11 kW AC drive of the VLT® AutomationDrive series has a rated current of 24 A with normal overload setting. This provides sufficient power reserve to drive a motor with a rated power of 11 kW.*

However, the rated current alone is not sufficient to achieve the corresponding electrical power input. For this, the AC drive must also provide sufficient motor voltage. In a 400 V power grid, this is the full 400 V at 50 Hz at the motor terminal board. There are still AC drives on the market that are unable to do this (see also ***Suitability of motors for AC drive operation***). Due to the voltage drop over filters, inductors and the motor cable, the output voltage at the motor is reduced, for instance to 390 V. In this situation, the motor needs more current to achieve the required power. The heat dissipation increases quadratically with increasing current, raising the motor temperature and reducing the motor lifetime. The user must also take the higher current demand into account in the design.

Note: *With the VLT® AutomationDrive, a special modulation process ensures full motor voltage. Even with up to 10% undervoltage on the grid, the rated motor voltage and rated motor torque are maintained.*

Constant or quadratic torque
The load driven by the motor is decisive for selection of the right AC drive.
A distinction must be made between loads with a torque characteristic that increases quadratically with speed and loads that can demand a high torque from the motor over the entire operating range, even at low speeds.

Applications with -constant torque include those where the load does not vary much with the speed. This includes conveyor belts, extruders and mixers. The energy required by this sort of system is proportional to the required torque and the speed of the motor.
If the speed can be reduced with a constant load, this results in direct energy savings. If speed adjustment is not possible or not desirable, energy savings can still be achieved with most AC drives. They control the output voltage to the motor depending on the load. The quality of this sort of control depends on the quality of the AC drive.

Applications with quadratic torque often involve pumps and fans, which means continuous flow machines. With these machines, the required energy can be decreased cubically by reducing the speed.

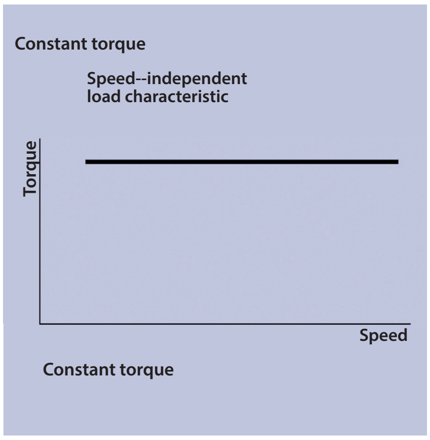
To avoid surprises with variable speed control of pumps and fans, during the project engineering phase the operator should bear in mind that the operating point, and thus the efficiency of the continuous flow machine, changes when the speed changes.

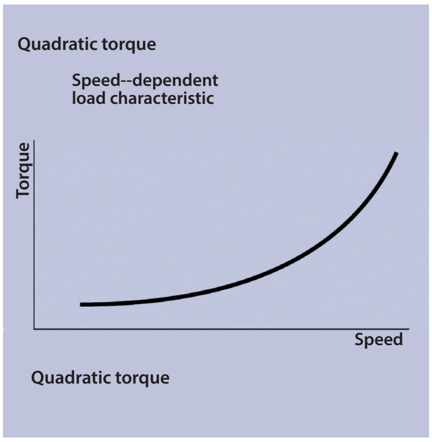
The interaction of the continuous flow machine and drive results in a speed range in which the system saves energy. This is the range within which the machine should run most of the time. If the difference between the maximum required power and the average partial load operation is too large, it is advisable to use a cascaded system. A variable speed pump handles the base load. If the consumption rises, the AC drive will sequentially activate additional pumps. This way the pumps operate as efficiently as possible. Pump control always ensures the best energy utilization of the system.
The same approach can also be used for fans.
The investment often pays for itself after a short time, even if an existing system is converted.

Note: *Positive displacement pumps, rotary piston blowers and compressors are not continuous flow machines. Due to the operating principle, AC drives must be designed for constant torque in this situation.*

Load characteristics of various applications

Assignment of characteristic curves to applications





Applications with constant torque (high starting torque)

- Axial piston compressor
- Rotary piston compressor
- External screw pumps (pay attention to the starting torque)
- Piston pumps
- Stirrers
- Sludge dewatering compactors
- Compressors (except turbo compressors)
- Positive displacement pumps
- Gear pumps
- Rotary vane pumps
- Compressors
- Conveyor belts
- Centrifuges
- Hoists and other material handling equipment
- Extruders

Applications with quadratic torque

- Centrifugal pumps
- Well pumps
- Booster pumps
- Filter feed pumps
- Groundwater pumps
- Hot water pumps
- Heating pumps (primary & secondary circuit)
- Ducted impeller pumps (solids)
- Cooling water circulation pumps (primary & secondary circuit)
- Rainwater basin drainage pumps
- Return flow sludge pumps
- Submersible pumps
- Turbo compressors
- Underwater pumps
- Excess sludge pumps
- Fans

Note: *Ask the pump or motor manufacturer for the torque characteristic.*

Operation and data display

Basic operating concept

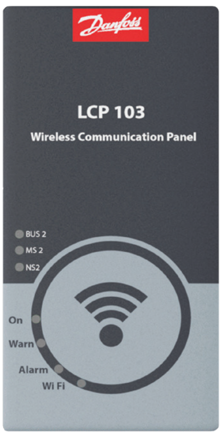
The basic technology of all AC drives is the same, so ease of use plays a decisive role. Many functions and integration into machines and systems require a simple operating concept. It should meet all requirements for simple and reliable configuration and installation.
The options range from simple, inexpensive numerical displays to convenient control panels that display information in plain text. Simple control panels are sufficient for simple viewing of operating parameters such as current or voltage. Convenient control panels, on the other hand, offer the option of displaying more parameters or displaying multiple parameters at the same time.

Clear grouping of functions and simple manual operation are just as much a part of this as access options via software, fieldbuses or even remote monitoring via the internet or mobile devices like phones or tablets.

A modern AC drive should be able to combine or enable all of the following operating concepts in the same device and at least allow switching between manual and remote operation at any time.

Graphic control panels offer ease of use and information in plain text.

LCP102



LCP103 WLAN

VACON® display

Operation and display

Local operation
On-site operation with a local control panel should be regarded as a basic requirement. Even in this age of networked communications, there are numerous tasks, such as commissioning, testing, process optimization or on-site maintenance in plants, that require direct access to the device. In any of these cases, it may be necessary for the operator or technician to change local values in order to immediately register changes in the system and, for example, to diagnose faults. For this purpose, the control panel should provide a simple and intuitively operable man-machine interface.

Clearly organized display
The ideal solution is a graphic display that allows operation in the language of the respective country and shows the essential parameters for the respective application in the basic function. To provide a good overview, this status information must be limited to the parameters that are absolutely necessary and must be adaptable or changeable at any time. It is also helpful to be able to block or hide certain functions according to the operator's level of knowledge, and to display and enable changes only for those parameters that are necessary in each case for process adaptation and control. With the multitude of functions offered by modern AC drives, which often have several hundred parameters for optimum adaptation, this reduces operating errors and resulting costly system downtime. The display should also have an integrated help function for the individual functions in order to provide the commissioning technician or service technician with assistance at any time, particularly with rarely used parameters, in order to rule out operating errors to the extent possible. In addition to an alphanumeric display, the option of displaying graphic curves (scope function) is very helpful for optimum use of integrated diagnostic functions. This sort of visualization, for example of ramp shapes and/ or the torque curves, often simplifies troubleshooting.

Uniform concept
There are many AC drives in a wide variety of applications in the industrial sector. The drives, usually all from the same manufacturer, differ primarily in terms of their electrical power and therefore in size and appearance. Uniform operation of the AC drives, always using the same control panel over the entire power range, offers advantages to the plant engineer as well as the system operator.

Note: *When project engineering an AC drive, you should ensure it has the right operating concept. A design that offers the greatest possible ease of use in parameterization and programming is advantageous, because both the functionality of the drive and fast, simple, intuitive operation are important today. This is the only way to reduce the effort, and thus the cost of training and subsequent access, of employees who work with the AC drives.*

As a general rule, the simpler the operation, the faster and more effective commissioning or troubleshooting can be. Concepts with control panels that can be plugged in during operation have therefore proven successful.

Integration in the cabinet door
In many systems in which AC drives are installed in the cabinet, plant engineers have to integrate the controls and indicators in the cabinet door for process visualization. This is only possible with AC drives that have removable control panels. When it is integrated into the cabinet door by a mounting frame, the AC drive can be operated with the cabinet closed, its operating status can be seen and process data can be read out.

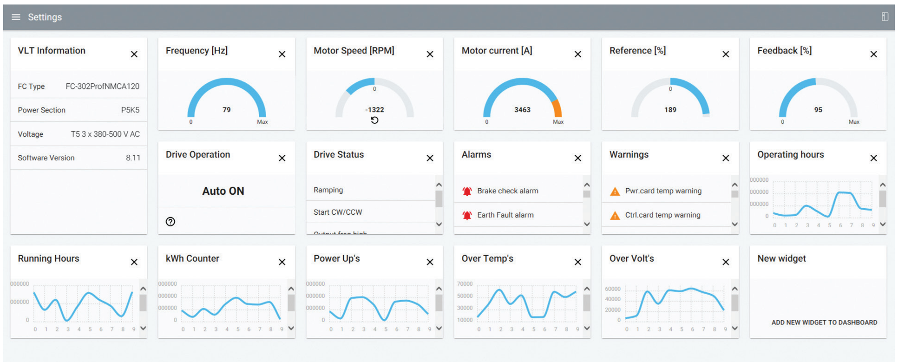
AC drives can also be configured and read out when the cabinet door is closed.

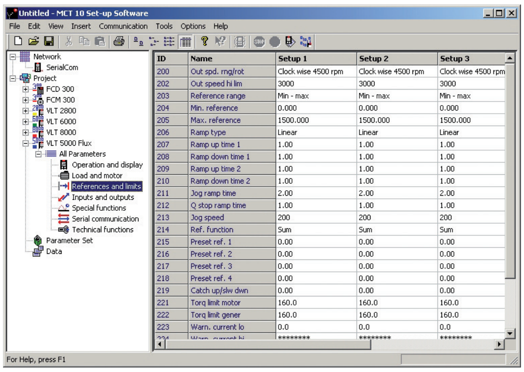
Operation and parameterization with a PC

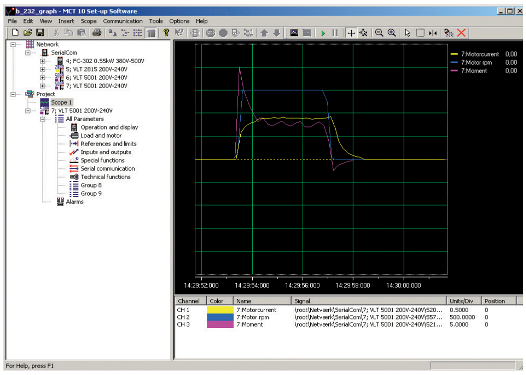
Expanded possibilities

In addition to operation via a control panel, modern AC drives usually offer the option of parameterization and data readout via PC software.
This software is mostly Windows-based and supports multiple communication ports. It allows data exchange over the traditional RS-485 interface, over a fieldbus (Profibus DPV1, Profinet, Ethernet, or other) or over a USB interface. A clear user interface provides a quick overview of all drives within a system. Good software also offers the option of managing large projects with many drives. Both online and offline project engineering is possible. Ideally, the software also offers the option of integrating documents into the project. This makes it possible, among other things, to access system circuit diagrams or operating instructions via the software.

Note: *The MCT 10 software is a Windows-based engineering tool for easier project planning, parameterization and programming of the VLT® AutomationDrive series. The basic version of the software is free of charge and can be downloaded from https://suite.mydrive.danfoss.com/content/tools*







PC software for AC drives offers parameterization as well as the possibility of recording process data or managing projects.

Data exchange

High availability systems

Permanent access to and availability of systems and machines is an absolute must for profitable business systems. In automation systems where high availability is required, Danfoss supports a number of technologies to provide high availability and high uptime.

Danfoss provides interruption-free data communications based on redundancy protocol like MRP (Media Redundancy), DLR (Device Level Ring) and redundant fieldbus systems. These technologies eliminates that a single fault on Ethernet based network leads to loss of the communication the drives.

The use of controller redundancy applies in system where a single controller fault would lead to complete standstill and to high production loss or even damage to the environment. Danfoss support simple controller redundancy in Modbus TCP and for the most demanding application via PROFINET IO System Redundancy S2 which ensured high availability to critical systems.

Bus systems
Modern AC drives are intelligent and therefore able to perform many functions in power drive systems. The full potential of AC drives can easily be exploited by users integrating them into their systems via a fieldbus connection. With just one hardware data point, they have full access to all elements of the connected AC drive. Commissioning and cabling are simplified, which leads to cost savings in installation. A large amount of data is available for effective system management with no additional components. The breakdown of the collective error messages makes it possible to isolate causes remotely and initiate the correct steps for error correction.

Better alarm management
Detailed alarm messages simplify the localization of possible causes of errors or faults and thus effectively support remote system monitoring. Remote monitoring via the internet makes it possible to quickly visualize status and/or fault messages even from remote plants or system components.

Better system management
The control console offers the option of monitoring and adjusting all AC drive settings remotely. Status data, such as the output frequency or power consumption, can be read out and evaluated at any time. Additional data for effective energy and peak load management is available without external components.

Reduced installation costs
- Not every AC drive needs its own display. The user or operator already has access to all of the relevant AC drive data via the control system.
- Simplified cabling through twin-wire connection.
- Unused inputs and outputs of the AC drive can be used as I/Os to integrate other components such as sensors, filters and limit switches into the control system.
- No need for input and output modules, as one hardware data point is sufficient for controlling the AC drives.
- Monitoring functions such as motor thermistor evaluation, dry-run protection, and others, as well as power meters and operating hour counters, are available without extra components.

Simplified commissioning
Parameterization is performed from the control console. All settings can be copied quickly and easily from one AC drive to the next. A backup of the settings can be permanently stored in the memory of the display.
Planners and commissioning personnel can document the settings at the push of a button.

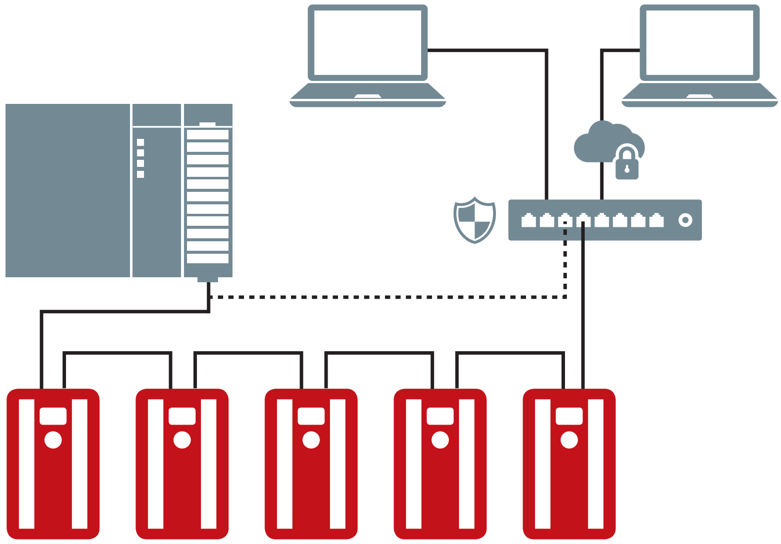
Fieldbuses available

PROFIBUS DP V1
DeviceNet
CANopen
PROFIBUS Converter
VLT® 3000
PROFIBUS Converter
VLT® 5000
PROFINET
EtherNet/IP
Modbus TCP
POWERLINK
EtherCat
PROFIsafe

Web server
FC300 drive with Ethernet based Fieldbus offers integrated webserver. It gives you drive statistics, fault information, Network information and Statistics. The WEB server has the ability to send you a Email notification if an error or warning occur. The interface ensures ease of use, and a customizable dashboard presents the most valuable information for your application at a glance. It is a responsive web page so that the layout changes based on the size and capabilities of the used device.

PROFIenergy
PROFIenergy is an energy management standard for production plants, based on the PROFINET communication protocol. FC300 drives supports PROFIenergy features where we ensure cost savings through omission of external hardware and energy saving even in short pauses thanks to granular switching.

Access the drive remotely



Real-time information is becoming increasingly important in industrial automation and control systems as we progress further into Industry 4.0. Immediate access to data increases transparency in production facilities, while making it possible to optimize system performance, collect and analyze system data and provide remote support around the clock from anywhere in the world.

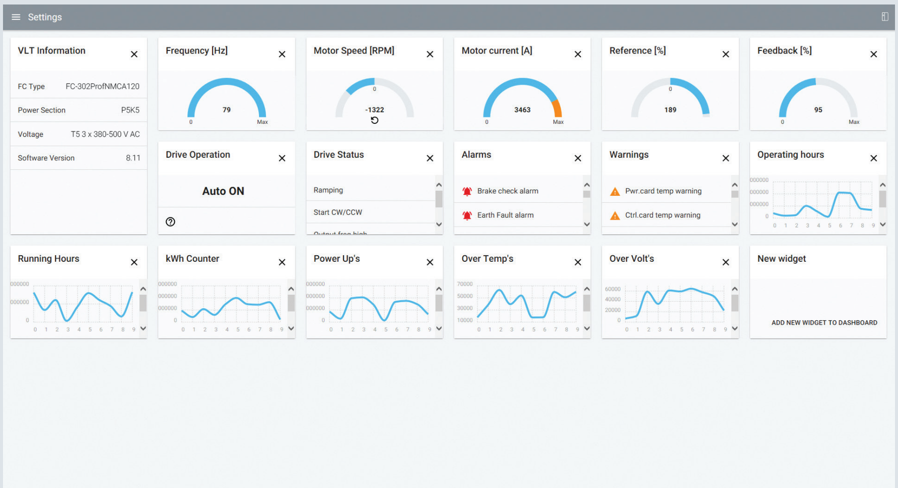
Regardless of your application or your preferred communication protocol, AC drives have an extremely wide variety of communication protocols to select from. In this way you can ensure that the AC drive integrates seamlessly into your chosen system providing you the freedom to communicate however you see fit.

Increase productivity
Fieldbus communication reduces capital costs in production plants. In addition to the initial savings achieved through the significant reduction in wiring and control boxes, fieldbus networks are easier to maintain, while providing improved systems performance.

User friendly and fast setup
Danfoss fieldbuses can be configured via the drive's local control panel, which features a user-friendly interface with support for many user languages.

The drive and fieldbus can also be configured using the software tools that support each drive family. Danfoss Drives offers fieldbus drivers and PLC examples for free from the Danfoss Drives website to make integration to your system even easier.

Web server dashboard

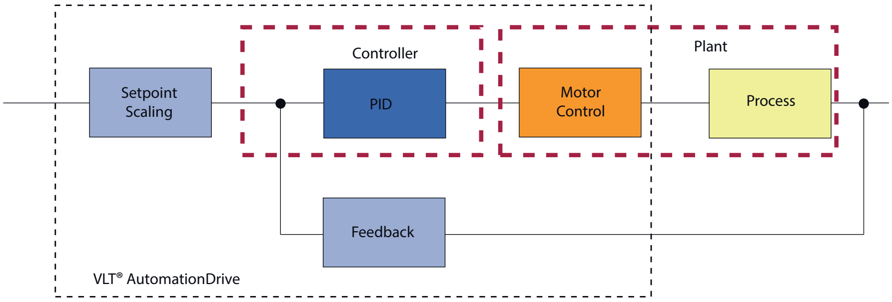


PROFINET · ETHERNET POWERLINK · DeviceNet · CANopen · PROFIBUS · EtherCAT · EtherNet/IP · Modbus

Additional selection factors

Process controller

Today's AC drives are intelligent drive controllers. They can take over PLC (Programmable Logic Controller) tasks or functions. The implemented process controllers also allow independent control loops to be set up with a high degree of accuracy. This aspect is particularly attractive for retrofitting when there is not enough PLC capacity available in the system or there is no PLC at all.
Active process parameter converters (which provide actual values for flow rate, pressure or level) can be powered by the 24 V DC control voltage of the AC drive if it has sufficient supply capacity.



PID process controller block diagram

Maintenance

Most AC drives are almost maintenance-free. For AC drives with higher power, filter mats are installed which operators must clean from time to time depending on the dust burden. However, it should be noted that manufacturers of some AC drives specify maintenance intervals for cooling fans (approximately 3 years) and capacitors (approximately 5 years).

Storage

Like all electronic devices, AC drives must be stored in a dry place. The manufacturer's specifications must be observed. Some manufacturers require regular forming of the devices. To do this, the user must apply defined voltages to the device for a certain period of time. This forming is necessary due to aging of the capacitors in the device's DC link. The rate at which they age depends on the quality of the capacitors used. Forming counteracts the aging process.

Never install AC drives directly in explosion hazard areas. They must be installed outside this zone in a cabinet or in a dedicated electrical switch room. The use of sine wave filters at the AC drive output is also recommended, because they attenuate the voltage slew rate dv/dt and the peak voltage Upeak. The length of the connected motor cable must be kept as short as possible due to the voltage drop on the cable and the sine wave filter.

Read also Facts worth knowing about AC drives

The scope of this document is low-voltage drives.

For information about medium-voltage drives, refer to the **website**

VLT® AutomationDrive FC 302

The modular VLT® AutomationDrive meets all the requirements of your drive tasks in the chemical and pharmaceutical industries. In order to optimally cover the range from standard to high-performance drives without compromise, modularity begins with the selection of the power platform.

All supply voltages

The VLT® AutomationDrive series covers the power range from 370 W to 1400 kW. It supports supply voltages of 200 V, 380–480/500 V, 525–600 V and 690 V. Operation with specific network configurations, such as IT networks, is also possible.
If necessary, 12-pulse devices are also available for AC drive power of 250 kW or more. They further reduce the mains harmonics in your application and ensure even better grid quality. A combination with the VLT® Advanced Active Filter as an individual drive with reduced harmonics also offers the possibility of taking greater advantage of the infrastructure under difficult grid conditions or of sustainability improving the supply situation by retrofitting the VLT® Active Line Filter.

Safe Torque Off

The VLT® AutomationDrive AC drives can significantly contribute to reducing the system costs for the functional safety of a machine or system. For this purpose, the FC 302 is equipped as standard with a safe digital input with the Safe Torque Off (STO) function implemented according to EN 61800-5-2 (FC 301/A1 enclosure optional).
The safety category that can be achieved with this corresponds to the typically used performance level d according to EN ISO 13849-1 or SIL 2 according to EN 61508.

- Full mains voltage at the output
- Connection of long motor cables (150 m /492 feet shielded or 300 m /984 feet unshielded)
- Dimensioned for long lifetime
- Integrated RFI filter compliant with EN 61800-3, category C1
- Integrated line reactor (UK 4%)
- Thermistor evaluation
- AEO function for especially high energy savings
- Thermal motor model integrated as software-based motor protection in the AC drive, which also takes the reduced internal ventilation of a motor at low speed into account (not possible with motor circuit breaker)
- Cold plate technology
- Various Communications interfaces
- RS485
- USB
- Wireless LCP
- Logical I/O link
- Controlled ramp-down function (kinetic backup)
- Digital motor potentiometer function
- Interface for encoder
- Flying start (Flystart)
- Modular concept
- Integrated Motion Controller IMC
- PID controller
- ProfiSafe option
- Safe Stop input
- Safe Torque Off input
- Scope function
- Torque control
- Smart logic control
- Switchable overmodulation
- Optional integrated fieldbus connections (also with external 24 V DC power supply)
- Optional active and passive line filters for additional harmonics reduction
- Optional sine wave filter and dU/dt filter for all power ratings
- 12-pulse versions for higher power sizes
- Optional All-mode sine-wave filters

Please reach out to your local Danfoss Drives Sales and Service office for detailed information.

The entire VLT® AutomationDrive family shares a consistent operating concept, uses identical extension modules, and is equipped with EMC filters and line reactors as standard.

Achieve maximum availability of your system – **with condition-based monitoring**

Equipped with intelligent monitoring functionality, the VLT® Automation Drive enables you to use the drive as a smart sensor. It can monitor the condition of your motor and application in real time, detect when current operation status is drifting away from the defined limits, and alert the operator to changes before they impact your process.

Condition-based monitoring

During installation, the condition-based monitoring (CBM) function establishes a baseline defining the recorded operation conditions for each monitoring element of the system, and threshold values are defined. During operation, CBM monitors motor stator windings, sensors and load-envelope conditions, all adjusted according to the actual speed of the system. When actual operation conditions exceed the defined limits, CBM sends alerts to notify personnel to take action.

The CBM function complies with relevant standards and guidelines, such as
- ISO 13373 standard for Condition Monitoring and Diagnostics of Machines
- VDMA 24582 guideline for condition monitoring
- ISO 10816/20186 standards for measurement and evaluation of mechanical vibration.

The unique embedded functionality means that the VLT® Automation Drive performs CBM monitoring inside the drive. When required, activate cloud or PLC connectivity to enable monitoring of numerous conditions or to send alerts when required.

Feature	Benefit
Condition-based monitoring functionality embedded in the drive	- No cloud connection required: high security level and no subscription fee - Reduced installation costs, since no external controller or PLC required to generate the CBM observation and notification - Documentation of system stability
Motor-stator-winding monitoring	- More uptime due to early detection and action on faults in the motor stator winding, before the fault develops into a crippling failure and unscheduled operational stop
Load-envelope monitoring Application baseline (run / online)	- Process optimization/maximized efficiency thanks to ability to compare actual system performance with baseline data and trigger maintenance actions
Sensor application monitoring (external) Application baseline (run / online)	- More uptime due to early detection and action on signs of mechanical misalignment, wear-out and looseness - Higher precision since sensor monitoring relates to motor speed

Read the white paper here

Motor-stator-winding condition monitoring

Motor-winding failures do not occur suddenly; they develop over time. They start with a small single-turn shortcircuit fault which causes additional heating. The damage then spreads to a level where the overcurrent protection activates, and the operation stops, causing unwanted downtime.

The unique winding condition monitoring function allows you to shift from reactively performing corrective maintenance of faulty motors, to proactively detecting motor isolation faults at an early stage and dealing with them during scheduled maintenance. In this way, you can avoid unwanted and potentially costly machine downtime caused by 'burned' motors.

Sensor selection

Four condition-based monitoring sensor inputs are defined by the analogue inputs. Using condition-based monitoring parameterization, you can scale the inputs to monitor the sensor signals where the vibration sensor is the most commonly used sensor type. Pressure and flow sensors could also be selected, provided that sensor selection is related to the drive speed of the system.

Mechanical-vibration monitoring

Avoid accelerated wear of the mechanical parts of a drive system by using CBM together with an external vibration transducer, to monitor the vibration level in a motor or application, related to the actual speed or rotation of the system.

Vibration monitoring is performed using standardized methods and threshold levels given in standards such as ISO13373 for Condition Monitoring and Diagnostics of Machines or ISO10816/20816 for Measurement and Classification of Mechanical Vibration.

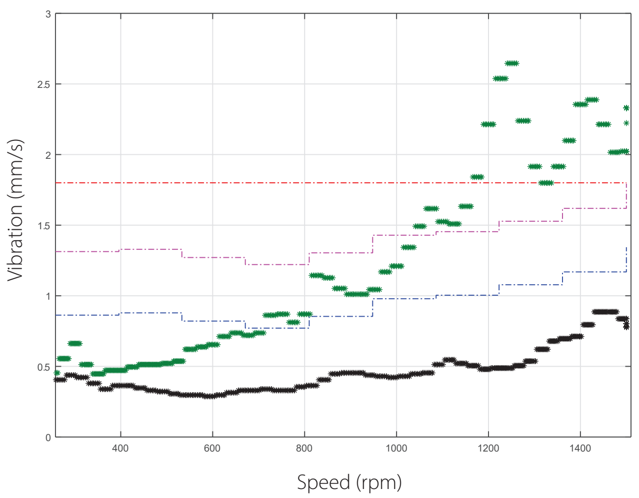
Baseline measurement of min/max and average values indicate the stability of a system at different speeds and are very useful as a hand-over test from contractor to end-user.

Load-envelope monitoring

Use the VLT® Automation Drive to compare the actual load curve to the initial values determined during commissioning. This empowers you to detect unexpected operating conditions, such as

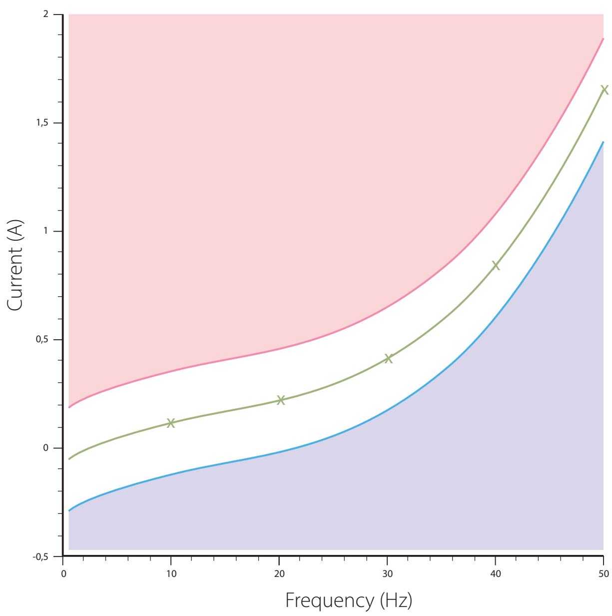
- leakage in an system. Inadequate or excessive power consumption indicates a problem, defined at individual speeds.
- pumps which have become fouled or sanded
- clogged air filters in ventilation systems

When a part has worn out, the load curve changes compared to the initial baseline, and a maintenance warning is triggered allowing you to quickly and effectively remedy the issue. Load-envelope monitoring can also help you to save energy by ensuring the equipment always runs in optimal conditions.



Application example showing changes in vibration signal

Baseline data
Faulty data
Alarm Level
Warning Stage 2 Level
Warning Stage 1 Level



Baseline - Load envelope monitoring of energy consumption.

Energy consumption above the limit

Energy consumption below the limit

Integrated motion controller – for **positioning** and **synchronization** applications

Perform high-precision positioning and synchronization, simply using an AC drive. With the Integrated Motion Controller (IMC) functionality, the **VLT® AutomationDrive FC 302** replaces more complex positioning and synchronization controllers, to save time and cost.

Positioning and synchronization operations are typically performed using a servo drive or a motion controller. However, many of these applications do not actually require the dynamic performance available from a servo drive.

Therefore the FC 302 with IMC is a cost-effective, high-performance alternative to servo in single-axis positioning and synchronizing applications.

Use IMC for many applications that have been solved with servo drives until now, such as:
- Rotary tables
- Cutting machines
- Packaging machines

Use FC 302 to run an induction or PM motor with **or without motor feedback** – with no need for additional hardware. With sensorless control (no motor feedback) best performance is achieved with a PM motor. The performance of sensorless control of induction motors is however sufficient for less-demanding applications.

With IMC you **save time and cost**:
- No advanced programming and fewer components means fewer hours needed for engineering, installation and commissioning
- Save further cost for a feedback device, cabling and installation by using sensorless control
- To save cost for a home sensor and cabling, use the "homing on torque limit" function

The IMC solution provides **easy and safe set-up**:
- Configuration via parameters, with no advanced programming required. Reduced complexity will minimize the risk of errors
- To add more functionality, use the Smart Logic Controller (SLC), which is fully compatible with IMC
- To realign the home position during operation, use the "home synchronizing" function

Encoder-free

to save costs and reduce complexity

Positioning

In positioning mode, the drive controls movement over a specific distance *(relative positioning)* or to a specific target *(absolute positioning)*. The drive calculates the motion profile based on target position, speed reference and ramp settings *(see the examples in Fig. 1 and Fig. 2 on the right)*.

There are 3 positioning types using different references for defining the target position:

- **Absolute positioning**
  Target position is relative to the defined zero point of the machine.
- **Relative positioning**
  Target position is relative to the actual position of the machine.
- **Touch probe positioning**
  Target position is relative to a signal on a digital input

This illustration *(Fig. 3)* shows the different resulting target with a set target position (reference) of 1000 and starting position of 2000 for each of the positioning types.

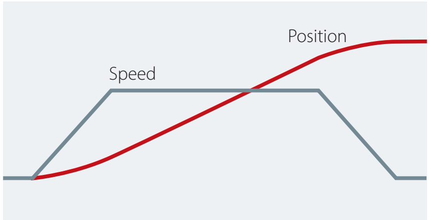


Fig. 1. Motion profile with linear ramps

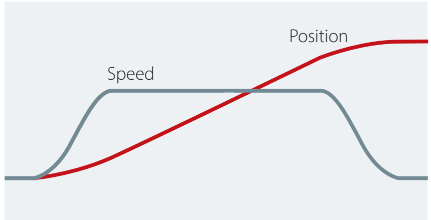


Fig. 2. Motion profile with S-ramps

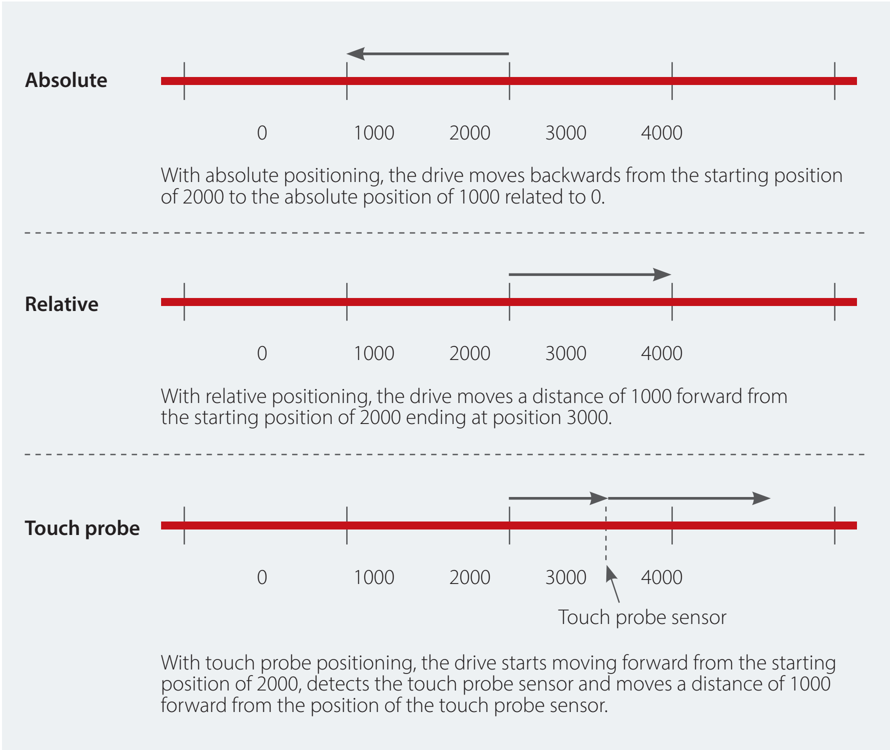


Fig. 3. IMC supports 3 positioning modes

Synchronizing

In synchronizing mode, the drive follows the position of a master; multiple drives can follow the same master.
The master signal can be an external signal, for example, from an encoder, a virtual master signal generated by a drive or master positions transferred by fieldbus. Gear ratio and position offset is adjustable by parameter.

Homing

With sensorless control and closed loop control with an incremental encoder, homing is required to create a reference for the physical position of the machine after power up.

There are several home functions with and without sensor to choose from. The home synchronizing function can be used to continuously realign the home position during operation when there is some sort of slip in the system. For example in case of sensorless control with an induction motor or in case of slip in the mechanical transmission.

Motion control and servo drive applications

Apart from the AC drives technology there might be a need for dynamic motion control technologies in different areas within the chemical and pharmaceutical industry.
Many of these motion applications for material handling, packaging, labelling or filling machines can be covered with state-of-the-art AC drives with integrated motion control features. See the section about Integrated Motion Controller (IMC) for synchronization and positioning applications with a standard AC drive. These integrated Motion features can replace mechanical solutions from the past and more complex motion/servo systems in many cases and reduce the need at end user side to invest in over specified drive technologies. Latest technologies also offer encoder-less motion features.

However, even if modern AC drives can apply a lot of functionality in terms of Motion applications, there are some given factors which can limit the usage of this more simply technology. For high dynamic motion control applications there could be a need for control loop cycle times in the µ sec. area as well on the internal control loop and at communication interfaces, e.g. Ethernet communication ports.

For such high dynamic applications there are so called servo drives available on the market for single and multi-axis drive systems. Also in this area Danfoss drives is offering a complete range of central and decentral solutions which are scalable, programmable and user friendly.

VLT® FlexMotion™ is a multi-purpose servo drive solution. Combining its central and decentral hardware variants provide a maximum level of flexibility when it comes to machine design and system integration. The smart platform concept ensures identical user interfaces and makes installation, programming and maintenance equally quick and easy. The modular system even allows trouble free machine extensions or adaptions in a later stage.

Open connectivity to common real-time Ethernet systems, such as PROFINET, POWERLINK and EtherCAT, and IEC 61131-3-based programming and PLCopen Motion Function Blocks makes the system even more flexible and easy to integrate into various engineering environments.

For more informations see
VLT® FlexMotion™ Selection Guide

VLT® Multiaxis Servo Drive MSD 510

VLT® Integrated Servo Drive ISD® 510

VLT® Decentral Servo Drive DSD 510

Product overview

VLT® AutomationDrive FC 302

VLT® Enclosed Drives

VLT® AutomationDrive FC 302

The VLT® AutomationDrive FC 302 is a modular drive designed to comply with all modern automation application requirements with easy configuration and a broad power range.

This intelligent drive features Integrated Motion Controller and condition-based monitoring, ready to use as an integrated sensor in an IIoT environment.

The VLT® AutomationDrive FC 302 features Safe Torque Off as standard. Easily configurable options are available: SS1, SLS, SMS and SSM.

Advanced active filter variants reduce harmonics to below 3% at best, and 12-pulse drives provide robust cost-effective harmonics reduction in supply applications.

Power range

3 x 200-240 V ....0.25-37 kW
3 x 380-500 V..............................0.37-1100 kW
3 x 525-600 V.................................. 0.75-75 kW
3 x 525-690 V................................ 1.1-1400 kW

Power range - 12-pulse drive

3 x 380-500 V...................... 250-1000 kW
3 x 525-690 V ....250-1400 kW

VLT® Enclosed Drives

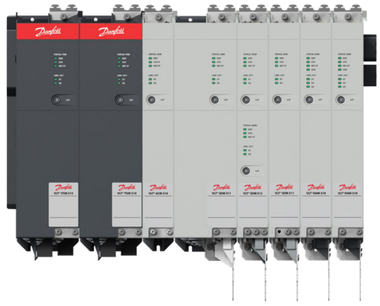
VLT® Enclosed Drives have been designed to meet the most demanding requirements for flexibility, robustness, compactness and service-friendliness, making them a smart choice for diverse applications. They are ideal for low harmonic drive (LHD) usage, with outstanding harmonic mitigation performance.

VLT® Enclosed Drives are configurable with input/output filters, control and enclosure options to meet practically all requirements of the application, eliminating the need for an extra enclosure.

Power range

380-480/500 V .... 90 kW-500 kW
525-690 V.................................. 90 kW-710 kW
with 150% overload

VLT® Integrated Servo Drive ISD® 510



VLT® Multiaxis Servo Drive MSD 510

VLT® Decentral Servo Drive DSD 510

VLT® Integrated Servo Drive ISD® 510

The VLT® Integrated Servo Drive ISD® 510 is a decentral servo drive with flexible modularity. It combines a servo motor and servo drive in one compact unit. It offers great benefits in diverse applications, such as turntables, labeling, capping, and packaging of food and pharmaceuticals.

Motion control is integrated into the drives to run the motion sequence independently and therefore free up the central PLC.

Rated voltage
565 - 680 VDC ±10%

Rated torque
1.5-11.2 Nm

Peak torque
6.1 – 38.6 Nm

VLT® Multiaxis Servo Drive MSD 510

The VLT® Multiaxis Servo Drive MSD 510 system is a generic central servo solution and the fundamental part of the VLT® FlexMotionTM concept.

Its flexibility and modularity in hardware and software gives the freedom to design or engineer machines according to the application needs.

Nominal input voltage
3 x 400 - 480 V AC ±10%

DC link voltage
565 - 680 V DC ±10%

VLT® Decentral Servo Drive DSD 510

Flexible modularity for decentral servo applications
The VLT® Decentral Servo Drive DSD 510 provides flexible modularity for decentral servo applications, extending the VLT® FlexMotion™ decentral servo drive concept. Supporting a wide range of feedback encoders and sensorless control, its architecture is completely open and allows you to choose your preferred PM or ACM motor.

Use the integrated motion controller to run the motion sequence independently and therefore free up the central PLC.

Rated voltage
565 – 680 V DC ±10%

Rated power
4 kW

Rated current
8 A (standalone)

VLT® FlexMotion™

VLT® FlexMotion™ servo concept
This modular and multi-purpose servo drive solution is designed to meet the requirements of tomorrow's machine architecture, today. Its modular platform provides you one system capable of creating a diversity of machine concepts, based on three servo product lines:
- VLT® Multiaxis Servo Drive MSD 510
- VLT® Integrated Servo Drive ISD® 510
- VLT® Decentral Servo Drive DSD 510

Read more about VLT® FlexMotion™

VACON® NXP Air Cooled

VACON® NXC Air Cooled Enclosed Drives

VACON® NXP Liquid Cooled Drive

VACON® NXP Air Cooled

The VACON® NXP Air Cooled drive is designed for a broad range of demanding industrial applications, focusing on higher power sizes and system drives.

Power range

3 x 208-240 V....................0.55-90 kW
3 x 380-500 V....................1.5-1200 kW
with DriveSynch 1.5-4000 kW
3 x 525-690 V....................2.0-2000 kW
with DriveSynch 2.0-4500 kW

VACON® NXC Air Cooled Enclosed Drives

The VACON® NXC combines the VACON® NXP product range with a wide range of options in a single enclosed drive format.

Easy to configure

Choose from a wide range of cabinet-installed options; and 6 or 12 pulse rectifiers or Active Front End (AFE).

Power range

3 x 380-500 V....................132-1200 kW
3 x 525-690 V....................110-2000 kW

Power range - AFE supply

3 x 380-500 V....................132-1500 kW
3 x 525-690 V....................110-2000 kW

Power range - Low harmonic, Active Filter supplies

400 V....................132-560 kW
500 V*....................132-560 kW
690 V....................110-800 kW

*requires 690 V active filter

VACON® NXP Liquid Cooled Drive

This dedicated liquid-cooled drive is well-suited to applications where air quality is critical, space is limited, and efficient heat transfer is required.

Power range

3 x 400-500 V....................132-4100 kW
3 x 525-690 V....................110-5300 kW

VACON® NXP Liquid Cooled Enclosed Drive

VACON® NXP System Drive

VACON® NXP Liquid Cooled Enclosed Drive

The VACON® NXP Liquid Cooled Enclosed Drive offers all the benefits of VACON® NXP Liquid Cooled drives for high power applications in a compact IP54 rated enclosed drive package.

Power range

3 x 400-500 V............................... 700-1100 kW
3 x 525-690 V...............................800-1550 kW

VACON® NXP System Drive

By combining common DC bus components the VACON® NXP System Drive provides you a drive configured and assembled to meet your needs - regardless of whether you need to control one or several motors.

Current ratings (main busbars)

3 x 380-500 V.................................630-5000 A
3 x 525-690 V.................................630-5000 A

VACON® NXP Common DC Bus

VACON® NXP Liquid Cooled Common DC Bus

VACON® NXP Grid Converter

VACON® NXP Common DC Bus

VACON® NXP Common DC Bus components are designed to enable systems integrators, machine builders, and OEMs to design and build efficient industrial drives systems.

Comprehensive range
Build almost any kind of system imaginable, with this fully complete range of components, including inverter units (INUs), active front-end units (AFEs), non-regenerative front-end units (NFEs), and brake chopper units (BCUs).

Power range
3 x 380-500 V .... 1.5-1850 kW
3 x 525-690 V .... 3-2000 kW

VACON® NXP Liquid Cooled Common DC Bus

This range of liquid-cooled common DC bus components brings the benefits of liquid cooling into common DC bus systems.

For demanding systems
Liquid cooling offers strong benefits in applications where cooling air supply or quality is limited, enabling creation of solutions that work even in demanding situations.

Power range
3 x 400-500 V .... 7.5-4100 kW
3 x 525-690 V .... 110-5300 kW

VACON® NXP Grid Converter

This range of air and liquid-cooled drives is specifically designed for energy storage and other power conversion applications.

Power range
Air-cooled
3 x 380-500 V .... 180-1100 kW
3 x 525-690 V .... 200-1200 kW

Liquid-cooled
3 x 400-500 V .... 160-1800 kW
3 x 525-690 V .... 210-1800 kW
To achieve even higher power capacity, combine multiple VACON® NXP Grid Converter units.

VACON® NXP DC/DC Converter

Energy support close to the consumption to help improve performance by making better use of energy, energy storage is increasingly being introduced into systems to create hybrid solutions. Various storage methods are being used but, due to reductions in battery costs and increases in energy density, battery utilization is seen as being the fastest growing and more easily integrated storage medium available today. DC/DC converters can be used to connect to sources such as batteries, super capacitors, fuel cells and solar panels.

Due to the wide input range of the source voltages, for example battery, the VACON® NXP DC/DC Converter application can be used to match source voltage to a common DC bus system in order to utilize the stored energy to create the right DC bus voltage required to operate the machinery running on these hybrid systems.

The VACON® NXP DC/DC Converter application can be installed in both liquid- and air-cooled VACON® NXP drive modules.

Supply voltages and power range
Air cooled
3 x 380-500 V...180-1100 kW with battery voltages from 100 VDC* to 800 VDC**
3 x 525-690 V...200-1200 kW with battery voltages from 100 VDC* to 1100 VDC **

Liquid cooled
3 x 380-500 V...160-1800 kW with battery voltages from 100 VDC* to 800 VDC**
3 x 525-690 V...210-1800 kW with battery voltages from 100 VDC* to 1100 VDC**

*Minimum voltage is case dependent
**Depending on system DC bus voltage. Source (battery) voltage must always be lower than the DC bus voltage.

VACON® 1000 & VACON® 3000 medium-voltage drives

This technical brochure addresses low-voltage drive applications. In higher power applications, medium-voltage (MV) drives may be preferred for various reasons. MV solutions are however beyond the scope of this brochure. For information about MV drive systems, please contact your local Danfoss office.

DrivePro® Life Cycle services
Delivering a customized service experience!

We understand that every application is different. Having the ability to build a customized service package to suit your specific needs is essential.

DrivePro® Life Cycle Services is a collection of tailormade products designed around you. Each one engineered to support your business through the different stages of your AC drive's life cycle.

From optimized spare-part packages to condition-monitoring solutions, our products can be customized to help you achieve your business goals.

With the help of these products, we add value to your application by ensuring you get the most out of your AC drive.

When you deal with us, we also offer you access to training, as well as the application knowledge to help you in planning and preparation. Our experts are at your service.

drivepro.danfoss.com

You're covered
with DrivePro® Life Cycle service products

Every AC drive application is different. DrivePro® Life Cycle Services is a collection of tailor-made products designed around your needs.
From optimized spare part packages to condition-monitoring solutions, customize our products to support your business through the different stages in the life cycle of your AC drive.

DrivePro® Site Assessment

Optimize planning based on a site-wide survey

Optimize your maintenance strategy with a complete onsite survey and risk analysis of all your AC drives collected in one detailed report. Together with a Danfoss expert, you can build a tailored plan for future maintenance, retrofits, and upgrades based on your exact needs.

DrivePro® Start-up

Fine-tune your drive for optimal performance today

Take the complexity out of commissioning with DrivePro® Start-up's full range of health checks and adjustments. Our DrivePro® experts inspect and test your AC drive and motor performance to ensure the best configuration of your AC drives.

DrivePro® Extended Warranty

Long-term peace of mind

Even the best performing AC drives need protection. DrivePro® Extended Warranty offers a wide range of warranty options and provides the longest coverage in the industry. Enjoy better uptime, repairs, replacements, and spare-part support for up to six years.

DrivePro® Spare Parts

Plan ahead with your spare part package

Maintain maximum uptime with a spare parts package that covers you in any AC drive breakdown. Choose from three customized packages to get your AC drive back up and running with minimal impact to operations.

DrivePro® Exchange

The fast, most cost-efficient alternative to repair

Maintain uptime with a fast alternative to repair when there is no time to waste. If an AC drive fails, the DrivePro® Exchange service can quickly exchange any drive to ensure as little production delay as possible.

DrivePro® Preventive Maintenance

Take preventive action

Take the guesswork out of your maintenance plan. With a structured maintenance program tailored to your needs, you can boost operational efficiency and reduce the effects of wear and tear.

DrivePro® Remote Monitoring

Fast resolution of issues

DrivePro® Remote Monitoring offers you a system that provides online information available for monitoring in real time.
It collects all the relevant data and analyzes it so that you can resolve issues before they affect your processes.

DrivePro® Remote Expert Support

You can rely on us every step of the way

DrivePro® Remote Expert Support offers speedy resolution of on-site issues thanks to timely access to accurate information. With the secure connection, our drives experts analyze issues remotely reducing the time and cost involved in unnecessary service visits.

DrivePro® Retrofit

Minimize the impact and maximize the benefit

Manage the end of product lifecycle efficiently, with professional help to replace your legacy drives. The DrivePro® Retrofit service ensures optimal uptime and productivity during the smooth replacement process.

To learn which products are available in your region, please reach out to your local Danfoss Drives sales office or ***visit our website***

Discover more about DrivePro® services ***here***

Directives related to AC drives

CE Mark

The CE mark (European Union) is intended to remove technical barriers to the movement of goods within the EC and EFTA states (EEA). The CE mark documents that the product manufacturer complies with all relevant EC directives that have been implemented in national laws. The CE mark says nothing about the quality of a product. Technical data cannot be derived from the CE mark. In environments in which AC drives are used, the Machinery Directive, the EMC Directive and the Low Voltage Directive, among others, must be observed.

Machinery Directive

The key message of the 2006/42/EC Machinery Directive is: "A machine, as an assembly of linked parts or components, at least one of which moves, must be designed in such a way that, when properly installed, maintained and used for its intended purpose, it does not endanger the safety of humans and livestock or the preservation of property." AC drives are electronic components and are therefore subject to the Machinery Directive. If plant engineers use AC drives in machines, they document their compliance with all relevant laws and safety measures by means of the manufacturer's declaration.

EMC Directive

The key message of the EMC Directive 2014/30/EU is: "Devices liable to cause electromagnetic interference or the operation of which may be affected by such interference must be so designed that the generation of electromagnetic interference is limited to such an extent that normal operation of radio and telecommunications equipment and other apparatus has adequate resistance to electromagnetic interference to enable normal operation. "Danfoss AC drives are CE marked for compliance with the EMC Directive and a Declaration of Conformity is available.

Low Voltage Directive

The key message of the Low Voltage Directive 2014/35/EU is: "Electrical equipment for use at a rated voltage between 50 and 1000 V AC or between 75 and 1500 V DC must be designed in such a way that, when properly installed, maintained and used for its intended purpose, it does not endanger the safety of humans and livestock or the preservation of property." Because AC drives are electrical equipment within the specified voltage range, they are subject to the Low Voltage Directive and are required to bear a CE mark.

Note: *Manufacturers of machines or systems should ensure that they use AC drives bearing a CE mark.*
An EC Declaration of Conformity must be provided on request.

Read also Facts worth knowing about AC drives

Read more about Enclosed Drives

Read more about medium-voltage drives

Medium-voltage drives
VACON® 1000 and VACON® 3000
This technical brochure addresses low-voltage drive applications. In higher power applications, medium-voltage (MV) drives may be preferred for various reasons. MV solutions are however beyond the scope of this brochure. For information about MV drive systems, please contact your local Danfoss office.

Reliable plant operation - day in, day out

In the chemicals industry, we know your plant never sleeps. It simply needs to keep working reliably, day in, day out, in the toughest environments and without any unexpected downtime. At Danfoss Drives, we enable just that with the highest-quality AC drives to keep you going, while at the same time lowering your energy consumption.

AC drives that enable peak performance

For your chemical plant to run at its absolute best, you need drives that enable peak performance. Designed with decades of industry knowhow, our quality AC drives deliver best-in-class reliability and robustness. Their leading energy efficiency lowers your total cost of ownership and makes a positive contribution to reaching the world's climate goals.

Further, predictive and condition-based monitoring are built into our drives to give you the intelligence you need to future-proof your systems. Our drives are also fully compatible with any motor or system, so you're free to run the optimal system for your plant.

Choose Danfoss as your AC drives partner and rely on us to keep you going.

Read more:
Facts worth knowing about AC drives

VLT® AutomationDrive FC 302 Selection Guide

VLT® FlexMotion Selection Guide

VACON® NXP and NXC Drives Selection Guide

Medium-voltage drives

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