
# ENGINEERED DRIVES MANUAL

VACON
DRIVEN BY DRIVES

# 1. INTRODUCTION TO THE ENGINEERED DRIVES MANUAL

In the engineered drives business it is essential that the sales organisation as well as the actual project team have sufficient access to the information that is needed to assure the drive system's optimal operation and high delivery quality.

The purpose of this document is to highlight the factors that must be taken into account when drive system contracts are negotiated, drive system delivery is designed and the drive system is commissioned. Detailed information is contained in the user's manuals and other technical documentation.

This document is written mainly for Vacon's sales personnel, system integrator partners, and panel builders, but it offers a useful introduction to engineered drives to other readers, too. For further development of this type of documentation, it is very important that you give us feedback on our work. Feedback address is documentation@vacon.com.

# 2. Process is the key

The most important factor when starting to define a drive system configuration is the customer's process where the drive system will be used. Customer is the starting point also when defining a drive system. You must first familiarise yourself with the customer's process requirements: torque, speed and load cycle. Only thorough knowledge of the customer's process can guide you to find out what is the optimal drive system type and configuration in each case.

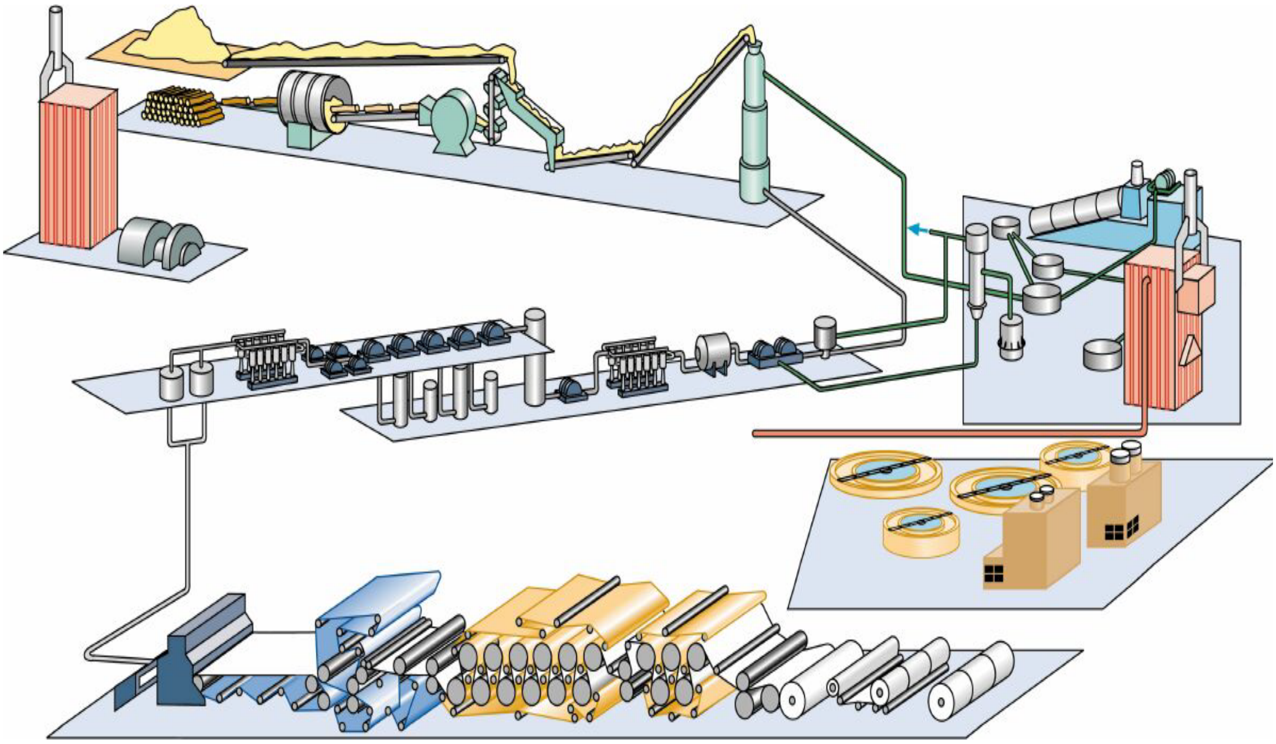


*Figure 1. Pulp and paper manufacturing*

## 2.1 Customer's installation environment

Customers are unique also in the way that the installation environments are different. When defining the drive system delivery, it is important to find out that the customer's installation environment is suitable for the drive system. Defining a drive system requires two-way communication. You must inform the customer about the requirements that the drive system sets to the installation premises, but also make sure that the customer understands that it is of their own best interest to provide accurate and adequate information on the installation environment and local interfaces.

*Figure 2. Ambient conditions must be considered*

Environmental factors that must be considered include ambient temperature, altitude of the installation premises, air quality - presence of for example dust and chemicals. These are discussed in more detail in the corresponding chapters of this document.

## 2.2 Drive system configuration

Successful drive system implementation is based on thorough planning and accurate dimensioning of the drive system.The actual savings are generated during the years of use - when the drive system´s dimensioning and configuration are optimal for the purpose. The implementation of a common AC or DC bus drive system is often an engineering project that results in a project-specific drive switchgear solution, consisting of one or more drive line-ups and in some cases also standalone drive units.

*Figure 3. A common DC bus line-up*

Each customer has a unique process, which means that each drive system is equally unique and must be designed in accordance with the requirements of the customer's process. The purpose of this document is to point out the factors that you must consider when defining a drive system for a customer.

# 3. DRIVE SYSTEMS

## 3.1 SINGLE DRIVES

A single drive usually refers to a complete 6 or 12 pulse frequency converter. Single drives include compact wall mountable drives, cabinet drives, and IP00 drive modules that need cabinet installation. A frequency converter mechanically consists of a power unit, control unit and possibly one or more chokes. All Vacon's frequency converters are delivered with chokes.

AC and DC chokes carry out several functions in Vacon's frequency converters. An input AC choke is needed as an essential component for motor control, to protect the input and DC-link components against abrupt changes of current and voltage, as well as to function as a protection against harmonics. DC choke covers the same functions except for the protection of input and DC link components.

The power unit contains diodes for rectifying the input voltage, capacitors and IGBT inverter which produces a symmetrical, 3-phase PWM-modulated AC voltage to the motor.

The control unit contains a microprocessor with firmware and application software. The microprocessor controls the motor basing on the information it receives through measurements, parameter settings, control I/O and control keypad. Control panel is a link between the user and the frequency converter. It is used for setting parameters, reading status data, and giving control commands. Control panel is detachable and can be operated externally and connected via a cable to the frequency converter. Instead of the control panel, also a PC can be used to control the frequency converter, if connected through a similar cable.

A single drive is normally ready to use, without installation of any auxiliary devices. Vacon's single drive product range covers all needs from compact low power drives to high performance drives used in industry.

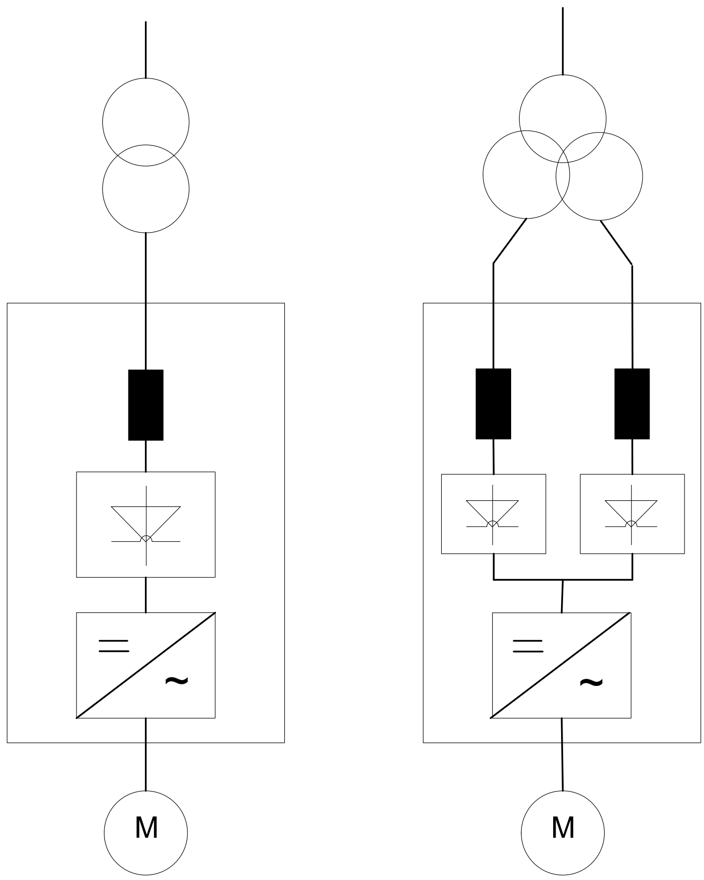



*Figure 4. 6 and 12 pulse single drives*

### 3.1.1 Typical single drive applications

A stand-alone drive is the simplest possible configuration for a frequency controlled motor. The drive has its own supply, and an output to the motor. Frequency converter can be placed anywhere between the supply and the motor, either in an electrical room or even close to the process.

Single drives can be used with simple open loop systems, where the drive gets no feedback from the motor, but also in complex industrial processes, together with a common DC bus system. Single drives are applicable for a variety of purposes, such as pumps, fans, HVAC etc.

A single drive has always fixed specifications such as power, output current and frame size. Single drives are documented standard products, which can be modified using standard options and option boards. A single drive is a good solution for a process where you do not need the flexibility and process-specific customisation offered by a common DC bus or common AC bus system.

*Figure 5. Typical stand-alone drive*

## 3.2 Common DC bus drive systems

A common DC bus drive system consists of one or more front end units that convert the mains AC voltage into DC voltage and current, providing power to the common DC bus. The common DC bus transfers the power to the inverter drives, and depending on the type of the front end, in some cases back to the mains network, too. A common DC bus drive system may include also a brake chopper unit, as a cost-effective solution for dissipating the braking energy in cases where regeneration of the power to the network is not feasible.

Common DC bus configuration can bring significant energy savings when the braking energy is used. This is the case when there is more than one drive connected to the DC bus, and at least one of them is braking. The braking power is directly fed to the other drives via the common DC bus.

Common DC bus drive systems have different kinds of front end units, depending on the requirements of the electricity network and the process where the drives are used. From the electricity network's point of view, the most important selection criterion is the acceptable level of Total Harmonic Distortion, THD. The process requirements refer mainly to the need of braking and feasibility of regeneration of power to the network.

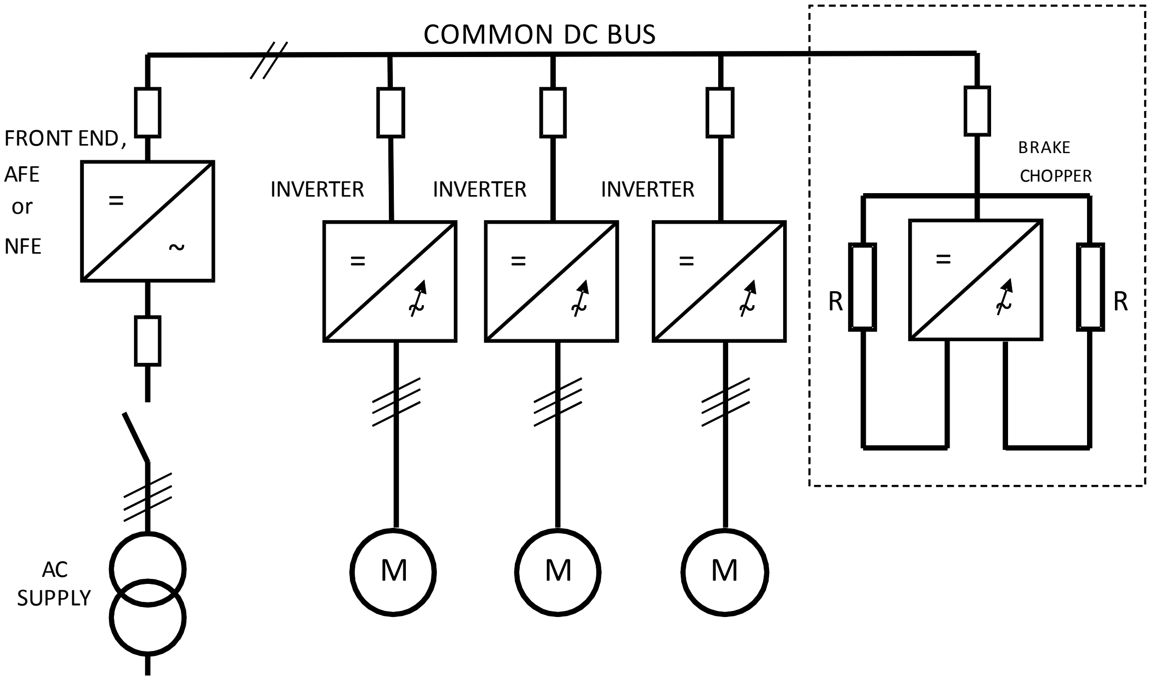



*Figure 6. Inverter units are fed from the DC bus, and they control the motors in accordance with process needs.*

### 3.2.1 Typical common DC bus system applications

A common DC bus system is an efficient solution for controlling production lines in various process industries, such as pulp and paper factories as well as various steel processing mills and plants. A common DC bus system is also applicable for the use of various cranes and winches etc.

DC bus systems can be divided into two main categories: regenerative and non-regenerative. In a regenerative DC bus system the front end unit is capable of generating power back to the mains network. This kind of system is suitable for processes where braking is needed often and the braking power is relatively high. In a non-regenerative system the braking power is redistributed to the other drives in the system via the common DC bus, and possible excess power is dissipated as heat using a break chopper unit and brake resistors. In small production lines or small paper machines where braking is needed seldom, a non-regenerative common DC bus system is a cost-efficient solution. In applications where excessive power is needed, it is possible to parallel multiple front end units.

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

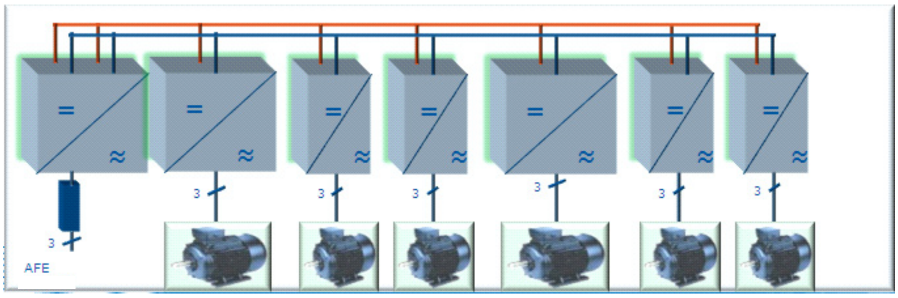



*Figure 7. A regenerative common DC-bus system*

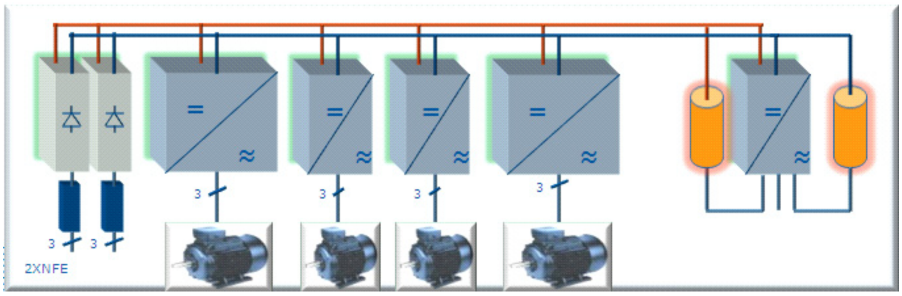



*Figure 8. A non-regenerative common DC-bus system*

### 3.3 Common AC bus drive systems

A common AC bus drive system consists of separate AC drives with one common supply point. Usually the drives are located in a row of cabinets, with a common AC bus as the power source for the frequency converters. Each drive is fed from the common AC bus, and from the drive cabinet, there is cabling to each motor. In an AC drive system the power is fed from the supply to each motor drive, but not vice versa. A common AC drive system is a cost-efficient choice for a process with multiple motors that are constantly on duty and consuming energy independent of each other.

Reduced cabling and drive line-up costs result from using a single common AC input for a number of drives. Installation in a separate electrical room, if one is available, keeps the drive system protected from the environmental effects of the actual operational or production premises. Each individual frequency converter can have a switch-disconnector, which means that each frequency converter can be individually isolated from the AC-bus for service purposes, if this is feasible for the process point of view.

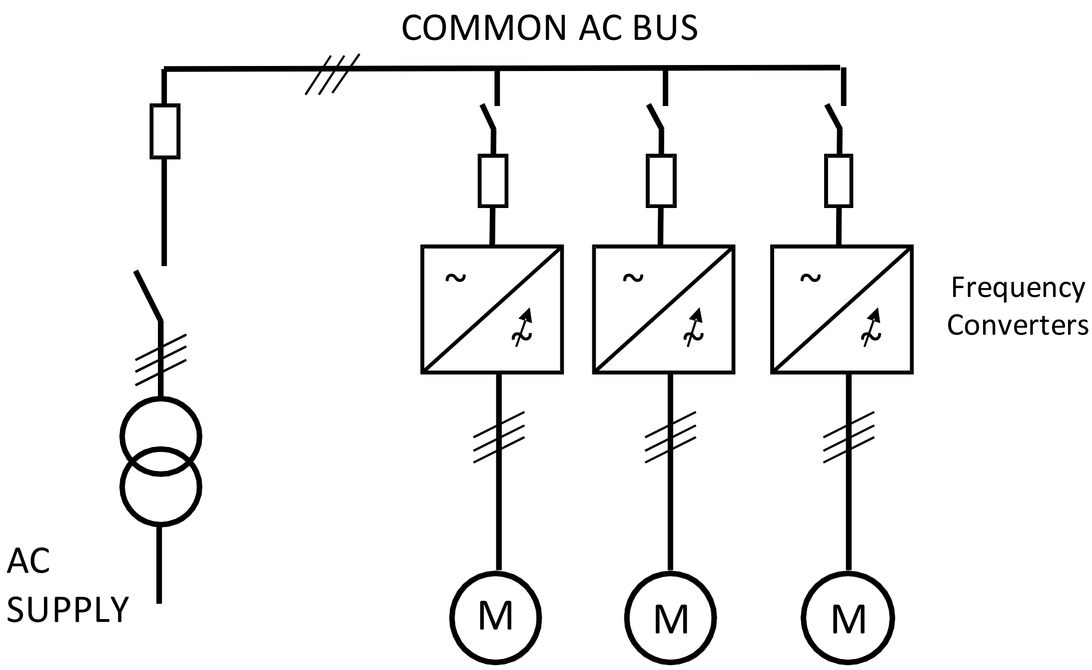



*Figure 9. Common AC bus system*

#### 3.3.1 Typical AC bus system applications

A common AC bus drive system is a relevant choice for a process where you need a set of drives that are operated separately, independent of each others, with no need for transferring power between the drives or back to the mains network. Typical applications for a common AC bus drive system include high power pump stations or locations where multiple fans are controlled by frequency converters.

A common AC bus system consists of separate frequency converters that are connected to a common AC bus, which is fed from a single mains connection.

## 3.4 Drive control

There are three ways to operate a drive or a drive system.

- manually, using the panel
- using I/O
- through fieldbus

Operating of a drive using the drive's own keypad is possible, but rarely feasible. In case the control need is simple start/stop commands and there is easy access to the drive, it may be an option.

Often, even in cases where simple start/stop commands are enough, it still makes sense to use a separate switch with an I/O connection to the drive. A typical example is lowering and lifting the anchor of a ship, where it is good to have a large ON/OFF switch on the deck of the ship, while the actual drive that controls the operation may be located in a more protected environment.

In complex industrial environments, where a drive line-up controls complicated production operations, fieldbus is the most efficient way to handle the control of the drives. In a fieldbus control system all controls go through a single cable from the automation system to the drive line-up.

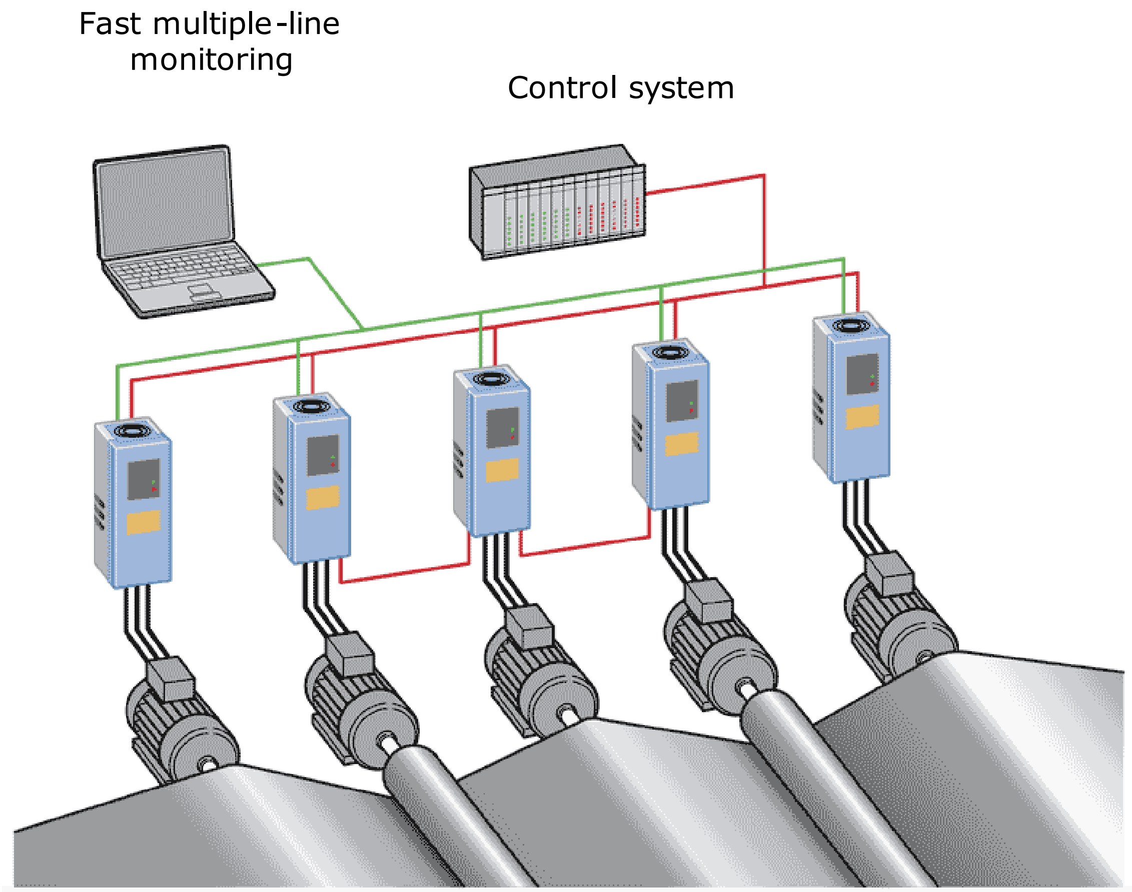



*Figure 10. Drive control*

### 3.4.1 FIELDBUS COMMUNICATION

Compatibility with the various different fieldbus communication systems is established using option boards. Some drives include support for certain communication options as standard, but depending on the communication protocol, you may need to acquire the option board that supports the communication system you use. Vacon's drives support a comprehensive selection of fieldbus communication systems through separate option boards.

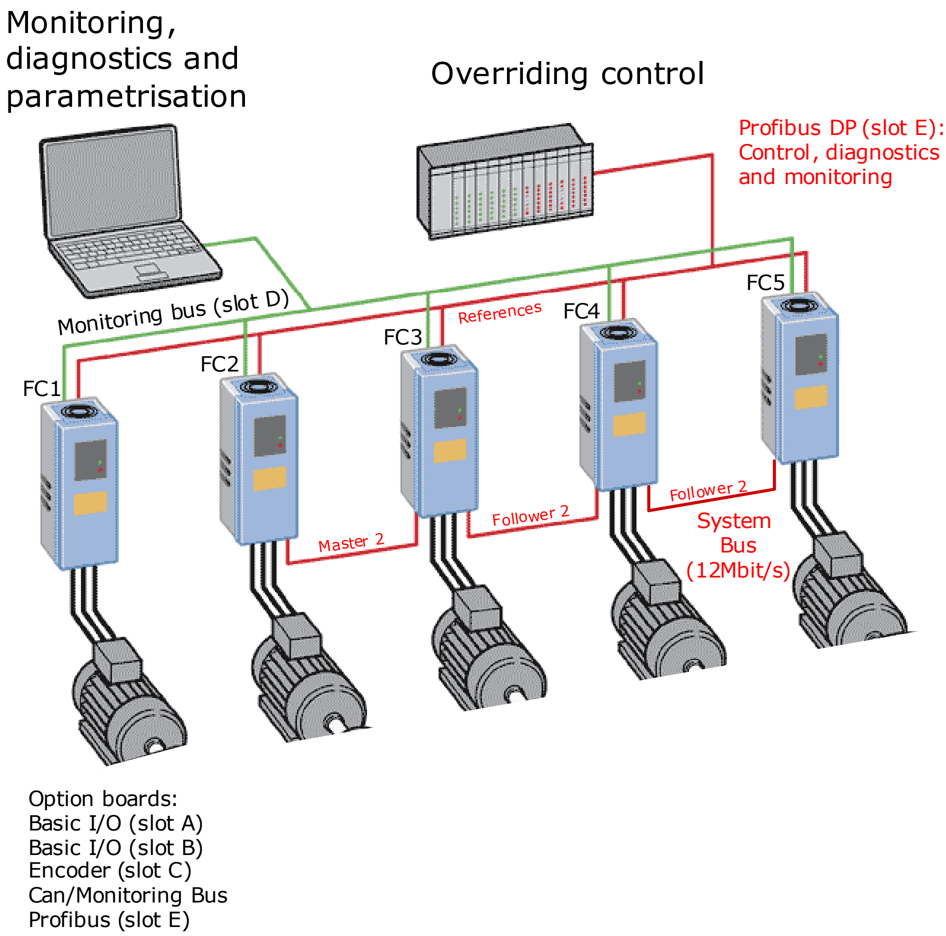



*Figure 11. A fieldbus communication system*

### 3.4.2 DATA TRANSMISSION CAPACITY

Data transmission capacity depends on the fieldbus system. Fieldbus system uses a certain protocol for data transmission with a drive. The amount of data that can be transferred depends on the protocol.

The drive's software application can be a limiting factor. Application contents vary from simple start/stop commands to more complicated PID control commands. You must find out what the control needs are to be able to select the software application. If the application you have does not support the required control functions, you can change it to a more suitable one quite easily.

Even if the software application supports certain controls, the fieldbus profile may limit the communication, as there are normally exact definitions of what data may be transmitted. In some cases, when the software application is suitable for the purpose, but fieldbus profile limits the communication, you may be able to use a ByPass mode. The use of ByPass mode is possible with certain specialised applications only. ByPass makes the application more flexible, and allows you to use the drive in more complex ways, as there are no limits to what data is transmitted.

Most fieldbus systems have a configurable communication speed. You need to find out what the required communication speed is. If the drive controls for example the liquid level of a huge tank, the required communication speed is quite low. If the drive controls a process that requires quick response time, for example in milliseconds, the communication speed must be very high. Communication speed has an effect on the installation, too. For example, the faster communication speed required, the shorter cable length is allowed.

### 3.4.3 Fieldbus installation

It is very important that the fieldbus system is installed in accordance with the instructions given in the manuals. With fieldbus communication, even 97% of the problems are caused by faulty installation. The bus does not work correctly, and communication fails. Selecting of cable type, earthing, place of cables, peeling and connecting must be done exactly as instructed in the manual. Ignoring the instructions may cause expensive repair work, if you have the wrong cable type and need to replace several hundred meters of cable.

# 4. Drive system dimensioning

First decision to make when starting to plan a drive system is whether it makes sense to build up a common DC bus system, or use AC drives either separately or with a common AC supply. You also need to decide the drive system's cooling, whether it should be air cooled or water cooled.

The following dimensioning guidelines are applicable for any drive system. Separate drive units can always be dimensioned one by one, but in a common DC bus system, the dimensioning is more complicated as the process that the drive system should control has a considerable effect on the dimensioning. In a common DC system the total load of the motors is the main defining factor in the front end dimensioning.

## 4.1 Process requirements and importance of dimensioning

Processes can be roughly divided into groups as follows:

- Basic shaft turners
- Processes with high starting torque requirements
- Processes with accurate torque limiting requirements
- High dynamics applications (accurate speed and/or torque control)

Typically, the process requires mainly force, torque or power. Force is needed when there is linear movement, like in conveyors, cranes, lifts and escalators. Torque is needed in rotating machines and tools like winders, extruders and tooling machines. Power is needed in pumps, fans wind mills and compressors.

The drive and the motor together must be able to fulfil the demands of the process. If the drive is too small, it cannot produce the required force, torque or speed.

Overdimensioning of the drive system decreases the control accuracy of the drive, and increases the costs of the frequency converter, and the electrical room where the drive line-up is installed, also other items included in the drive system, such as supply transformer and cabling, circuit breaker, switchgear, motor cabling and the motor itself.

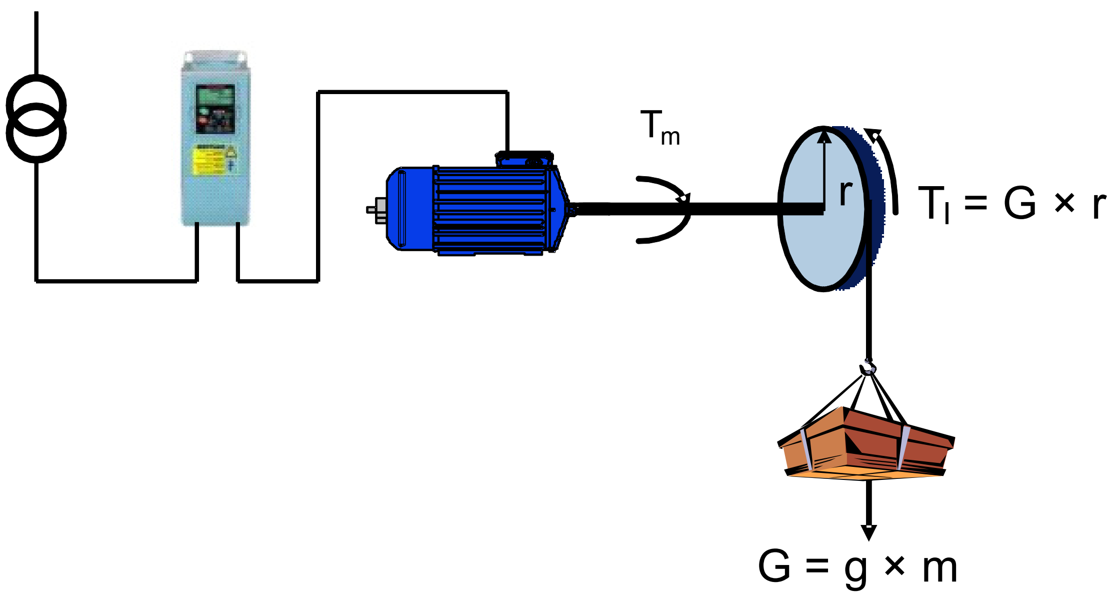



*Figure 12. Example of physics behind a main hoist*

## 4.2 Main steps for dimensioning

The system must be dimensioned in accordance with the steps described in the following chapters. It is important that the system is dimensioned in a logical sequence. The most important factors are the process where the drive system will be used, electrical properties of the supply and load requirements.

### 4.2.1 Check the supply: voltage and frequency

Keep in mind that according to the IEC 60038-1, a typical network requirement for voltage variation is between -10%...+10%. The corresponding frequency variation is +/- 5%.

### 4.2.2 Define the required load data

#### *4.2.2.1 Load types*

Load types vary greatly between different processes. The figure below presents some typical load types and process examples.

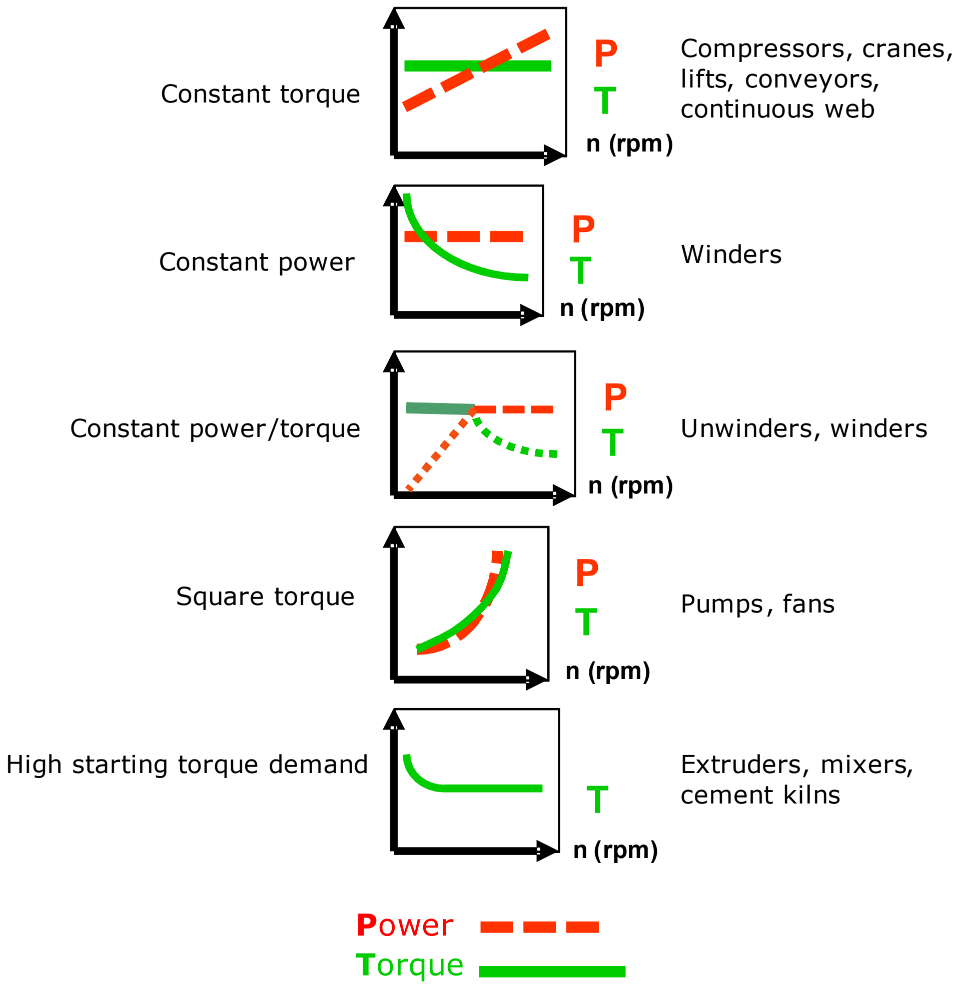



*Figure 13. Load types*

*Table 1. Process data*

| Name | Definition |
|---|---|
| *n*min | Minimum continuous speed [RPM]. |
| *n*base | Speed [RPM], at the end of the constant torque, and at the starting point of constant power. |
| *n*max | Maximum continuous motor speed [RPM]. |
| P[*n*base] | Base power [kW], motor's shaft power at the end of the continuous constant torque. This is also motor's shaft power at the starting point of continuous constant power. |
| T[*n*base] | Base torque [Nm], motor's continuous constant shaft torque. Also motor's shaft torque at the starting point of the continuous constant power. |
| *OL* | Overload [%], the relation of short time max. torque to the base torque. (100% = no overload) |

#### *4.2.2.2 Mechanical theory: Power & Torque*

Motor's power is normally given in kW (hp), and motor's speed in rpm.

Power in kW:

$$P = T \times \frac{2 \times \pi \times n}{60 \times 1000} [kW] \qquad P \approx \frac{T \times n}{9550} [kW]$$

Torque in Nm:

$$T \approx \frac{P \times 9550}{n} [Nm]$$

Where P = Power in kW, T = Torque in Nm and n = Rotational sped in rpm

#### *4.2.2.3 Characteristics of an asynchronous motor*

Asynchronous AC motors have a slip ($s_n$) which is defined at the nominal duty point:

$$s_n = (n_s - n_n) / n_s \times 100\%$$

Synchronous speed ($n_s$):

$$n_s = \frac{2 \times fn \times 60}{pole\#} [rpm]$$

Where pole# is the pole number of the motor.

Nominal speed ($n_n$):

$$n_n = n_s - s_n$$

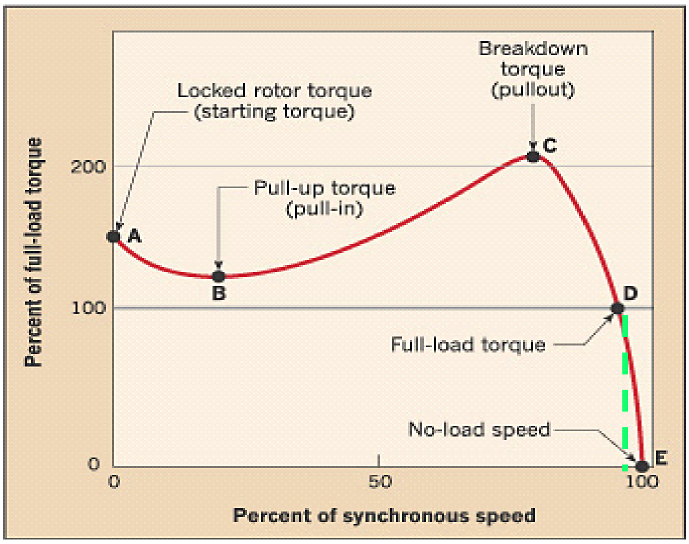



*Figure 14. Typical torque speed curve of an asynchronous motor at DOL duty*

### 4.2.3 Select the motor

- Check the supply voltage
- Check the speed range
- Check the constant torque and start-up torque
- Check the effect of acceleration (duration and inertia)
- Choose the motor so that the required torque is below the thermal loadability curve (self or separate ventilation)

#### *4.2.3.1 Motor's loadability*

Motor's thermal loadability decreases as the speed (=ventilation) decreases. In field weakening, the loadability decreases in relation to 1/n and maximum torque decreases in relation $1/n^2$. Motor's thermal time constant varies from minutes - hours by size. The loadability curve defines the load points of a motor at frequency converter duty where the temperature rise is the same as at nominal load with direct online supplied (DOL) motor.

Recommended margin between the maximum short time torque and theoretical breakdown torque is approximately 30%.

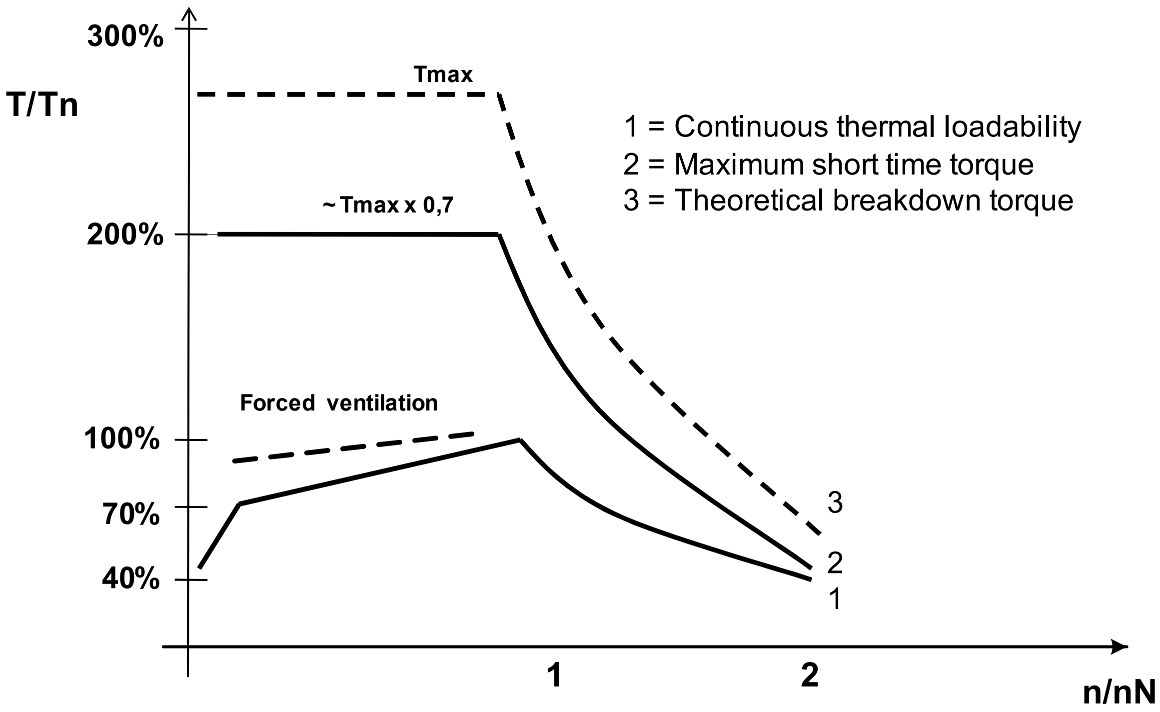



*Figure 15. Loadability curve of a typical motor*

Choose the motor so that the required continuous torque is below the thermal loadability curve. The short term required torque must also be below the maximum short time torque of the motor. Calculate the current in the extreme load points, and assume that current is linear or at least not higher.

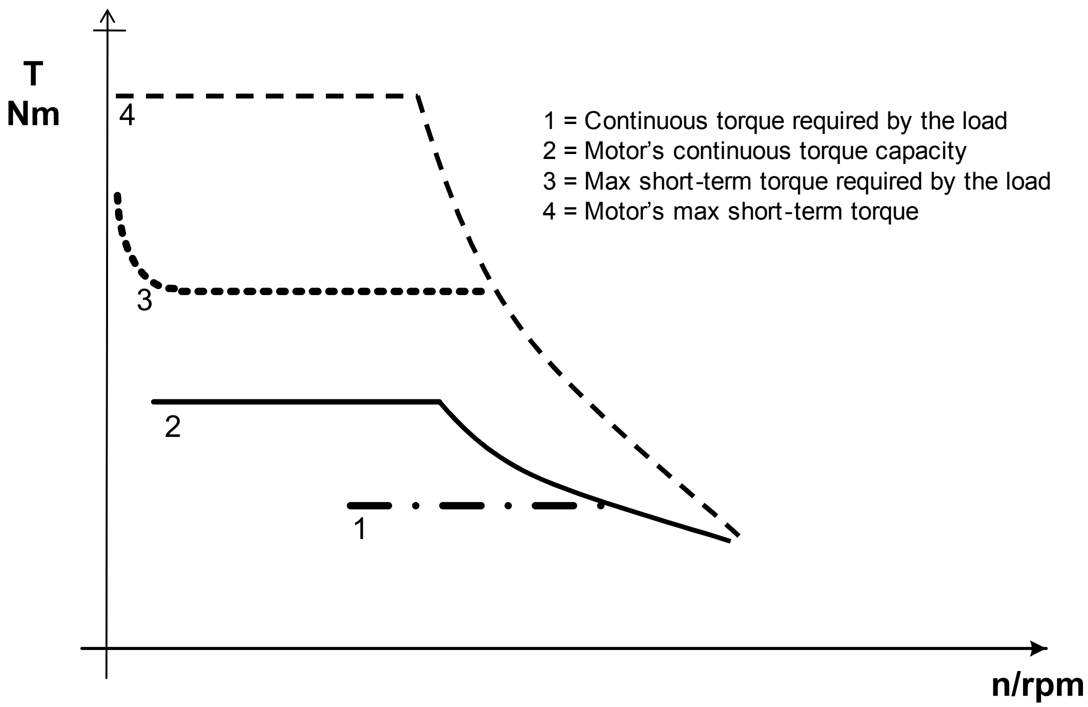



*Figure 16. Continuous and short-term torque*

### 4.2.3.2 Calculating of load current

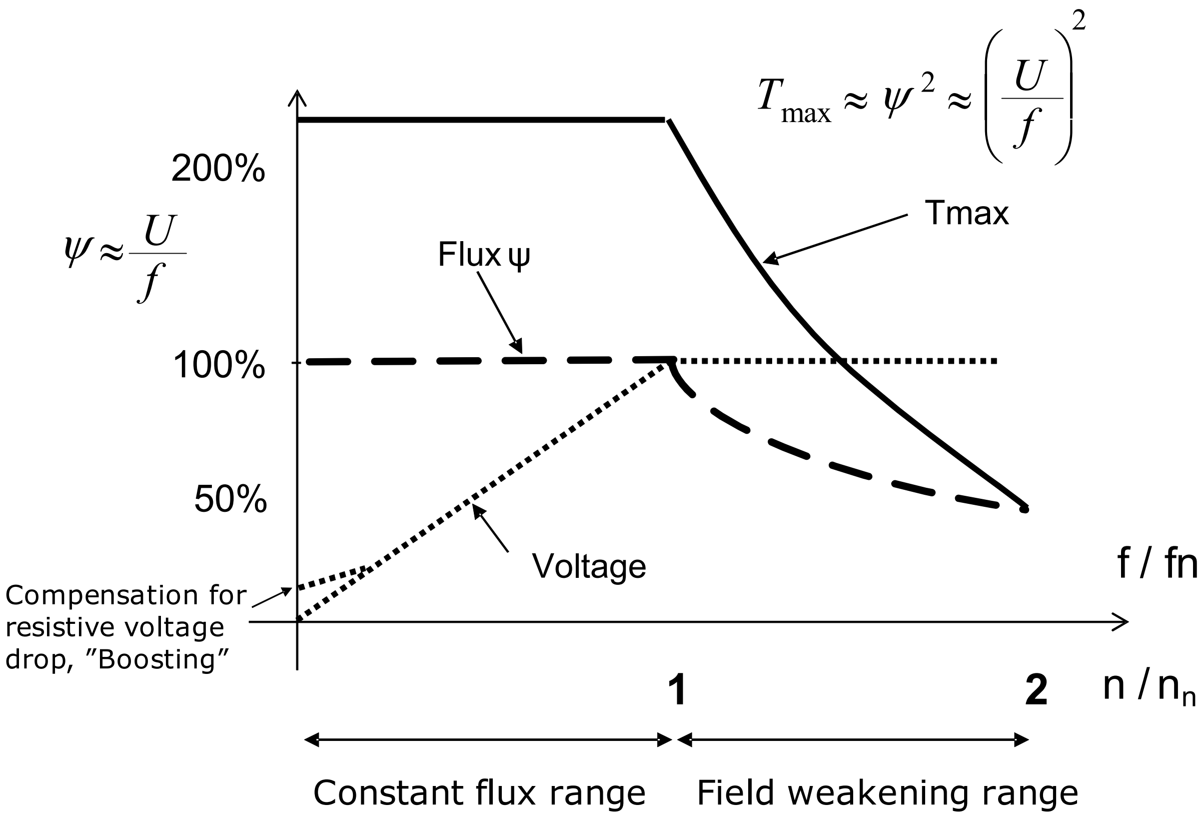



*Figure 17. Max torque, voltage and flux as a function of the relative speed*

Frequency range < fn = constant flux range

Frequency range > fn = field weakening range

### 4.2.3.3 Approximation of load current in constant flux area

When the load torque $T_{load}$ is in the range of 0,8 * $T_n$...0,7 * $T_{max}$

$$I_m = \frac{T_{load}}{T_n} \times I_n$$

#### 4.2.3.4 Approximation of load current in field weakening area

When the load torque $T_{load}$ is in the range of 0,8 * $(n_n/n)$* $T_n$.....0,7 * $(n_n/n)^2$ * $T_{max}$

$$I_m = \frac{T_{load}}{T_n} \times \frac{n}{n_n} \times I_n$$

Where $I_n$ = Motor's nominal current

Where $I_m$ = Motor's current at the required load

### 4.2.4 Select Vacon frequency converter

Criteria for selecting the frequency converter include:

- Continuous load current
- Maximum load current and load cycles
- Note the derating factors described in the chapter Ambient conditions

#### 4.2.4.1 Current capability

A drive is designed for a certain current rating at a specified ambient temperature, which is usually 40 or 50 °C. The basic sizing criteria is thermal - i.e. at the rated current and rated temperature, the internal temperatures of the drive do not exceed specified temperature limits. In addition, the IGBTs are chosen to be able to supply a heavy overload current for a short time - during this time the heat sink's temperature does not change appreciably. Usually the published currents are chosen to allow some overloadability. The overload duty cycle used in Vacon's current ratings tables is defined as 1 min / 10 min.

The RMS value of the current may not exceed the rated thermal current.

$$I_{RMS} = \sqrt{\frac{1}{T}\sum_{i=1}^{T} I_i^2}$$

### 4.2.4.2 Example of a cyclic load

1 min @ 226A / 9 min @ 202A

$$\mathbf{I_L} \qquad I_{rms} = \sqrt{\frac{226^2 \times 1 + 202^2 \times 9}{10}} = 205A$$

1 min @ 225A / 9 min @ 158A

$$\mathbf{I_H} \qquad I_{rms} = \sqrt{\frac{255^2 \times 1 + 158^2 \times 9}{10}} = 170A$$

$\mathbf{I_L}$ $\mathbf{I_H}$

**380-500 VAC Inverter modules**

| Type | Unit | | Low overload (AC current) | | High overload (AC current) | | $I_{max}$ |
|---|---|---|---|---|---|---|---|
| | Code | Frame | $I_{L\text{-}cont}$ [A] | $I_{1min}$ [A] | $I_{H\text{-}cont}$ [A] | $I_{1min}$ [A] | $I_{2s}$ [A] |
| INU | NXI_0004 5 | FR4 | 4,3 | 4,7 | 3,3 | 5,0 | 6,2 |
| | NXI_0009 5 | FR4 | 9 | 9,9 | 7,6 | 11,4 | 14 |
| | NXI_0012 5 | FR4 | 12 | 13,2 | 9 | 13,5 | 18 |
| | NXI_0016 5 | FR6 | 16 | 17,6 | 12 | 18 | 24 |
| | NXI_0022 5 | FR6 | 23 | 25,3 | 16 | 24 | 32 |
| | NXI_0031 5 | FR6 | 31 | 34 | 23 | 35 | 46 |
| | NXI_0038 5 | FR6 | 38 | 42 | 31 | 47 | 62 |
| | NXI_0045 5 | FR6 | 46 | 51 | 38 | 57 | 76 |
| | NXI_0061 5 | FR7 | 61 | 67 | 46 | 69 | 92 |
| | NXI_0072 5 | FR7 | 72 | 79 | 61 | 92 | 122 |
| | NXI_0087 5 | FR7 | 87 | 96 | 72 | 108 | 144 |
| | NXI_0105 5 | FR7 | 105 | 116 | 87 | 131 | 174 |
| | NXI_0140 5 | FR8 | 140 | 154 | 105 | 158 | 210 |
| | NXI_0168 5 | FI9 | 170 | 187 | 140 | 210 | 280 |
| | NXI_0205 5 | FI9 | 205 | 226 | 170 | 255 | 336 |
| | NXI_0261 5 | FI9 | 261 | 287 | 205 | 308 | 349 |
| | NXI_0300 5 | FI9 | 300 | 330 | 245 | 368 | 444 |
| | NXI_0385 5 | FI10 | 385 | 424 | 300 | 450 | 540 |
| | NXI_0460 5 | FI10 | 460 | 506 | 385 | 578 | 693 |
| | NXI_0520 5 | FI10 | 520 | 572 | 460 | 690 | 828 |
| | NXI_0590 5 | FI12 | 590 | 649 | 520 | 780 | 936 |
| | NXI_0650 5 | FI12 | 650 | 715 | 590 | 885 | 1062 |
| | NXI_0730 5 | FI12 | 730 | 803 | 650 | 975 | 1170 |
| | NXI_0820 5 | FI12 | 820 | 902 | 730 | 1095 | 1314 |
| | NXI_0920 5 | FI12 | 920 | 1012 | 820 | 1230 | 1476 |
| | NXI_1030 5 | FI12 | 1030 | 1133 | 920 | 1380 | 1656 |
| | NXI_1150 5 | FI13 | 1150 | 1265 | 1030 | 1545 | 1854 |
| | NXI_1300 5 | FI13 | 1300 | 1430 | 1150 | 1725 | 2070 |
| | NXI_1450 5 | FI13 | 1450 | 1595 | 1300 | 1950 | 2340 |

### 4.2.5 Ambient conditions

Any drive system has to handle different environmental stresses such as moisture or electrical disturbances. The squirrel cage motor is very compact and can be used in very hostile conditions. The IP 54 degree of protection guarantees that it can work in a dusty environment and that it can bear sprinkling water from any direction.

The frequency converter usually has an IP 21 degree of protection. This means that it is not possible to touch the live parts and that vertically dripping water will not cause any harm. If a higher degree of protection is required, it can be obtained, for example, by installing the drive inside a cabinet with the required degree of protection. In such cases, it is essential to ensure that the temperature inside the cabinet will remain within the allowed limits.

Air humidity and risk of condensation must be taken into account. The humidity limit is 95%. If the drive is placed outdoors, it must be protected from condensation. Cabinet heaters are not sufficient, as the air must be dry, not hot and humid.

Another important environmental feature is electromagnetic compatibility (EMC). It is very important that a drive system fulfills the EMC directives of the European Union. This means that the drive system can bear conductive and radiative disturbances, and that it does not send any conductive or radiative disturbances itself either to the electrical supply or the surrounding environment.

- De-rate for temperature above 40°C
- Be aware of high relative humidity - risk of condensation
- Problematic dusts at e.g. cement factories and iron mines
- Vibration - especially in marine applications
- Availability of space

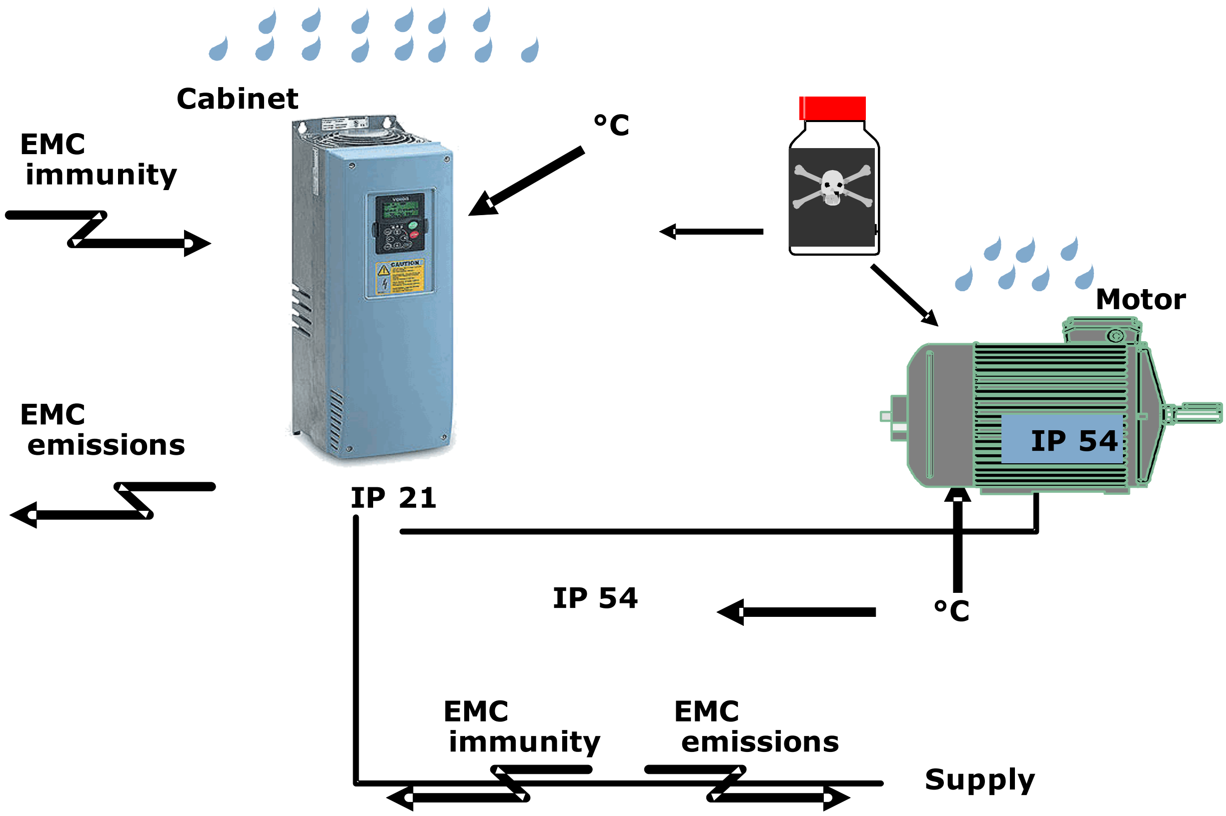



*Figure 18. Environmental factors and EMC of the AC drive*

## 4.3 Dimensioning of inverter unit for drive systems

When dimensioning a drive system consisting of several drives, each drive must be separately dimensioned in accordance with the dimensioning steps described in the above chapters.

## 4.4 Type of front end

In a common DC bus system, you need to select the type of the front end unit. When selecting the front end unit type, consider the following:

- Type of the supply network: What is the voltage range?
- What is the frequency range?
- What is the acceptable THD level? If the acceptable THD level of the supply network is very low, < 5%, the front end unit must be Active Front End (AFE). If the acceptable THD level of the supply network is higher, >5%, the type of the front end unit can be either AFE or Non-regenerative Front End (NFE).
- What kind of process will the drive be used in? If braking is needed often, and the braking power is relatively high, an AFE unit is a relevant option. Otherwise an NFE is adequate.

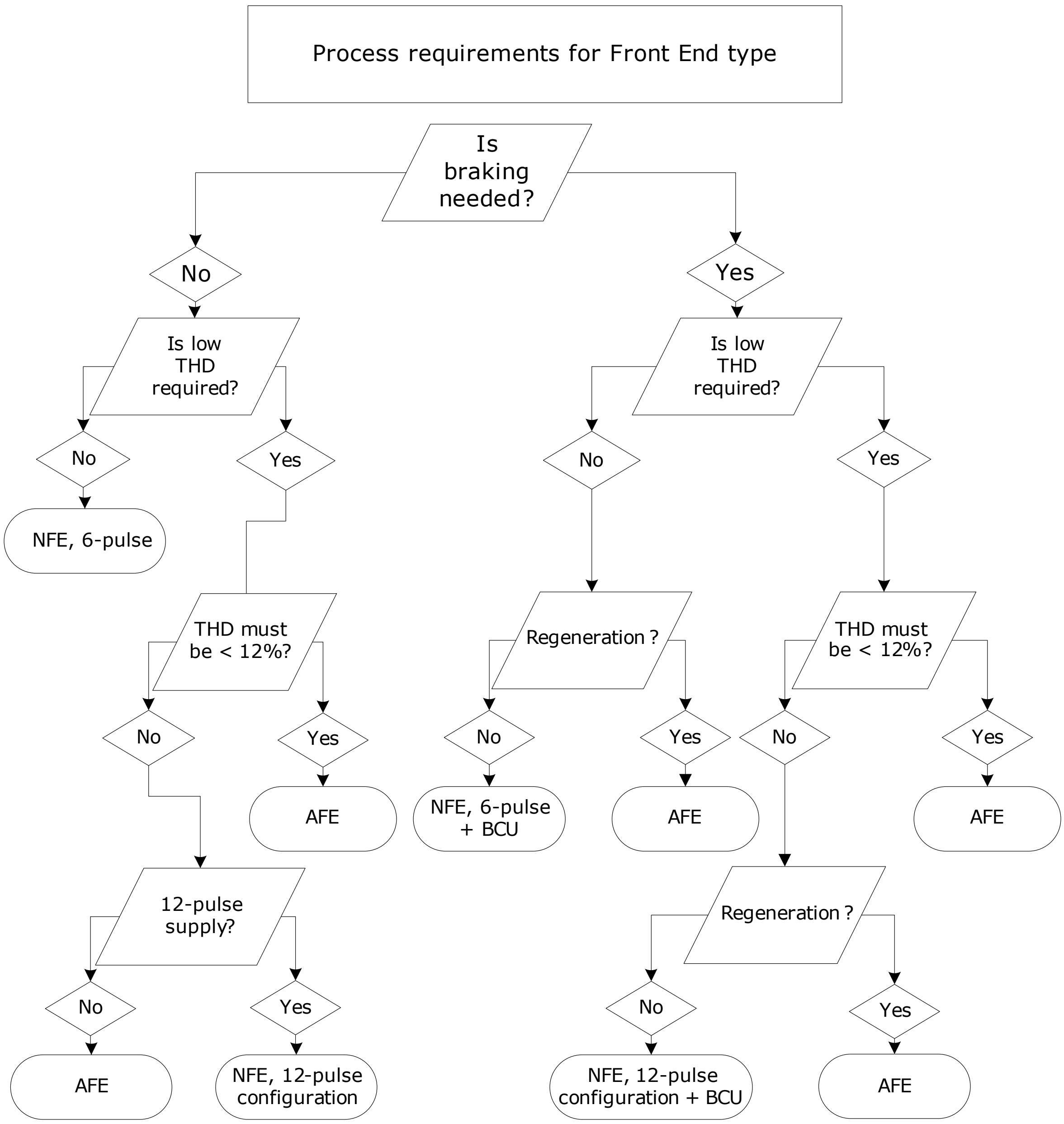



*Figure 19. Front End selection guidelines*

## 4.5 Dimensioning of front end for drive systems

The dimensioning of the rectifier is based on the shaft power required and on the efficiency of the system. The required shaft power is not necessary the same as the sum of the nominal rated motor powers. You must know the maximum instantaneous power on the DC bus, and consider the direction of power (motoring/generating).

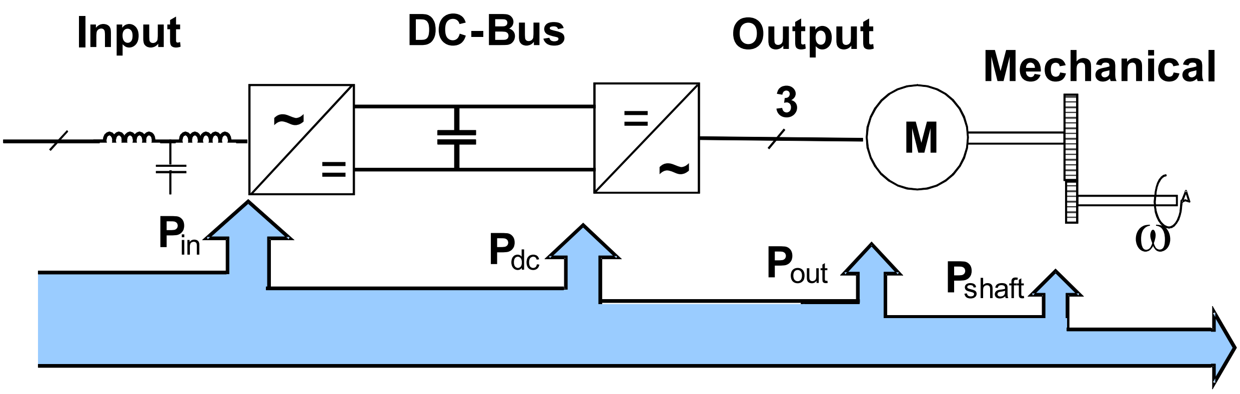
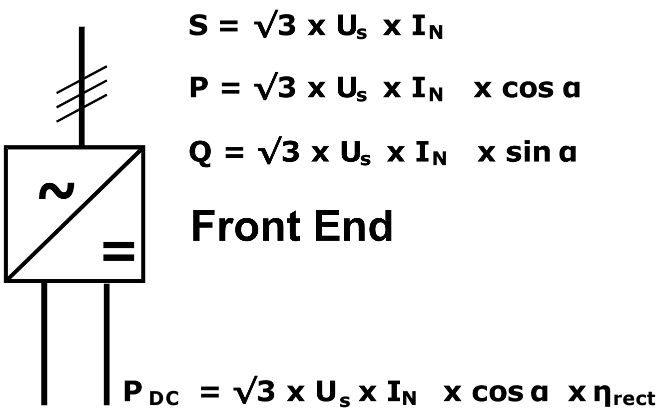



*Figure 20. Dimensioning the front end*

Parameters needed for correct dimensioning are:

- Supply voltage
- Sum of shaft powers, including direction of power
- Efficiency of the inverter unit
- Efficiency of the output filter(s)
- Efficiency of the motor(s)

The rectifier takes apparent power (S) from the supply network. Apparent power includes a reactive power component (Q) and an active power component (P). The rectifier can only transfer active power to the DC link. The power factor of the rectifier determines how much reactive power is taken from the supply network. The power factor of an AFE is 0.99 and the power factor of an NFE is 0.93. When you calculate the DC link power, you must take into account the efficiency of the rectifier.




*$I_N$ is the nominal current of the unit and $\eta_{rect}$ is the efficiency of the rectifier.

*Figure 21. Calculating the DC link power*

If you connect rectifiers in parallel, there is an unbalance between the rectifier modules. When you calculate the DC link power, you must take this unbalance into account by derating 5% for each rectifier. You can only connect same type of rectifiers, AFE and AFE **or** NFE and NFE, in parallel.

### 4.5.1 Calculating the values

- Determine the required shaft power.
- Calculate the required motor input power by dividing the required shaft power by the efficiency of the motor.
- Calculate the required output power of the inverter. Divide the required motor input power by the efficiency of the output filter.
- Calculate the required DC power. Divide the required output power of the inverter by the efficiency of the inverter.
- The DC power of the rectifier must exceed the calculated value.
- Calculate the required AC current

You can calculate the DC power of the AFE based on the $I_{L\text{-}cont}$ current you find in the manuals. If you need to calculate the power for the $I_{H\text{-}cont}$ current, you can use the current ratio.

$$P_{H-cont} = I_{H-cont} / I_{L-cont} \times P_{L-cont}$$

For $P_{1min}$ you must use the overloadability ratio.

$$P_{1\min} = 1{,}1 \times P_{L-cont} \qquad \text{OR} \qquad P_{1\min} = 1{,}5 \times P_{H-cont}$$

### 4.5.2 Examples of how to calculate the DC power

Motor's load is 270 kW, with the speed of 1700 rpm, and the load type is constant torque. You need a 280-kW motor and an inverter. The efficiency of the motor is 0.96 and that of the inverter is 0.98. If you need an output filter, you must take that into account, too. The rated DC powers of Vacon Front End Units can be found in the product manuals. The required DC power can be calculated using the following formula:

$$P_{DC} = P_{shaft} \times \frac{1}{\eta_{motor}} \times \frac{1}{\eta_{filter}} \times \frac{1}{\eta_{INU}}$$

Where:

$P_{DC}$ = the DC power needed from the rectifier

$P_{shaft}$ = the motor shaft power needed

$1_{motor}$ = the efficiency of the motor

$1_{filter}$ = the efficiency of the output filter (if not used, then =1)

$1_{INU}$ = the efficiency of the inverter

In the example, no output filter is used, thus the required DC power from the rectifier is:

$$P_{DC} = 270kW \times \frac{1}{0{,}96} \times \frac{1}{1} \times \frac{1}{0{,}97} = 290kW$$

The DC power of the rectifier should exceed the calculated value.

If accurate efficiency values are not available, you can calculate the required DC power using the following formula:

$$P_{DC} = P_{shaft} \times \frac{1}{0{,}9}$$

If more than one inverter is connected to the same DC bus, the total DC power requirement is the sum of the required power of the inverters. You must dimension the rectifier so that it can handle that power.

If the rectifiers are connected in parallel (to the same AC supply), the total rectifier DC power is the sum of the DC power of the rectifiers. To get the total DC power, the sum has to be derated by 5%.

If the system has inverters which are used for motoring purposes and other inverters which are used for regenerating purposes, then the required DC power can be calculated by using the following formula:

$$P_{DC} = \Sigma P_{motor} \times \frac{1}{0{,}9} - \Sigma P_{gen} \times 0{,}9$$

Where:

$P_{DC}$ = the DC power needed from the rectifier

$P_{shaft}$ = the motoring power needed

$1_{motor}$ = the regenerative power needed

## 4.6 Derating due to high ambient temperature

The current rating of an air cooled Vacon NXP drive unit is valid for ambient temperatures up to 40ºC. If the drive unit is to be used in higher ambient temperatures, its current rating must be subjected to derating, in order to keep the thermal load of the main components below the specified level. The derating coefficient is typically 1.5%/1ºC. Maximum ambient temperature is 50ºC.

For more detailed instructions regarding the derating of both air cooled and liquid cooled Vacon NXP drives, see the relevant product manuals.

## 4.7 Derating due to high altitude

In higher altitudes air is thinner. Thin air has poor thermal capacity, i.e. temperature rise per absorbed energy at fixed volume. Thin air also has poor ability to withstand electric field (breakdown voltage / distance).

Full thermal performance of Vacon frequency converters has been designed for the altitude of up to 1000 m (air-cooled units), and electric insulations have been designed for the altitude of up to 2000 m (Vacon NX, Vacon 100 and 1000).

If you need to install Vacon's drives to a higher altitude, follow the guidelines given in the following chapters. The rules are based on user safety.

### 4.7.1 Thermal performance

The power losses of a frequency converter are generally proportional to the output current. This is why the thermal performance is given as a percentage of the rated full output current. The full thermal performance of Vacon's frequency converters is achieved at installation altitudes up to 1000 m.

When the installation altitude is above this limit, the maximum load current must be decreased by 1% for each 100m. Thus at the altitude of 2500 m the load current must be limited down to 85% of the rated output current. (100% - (2500 m - 1000 m) / 100 m x 1% = 85%)

The installation altitude has no effect on the thermal performance of Vacon's liquid cooled frequency converters.

### 4.7.2 Electric insulation

The installation altitudes of Vacon AC drives have been specified for the worst case conditions at the altitude of 2000 m. i.e. both at the highest value of the rated mains voltage range and corner-grounded network system (corner grounding is possible for the 500V drives only.)

Higher installation altitudes are possible, with the following limitations.

#### *4.7.2.1 Mains voltage*

Maximum installation altitude of the 500 V Vacon NX units, 480 V Vacon 10 units and 500 V Vacon 100 / 1000 units is up to 3000 m at rated voltage, if the network is not corner-mounted. In special cases higher installation altitudes may be possible, with certain limitations.

Maximum installation altitude of the 690 V Vacon NX units is 2000 m. At higher locations the mains voltage should be limited to equal or less than 519 V, and these products are not designed for this voltage level (aux. power supply operating voltage range)

#### *4.7.2.2 High voltage I/O signals*

The relay output signals at standard I/O boards and option boards, when all relay circuits are connected to the same supply voltage are specified for up to 250 V at the altitude of 2000m (OPT A2 and OPT AC are exceptions, they can be used only up to 150 V voltage at 2000 m). The signals can be used at 150 V up to the altitude of 4866 m, with the following exceptions:

- OPT B5 can be used at 250 V up to the altitude of 4866 m and
- OPT BF can be used at 250 V up to the altitude of 3800 m and at 150 V above that

The relay output signals at standard I/O boards and option boards, when another relay circuit on the same board is connected to a low voltage circuit (e.g. 24 Vdc) can be used up to 150 V voltage up to the altitude of 4888 m, with the following exceptions:

- OPT AC can be used at 150 V up to the altitude of 3000 m and at 100 V above that
- OPT AF and OPT B5 can be used at 250 V up to the altitude of 2000 m and at 150 V above that

High voltage digital inputs at option boards are specified for the range from 42 - 250 Vac at the altitude of 2000 m and can be used at the range of 42 - 150 Vac at the altitude of up to 4866 m with the following exception:

- on OPT B9 board, if the relay output next to the HV input is connected to a low voltage circuit (e.g. 24 Vdc), the voltage at this input must be limited to 150 V up to the altitude of 2000 m and 100 V above that.

Thermistor inputs at option boards are specified for the nominal motor voltages up to 690 V and they can be used at the same voltage level and altitudes as specifies in the chapter Mains Voltage.

## 4.8 Appendix

### 4.8.1 Units of measure

*Table 2. Units of measure*

| | | |
|---|---|---|
| Torque | T | [Nm] |
| Force | F | [N] |
| Moment of inertia | J | [kg m$^2$] |
| Shaft power | Pm | kW |
| Gear ratio | i | |
| Angular velocity | ω | [rad/s] |
| Angular acceleration | a | [rad/s$^2$] |
| Rotational speed | n | [rpm] |
| Flow | Q | [m$^3$/s] |
| Speed | v | [m/s] |
| Pressure | P | [Pa] |

### 4.8.2 Mechanical theory: Force

Unit of force is [kg m/s$^2$]. At constant speed the force:

$$F = m \times g \times (\sin a + \mu \times \cos a)$$

Acceleration force is:

$$F_a = m \times a$$

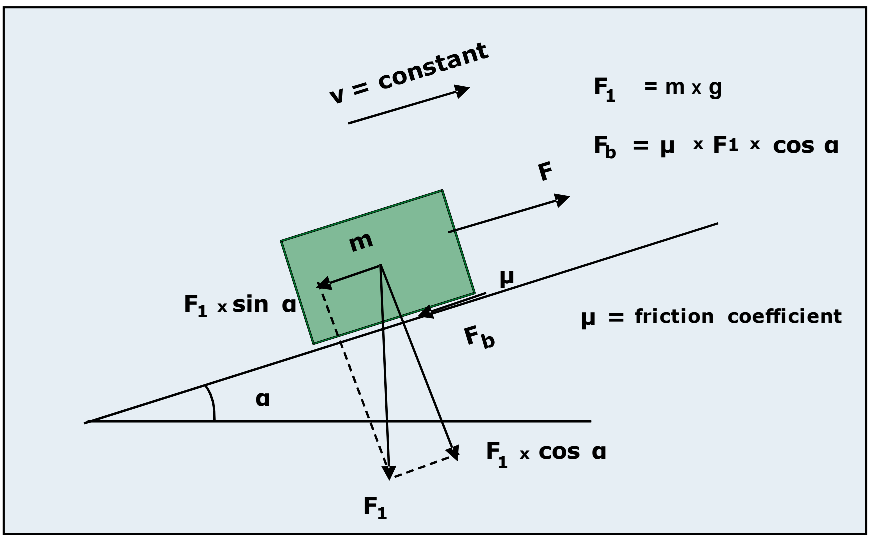



*Figure 22. Force*

### 4.8.3 MECHANICAL THEORY: TORQUE

Unit of torque is [Nm]

Constant speed:

$$T = F \times r$$

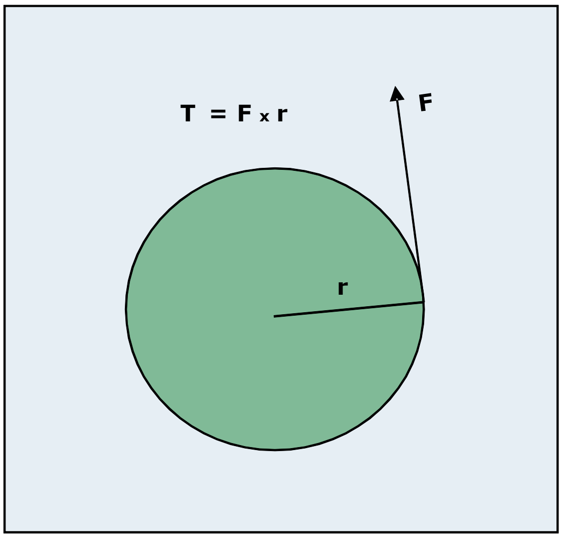



Figure 23. Torque

Acceleration:

- $\omega$ = angular velocity, [rad/s]
- a = Angular acceleration, [rad/s$^2$]
- J = Inertia, [kg m$^2$]

$$T = J \times a \qquad T = J \times \frac{d\omega}{dt}$$

### 4.8.4 MECHANICAL THEORY: INERTIA

Mass and inertia have a damping effect on acceleration.

Unit of inertia is [kg m$^2$]

Inertia of a solid roll:

$$J = \frac{M \times R^2}{2}$$

Inertia of an “empty” cylinder:

$$J = \frac{M \times (R_1^2 + R_2^2)}{2}$$

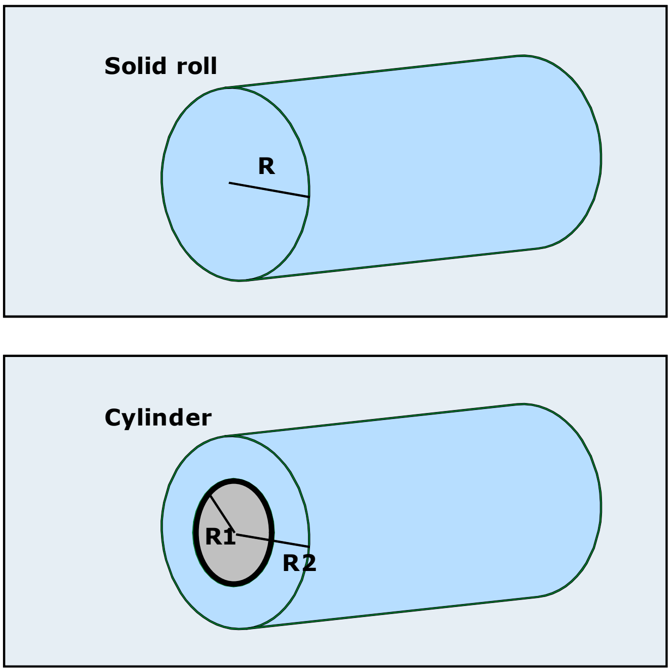



Figure 24. Inertia

### 4.8.5 Mechanical theory: Power at constant speed

Power is the work obtained by the force over a certain length per unit of time.

| Work: | Rotational work: |
|---|---|
| $W = F \times s$ | $W = T \times \theta$ |
| Power: | Rotational power: |
| $P = F \times v$ | $P = T \times \omega$ |

### 4.8.6 Mechanical theory: Acceleration

Acceleration torque is the extra torque needed to accelerate from speed 0 to $n_{max}$ at a given acceleration time t.

$$T_a = J \times \frac{(\omega_m - 0)}{t} [Nm] \qquad T_a = J \times \frac{2 \times \pi \times n_m}{60 \times t} [Nm]$$

Acceleration power at $n_{max}$:

$$P_a = T_a \times \omega_m \qquad P_a = J \times \frac{\omega_m^{\ 2}}{t} [W] \qquad P_a \approx \frac{J \times n_m^{\ 2}}{91189 \times t} [kW]$$

# 5. EMC, PRINCIPLES AND PRACTICES

Electromagnetic compatibility (EMC) is an important part of drive system design. The high frequency components of frequency converter's output voltage and current, due to the high switching speeds can cause significant problems, for example control system malfunction and communication errors, if EMC is not taken care of.

A device can be described as electromagnetically compatible, if its emissions are at an acceptable level and its immunity to interference is appropriate. Electromagnetic compatibility, (EMC), includes both immunity to external interference and low emitted interference.

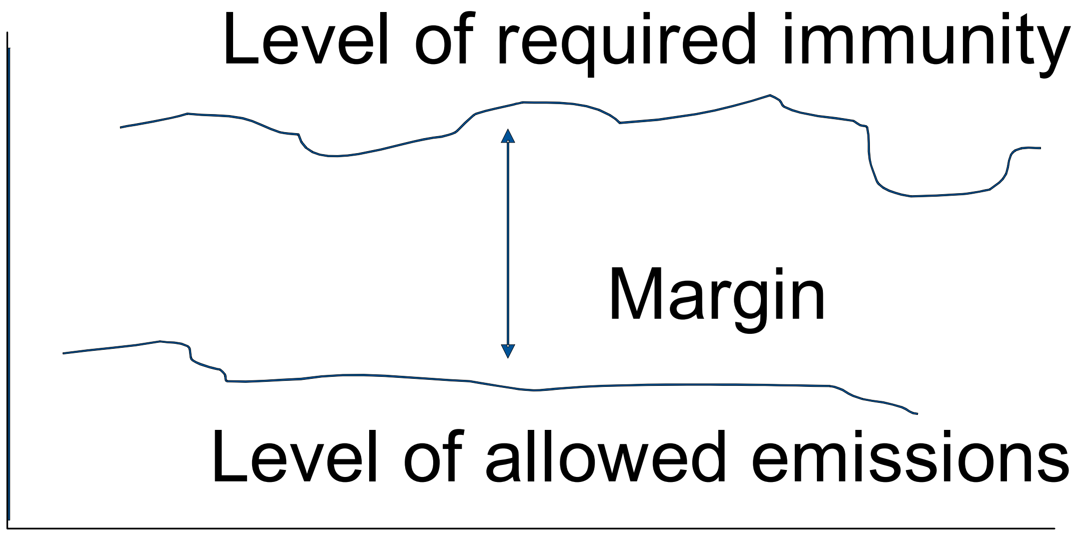



*Figure 25. Acceptable EMC level*

Electromagnetic immunity to interference defines the operational reliability of the device in its intended environment. It describes how the device behaves under the influence of electromagnetic interferences coming from an external source.

The electromagnetic emissions of a device define its capability to interfere with other electric circuits, devices and systems located in the same environment.

Any electric device can simultaneously be a source and a target of electromagnetic interference. With drives, you normally need to define only the acceptable emission level. All Vacon's drives have industrial grade immunity against electromagnetic interference.

Examples of interference types include high-frequency voltages, transients, electrostatic discharges and radiating electromagnetic fields.

Low frequency disturbances are discussed in chapter "Harmonics" on page 43.

## 5.1 THE EMC DIRECTIVE

The EMC directive is a New Approach directive and it is valid for all equipment and apparatus for sale within the EU. The directive does not set out detailed technical requirements, but only essential ones. It also sets out ways of complying with the essential requirements. The EMC directive is a public document, and it is available on the internet in the *Official Journal of the European Union (OJEU).* Detailed requirements are found in the harmonised standards published in the *OJEU*.

#### 5.1.1 Essential requirements

The directive states two essential requirements:

“Equipment shall be so designed and manufactured, having regard to the state of the art, as to ensure that:

- the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;
- it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.”

#### 5.1.2 Compliance

If a relevant harmonised standard exists and is listed in the Official Journal of the EU, compliance with this is considered compliance with the essential requirements.

### 5.2 Standards in europe

There are several standards that may be relevant for frequency converters. The actual standard documentation is available for purchasing on the internet: www.iec.ch/webstore. IEC standards are global standard of International Electrotechnical Commission. EN is European Norm. EN standards, if they are listed in the EMC directive represent a European law on the matter.

- IEC/EN 61800-3 for power drive systems
- IEC/EN 61000-6-1 and -2 for generic cases regarding immunity, public and private networks
- IEC/EN 61000-6-3 and -4 for generic cases regarding emissions
- EN 55011 - the basic standard for EMC (CISPR 11)

Of the above listed, EN61800-3 is a product family standard and, as such, takes precedence over the generic standards (EN55011, EN61000-6-1, -2, -3 and -4). With drives, the generic standard is more demanding than the product family standard, which is usually not the case. For drives, the less demanding product family standard has been accepted, because drives are much less numerous than household equipment, such as TV’s radios, computers, etc. Therefore the impact of drives on the electromagnetic environment is much less.

### 5.3 Standards outside europe

The body responsible for regulation of EMC emissions in the USA is the Federal Communications Commission (FCC). The specific regulations are Part 15 (Radio Frequency Devices) and Part 18 (Industrial, Scientific and Medical Equipment).

In Canada the tendency is towards following the IEC standard.

In the rest of the world, if any standard is followed, it is usually the global IEC standard.

**Note!** For IT networks conducted emission limits are not defined. Due to the nature of the network, you cannot measure the disturbance level. However, the essential requirements of the EMC directive are still valid, and usually an EMC plan must be created. See chapter “EMC plan” on page 36.

## 5.4 Environments

The standards define two environments: the first environment and the second environment.

### 5.4.1 First environment

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

First environment is also known as public networks, or residential environment. In EN 55011, Class B limits are applied in this environment.

### 5.4.2 Second environment

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

Second environment is also known as private networks, or industrial environment. In EN 55011, Class A limits are applied in this environment.

## 5.5 Four drive categories by EN 61800-3

In addition to environments, the standard EN 1800-3 defines four categories for power drive systems. Vast majority of drives today can be considered part of categories 2-4, depending on the customer and application details. A Category C1 drive is, according to the definitions, a movable product equipped with plugs for connecting to the motor/supply.

In practice, the emission levels for Category C2 and C3 defined in the standard EN 61800-3 are similar to those required for the industrial environment by EN 55011 class A, and the generic standard EN61000-4.

**PDS (Power Drive Systems) of category C1**

Drive systems with rated voltage of less than 1 000 VAC, intended for use in the first environment.

**PDS of category C2**

PDS with rated voltage of less than 1 000 VAC, which is neither a plug-in device nor a movable device and, when used in the first environment, is intended to be installed and commissioned only by a professional. A professional is a person or an organisation having necessary skills in installing and/or commissioning power drive systems, including their EMC aspects.

**PDS of category C3**

PDS of rated voltage less than 1000 VAC, intended for use in the second environment and not intended for use in the first environment. (Note that limits change at 100 A.)

**PDS of category C4**

PDS of rated voltage equal to or above 1000 VAC, or rated current equal to or above 400 A, or intended for use in complex systems in the second environment. (Note that limits change at 100 A.)

### 5.5.1 EN 61800-3 versus generic standards

The standards are compared here as regards emission levels.

*Table 3. Comparison of standards*

| Generic standard (EN 55011) | EN 61800-3 |
|---|---|
| Generic commercial level, Class B | First environment, Category C1 |
| Generic industrial level, Class A | First environment, Category C2 |
| Group 2 equipment | Second environment, Categories C3 and C4 |

Vacon NX and Vacon 100 are designed to meet the requirements of the EN 61800-3, and they can be used in any environment, if installed by a competent electrician.

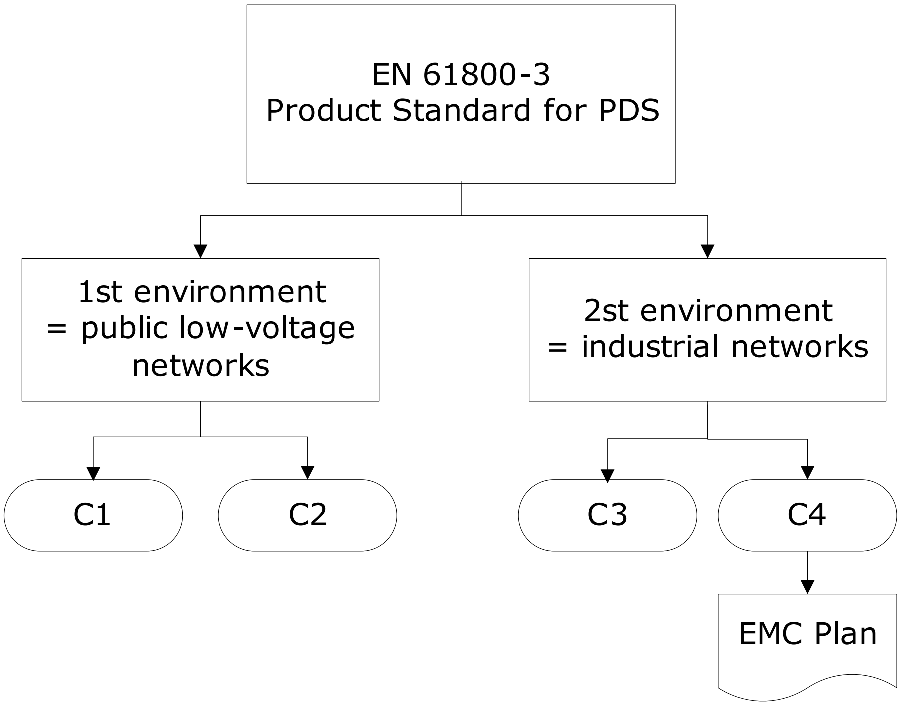



*Figure 26. Standards, environments and classes*

### 5.5.2 EMC plan

An EMC plan is needed for large installations. EMC plan describes the methods used to achieve electromagnetic compliance. The plan covers the entire installation, including filters, installation procedures, grounding, shielding, mechanical construction etc. Exact content or structure of an EMC plan has not been defined.

## 5.6 Conducted emission levels

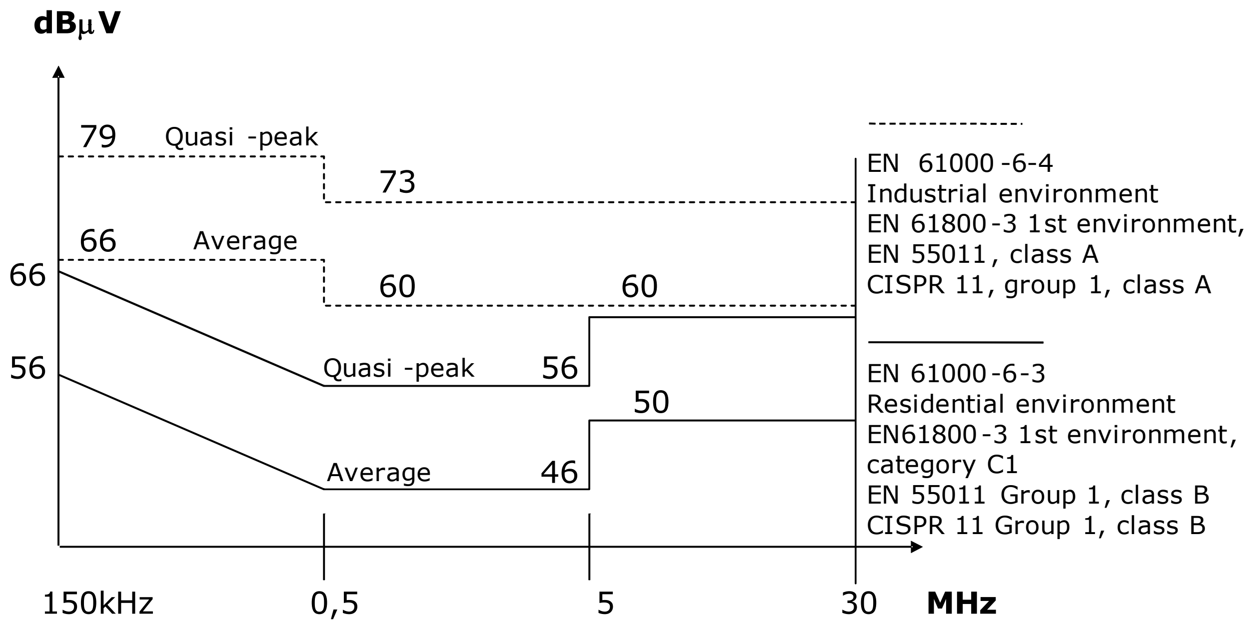



*Figure 27. Comparison of standards regarding conducted emission levels.*

## 5.7 Radiated emission levels

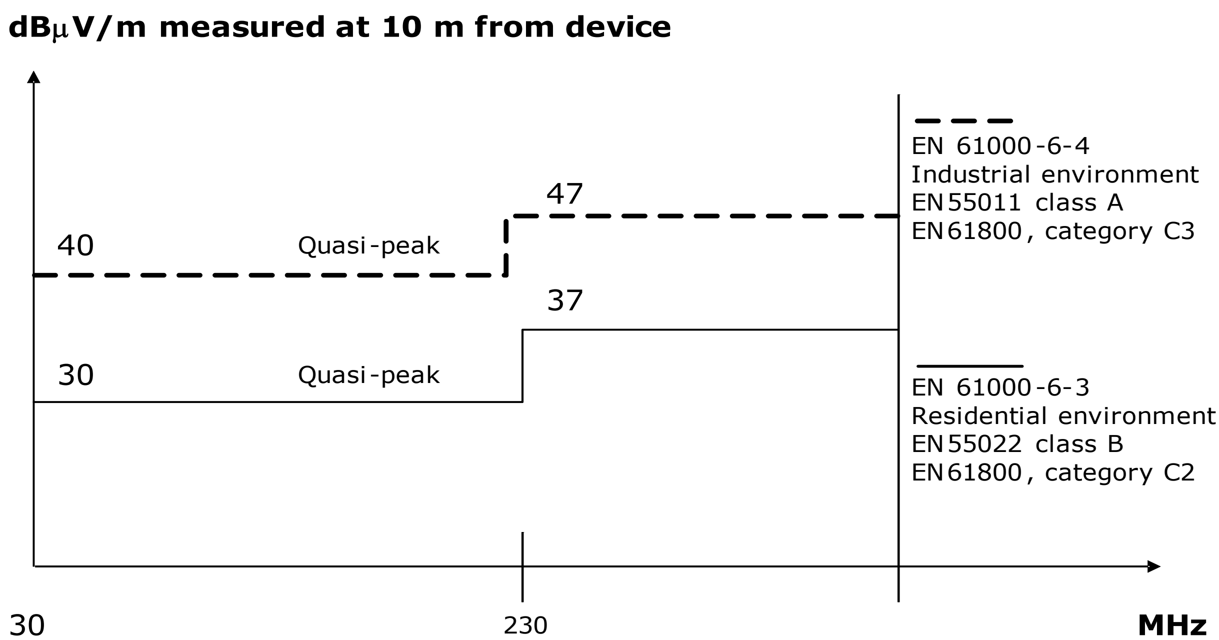



*Figure 28. Comparison of standards regarding radiated emission levels*

## 5.8 Good engineering practices regarding EMC

Find out what type of environment the drive will be used in. Choose the drive type accordingly. The drive types listed in the following table refer to the type designation code that designates the EMC emission level in accordance with the EN 61800-3.

*Table 4. EMC emission suppression in Vacon AC drives*

| Type | Compliance |
|---|---|
| N | None |
| H | Complies with the industrial environment requirements of the generic standard, and also with the 1st environment C2 requirements |
| C | Complies with the commercial environment requirements of the generic standard, and also with the 1st environment C1 requirements |
| T | Designed for IT networks |
| L | Complies with the C3 and C4 requirements for the 2nd environment |

Drives of type ...H... are usually suitable for all applications. The ...C... type is recommended for use in hospitals and laboratories etc. External filters can be used to provide additional reduction of EMC emissions.

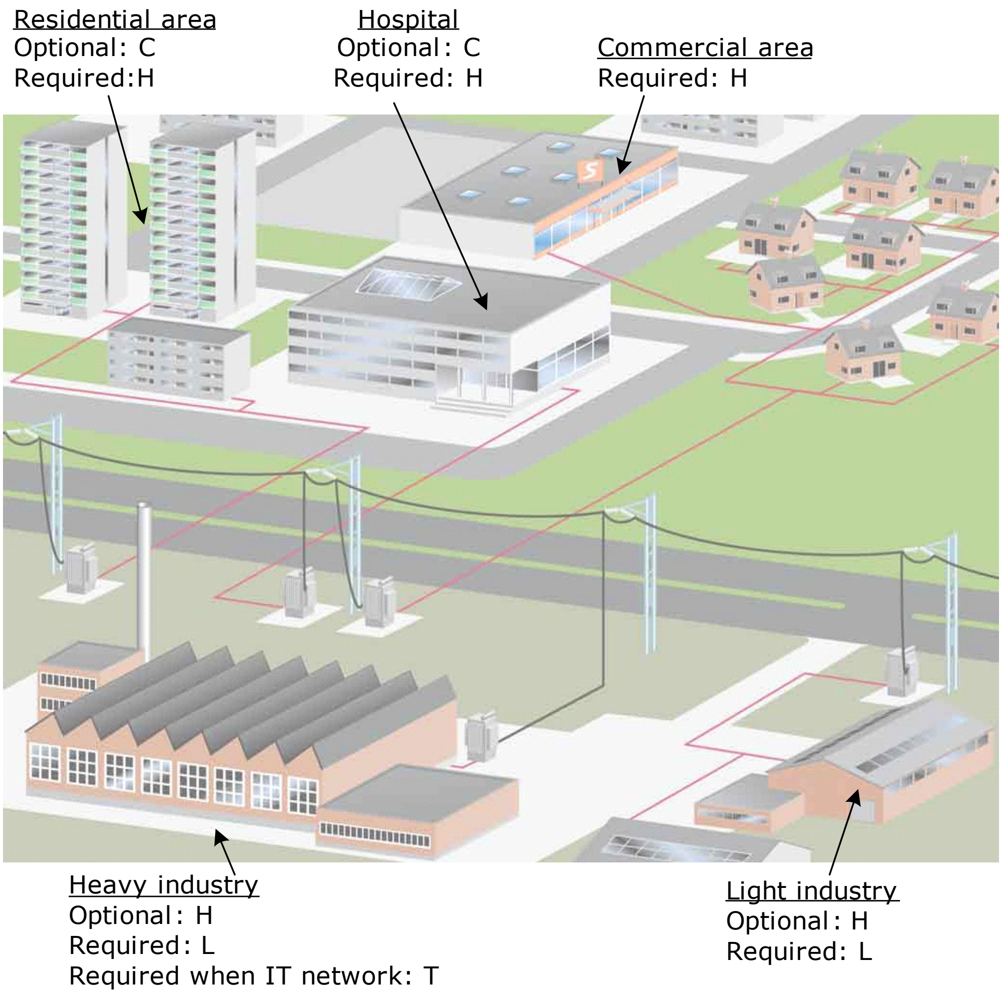



*Figure 29. Environments and Vacon's EMC classes*

### 5.8.1 Motor cable and grounding

The most basic guideline within installations is to optimise the physical separation between interference sources and potentially sensitive equipment. In drive systems, shielded cables are often the key to appropriate protection, as motor cables are the main source of interference. Grounding also needs special attention.

The motor cable plays an important role in relation to the electromagnetic interference of the drive system. With right cable selection interferences can be avoided. The type of the cable is of particular importance for the radiated emission of the cable.

In the industrial environment a shielded cable is usually sufficient. In public environment, a cable with a low impedance shield for high frequencies is needed.

We recommend that you use symmetrical three-phase cables with symmetrical phase conductors, symmetrical PE conductors and symmetrical shield, whenever possible. Single core cables are not recommended.

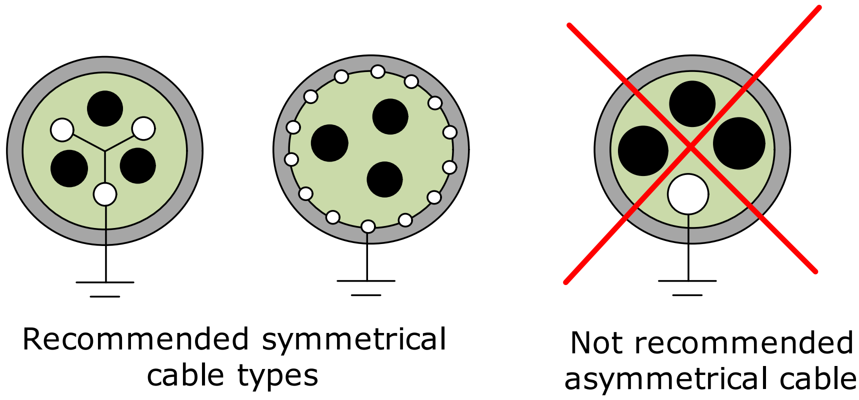



*Figure 30. Two symmetrical cables and an asymmetrical cable*

If the cable shield is made of iron, it offers protection from EMC disturbance, but cannot be used as PE. An iron shield cable can only be connected at the inverter end, and it must be isolated at the motor end. A separate PE conductor must be used. For EMC purposes, both ends of the motor cable shield must be 360° grounded.

Grounding may not form a loop, but it must be in star configuration. If there is a potential difference between the devices, it must be equalised by proper grounding.

Keep the motor cable as short as possible, both inside and outside the drive enclosure. You can use the shield of the motor cable for grounding purposes when the cross section of the shield is greater than 50% of one phase conductor. Otherwise, use a separate ground conductor. If you install components between the motor and the drive, make sure that the shield is continuous.

The standard EN/IEC 61800-5-1 defines the requirement of the PE conductor as follows:

*Table 5. Cross-section of protective earthing conductor*

| Cross-sectional area of phase conductors of the PDS/CDM/BDM S ($mm^2$) | Minimum cross-sectional area of the protective earthing conductor ($mm^2$) |
|---|---|
| $S \le 16$ | S |
| $16 < S \le 35$ | 16 |
| $35 < S$ | S/2 |

The values are valid only if the protective earthing conductor is made of the same metal as the phase conductors. If this is not so, the cross-sectional area of the protective earthing conductor shall be determined in a manner which produces a conductance equivalent to that which results from the application of the values presented in the table above.

The cross-sectional area of every protective earthing conductor which does not form part of the supply cable or cable enclosure shall, in any case, be not less than:

- 2,5 mm$^2$ if mechanical protection is provided

or

- 4 mm$^2$ if mechanical protection is not provided. For cord-connected equipment, provisions shall be made so that the protective earthing conductor in the cord shall, in the case of failure of the strain-relief mechanism, be the last conductor to be interrupted.

For special systems topologies, such as 6-phase motors, the PDS designer shall verify the protective earthing conductor cross-section required. For more information, see the EN/ISO 61800-5-1.

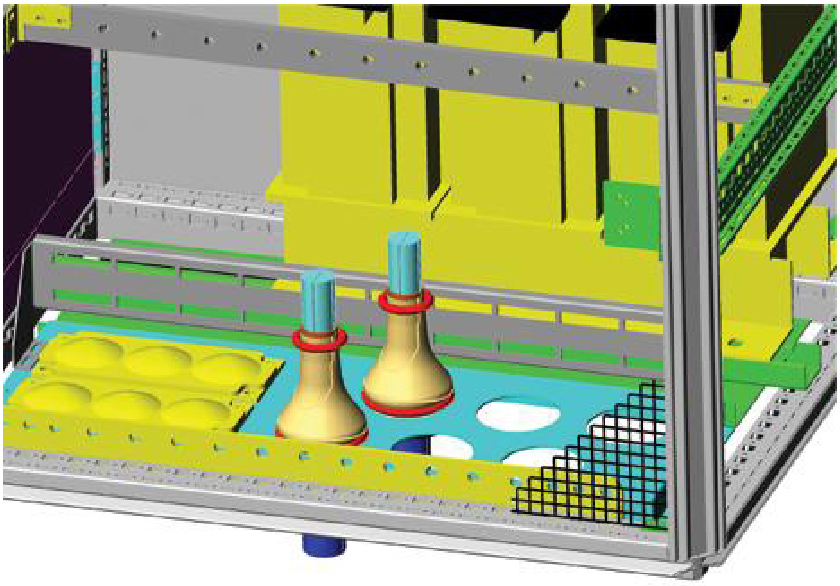


*Figure 31. Routing of supply and power cables*

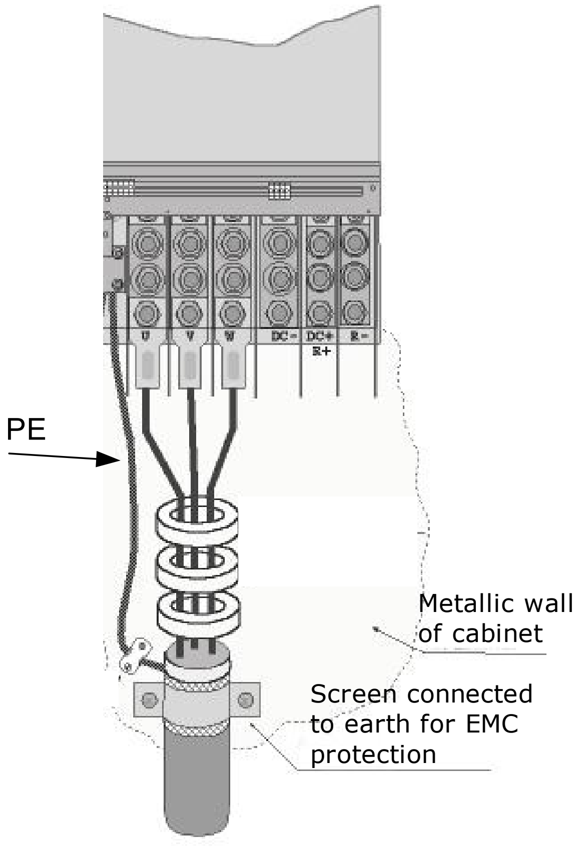



*Figure 32. EMC and PE grounding on single motor cable*

The EMC grounding must be suited to the output cable diameter to give a 360° contact with the cables. There are also cables in which the mechanical protection shield is made of iron. Due to high impedance of the shield, you must not use this type of shield for grounding, but it must be left open at the motor end. With iron shielded cable you always need a separate PE cabling. The separate PE cable must be connected to the motor and the drive's PE terminals.

If a device has been installed between the drive and the motor, the motor cable shield must be kept continuous. The shield must be connected at the input and output of the device so that a continuous low impedance connection between the two is ensured. If necessary, the components have to be installed in grounded sheet steel enclosures. The cables of auxiliary equipment, tachometers, encoders or other sensors must be shielded. The shield may not be broken by intermediate connectors, and must be connected at the drive end only.

### 5.8.2 Cable positioning

You must plan the enclosure layout as well as internal and external cabling so that the power, control, and signal cables are spatially separated.

In order to be efficient, a shield must have good conductivity, continuity (no gaps) and grounding. Proper grounding of signal cables is often the key to EMC. All external cables connected to the enclosure, except the supply cable, must be shielded. Signal cables should be shielded and have both ends 360° grounded. In addition, signal cables should not run close to power cables and never in parallel. If they have to cross, the angle should be 90 degrees. For distances between the cables, see the figure below.

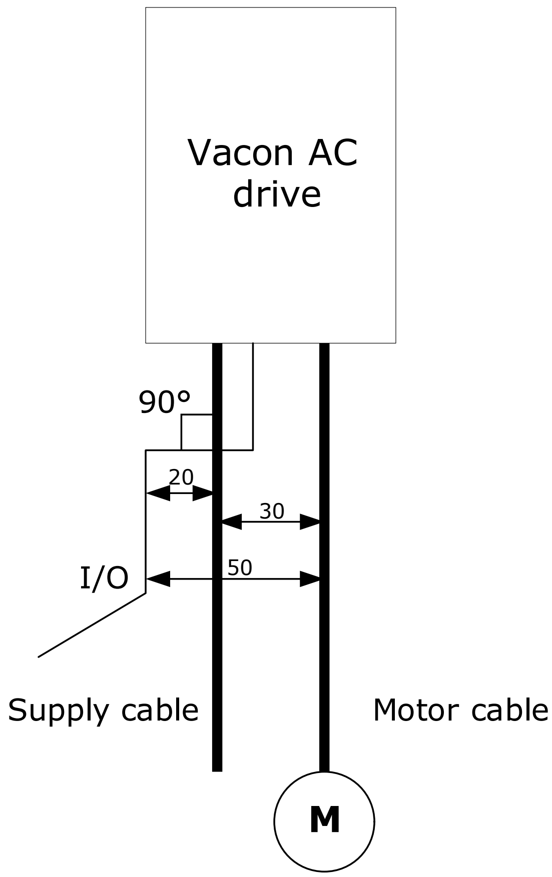



*Figure 33. Cable positioning and distances*

Connect the shield of I/O cables to ground at the drive end. If necessary, ground the non-drive end via a 10nF capacitor. Ground the fieldbus cable shield at each node. The end of the grounded shield (so called pigtail) must be kept as short as possible.

In order to reduce current in the shield, long cables can have multiple grounding or an additional conductor may be used.

If signal cable's isolation level is less than 230 VAC, you must not place the cables on the same cable tray with power cable or any other cables.

For more details on filters, see the Filter manual

# 6. Harmonics

Power systems are designed for 50/60 Hz operation, based on the assumption that all loads are linear and thus all currents are beautiful sine waves. In reality, many of today's devices are nonlinear - they have input currents that are far from sinusoidal - they contain harmonics.

Harmonic currents are multiples of the basic frequency, i.e. at 100, 150, 200 Hz.

$$f(t) = \sum_{n=1}^{\infty} A_n \sin/(n\omega t + \varphi_n)$$

Typical sources of harmonic currents include all devices containing switching power supplies or rectifiers, i.e. TVs, computers, copiers, etc. A strong source of harmonics is fluorescent lighting - either with electronic ballasts (switch mode power supply) or with conventional ballasts. In the industry, the main sources are power electronics - AC and DC drives, arc furnaces, etc.

For normal rectifiers, the amplitude of the harmonic decreases with increasing frequency. Theoretically, (for a square wave) $I_n = I_1/n$ - the amplitude of the n:th harmonic = fundamental current divided by the number (n) of the harmonic.

Power electronics generate only odd harmonics - even harmonics are excluded as long as the positive and negative halves of the current cycle are identical.

In three-phase systems only harmonics with the order *v= k * p+-1* exist, for a six pulse system these are the 5th, 7th, 11th, 13th etc.

- *v*= multiple of basic frequency
- *k* = 1,2,3,
- *p* = pulse number of the rectifier bridge (6,12,18 etc)

In single phase systems all odd harmonics may exist.

Note that as long as the voltage is not appreciably distorted, only the basic frequency transmits power, currents at other frequencies just flow, technically forming a kind of reactive current. For rectifiers the fundamental power factor is approximately 0.95 or higher.

Generally the power factor can be defined as kW/kVA =

$$pf = \cos\varphi \times \sqrt{1 - THD^2}$$

where cos phi = fundamental power factor and THD = the THD (total harmonic distortion) value in percent.

The THD is defined as

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} i_n^2}}{i_1}$$

where $i_n$= n:th harmonic and $i_1$ = fundamental current.

THD is a complex function of the load, supply transformer data and components of the frequency converter's circuit. Generally a big transformer (stiff source) leads to higher current distortion and lower voltage distortion and a small transformer (soft source) leads to lower current distortion and higher voltage distortion. As the size of the transformer is considered relative to the drive's load, this also means that the current distortion will increase with lower loads for a given source/drive combination, whereas the voltage distortion will decrease.

The harmonic currents added to the basic frequency current create a higher RMS current with higher heating effects in the wiring and transformer. The harmonic currents also flow through the impedance of the source (transformer or generator) creating harmonic voltages that can be "seen" through the system. These effects can have a severe impact on the transformer and on other devices connected to the same supply.

**NOTE:** In DOL applications the (sinusoidal) motor current is often higher than the input RMS current to a drive, due to the low power factor of a motor. The drive supplies the required reactive current to the motor. It is not taken from the mains.

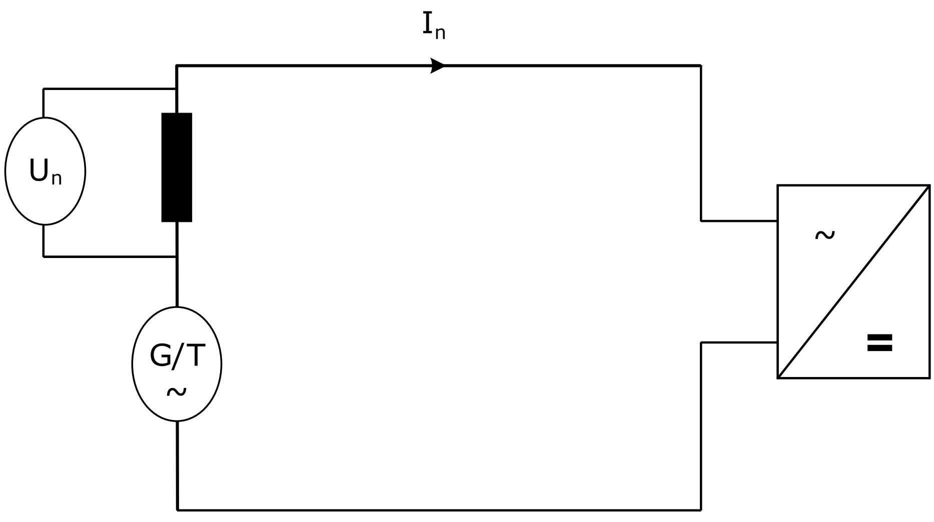



*Figure 34. Source of harmonic voltages*

The most problematical harmonic is the third, as the currents created in the three supply phases are added in phase in the neutral conductor and may overload it. Balanced three-phase loads do not create any 3rd harmonics - they are created by nonlinear single-phase loads, typically UPSs, fluorescent lighting and PCs as well as other office equipment.

Additional transformer heating caused by the harmonic currents can be calculated as defined in the standard IEC 61378 - 1

The derating factor is spectrum dependent - i.e. the spectrum influences the derating. A typical example is shown in the figure below.

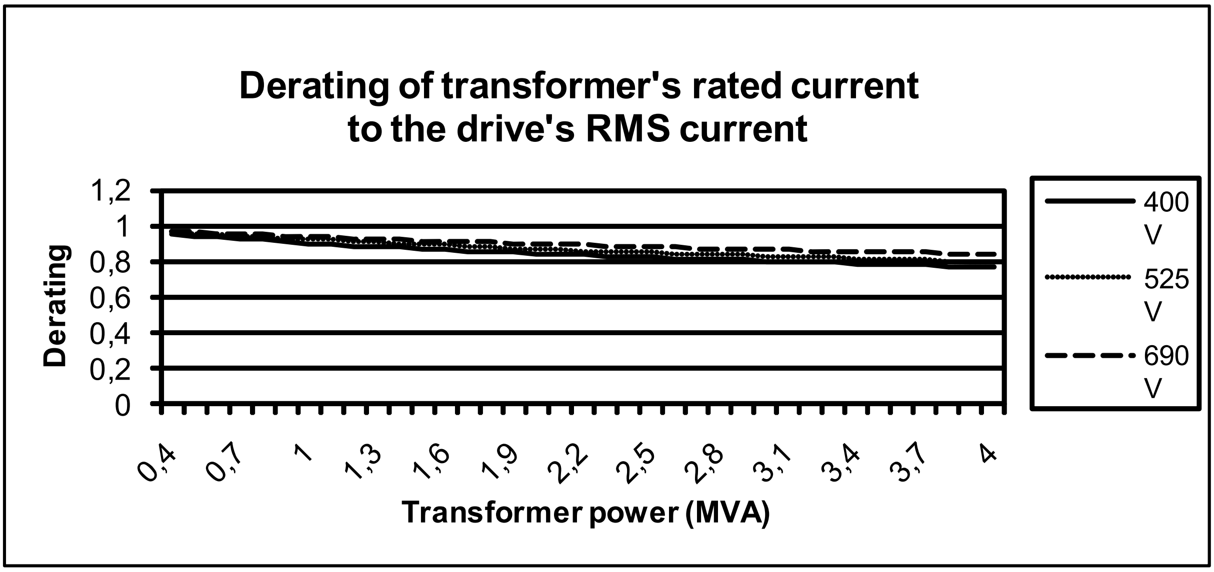



*Figure 35.Derating of transformer, typical drive spectrum*

## 6.1 EFFECTS OF HARMONICS ON MOTORS

The harmonic currents generated by non-linear loads do not affect direct-on-line motors. The harmonic voltages existing in the system might have significant influence on motor heating. The fifth harmonic creates a counter-rotating torque, the seventh one rotating in the original direction. The current drawn might be significant- the situation for the motor is as if it was starting with a large slip all the time- its impedance is low, hence even a low voltage might create high currents. In rare cases with high voltage distortion, this effect has been known to overheat motors.

## 6.2 Standards

### 6.2.1 Product standards

IEC has written two standards for the allowed harmonic content of the input currents of products connected to public supplies (supplies where anybody can connect anything):

- IEC 61000-3-2 for currents < 16 A per phase
- IEC 61000-3-12 for currents > 16 A and < 75 A per phase

Typically the allowed values depend on the short circuit power of the transformer - the smaller the transformer is, the lower the allowed harmonics.

According to the IEC 61000-3-2, drives are considered to be professional equipment for which no limits apply.

**NOTE:** No IEC standards exist for private (industrial) networks.

**Table 4 – Current emission limits for balanced three-phase equipment under specified conditions**

| Minimal $R_{sce}$ | Admissible individual harmonic current $I_n/I_1$ [a] % | | | | Admissible harmonic current distortion factors % | |
|---|---|---|---|---|---|---|
| | $I_5$ | $I_7$ | $I_{11}$ | $I_{13}$ | *THD* | *PWHD* |
| 33 | 10,7 | 7,2 | 3,1 | 2 | 13 | 22 |
| ≥120 | 40 | 25 | 15 | 10 | 48 | 46 |

The relative values of even harmonics up to order 12 shall not exceed 16/*n* %. Even harmonics above order 12 are taken into account in *THD* and *PWHD* in the same way as odd order harmonics.

NOTE Linear interpolation between successive $R_{sce}$ values is permitted. See also Annex B.

[a] $I_1$ = reference fundamental current; $I_n$ = harmonic current component.

*Figure 36. An extract from the IEC 61000-3-12 standard*

### 6.2.2 System standard IEEE 519:1992

IEEE 519:1992 - Recommended practices and Requirements for Harmonic Control in Electrical Power Systems

This is a recommendation for controlling harmonics in systems, and it should not be applied to single products. It calls for very low allowed values of harmonic loading - typically 5% THD at the point of common coupling (PCC). The PCC is generally "the location in the system where another customer can be served". The basic concept behind this is that no single user should emit harmonics to a degree that can disturb other users.

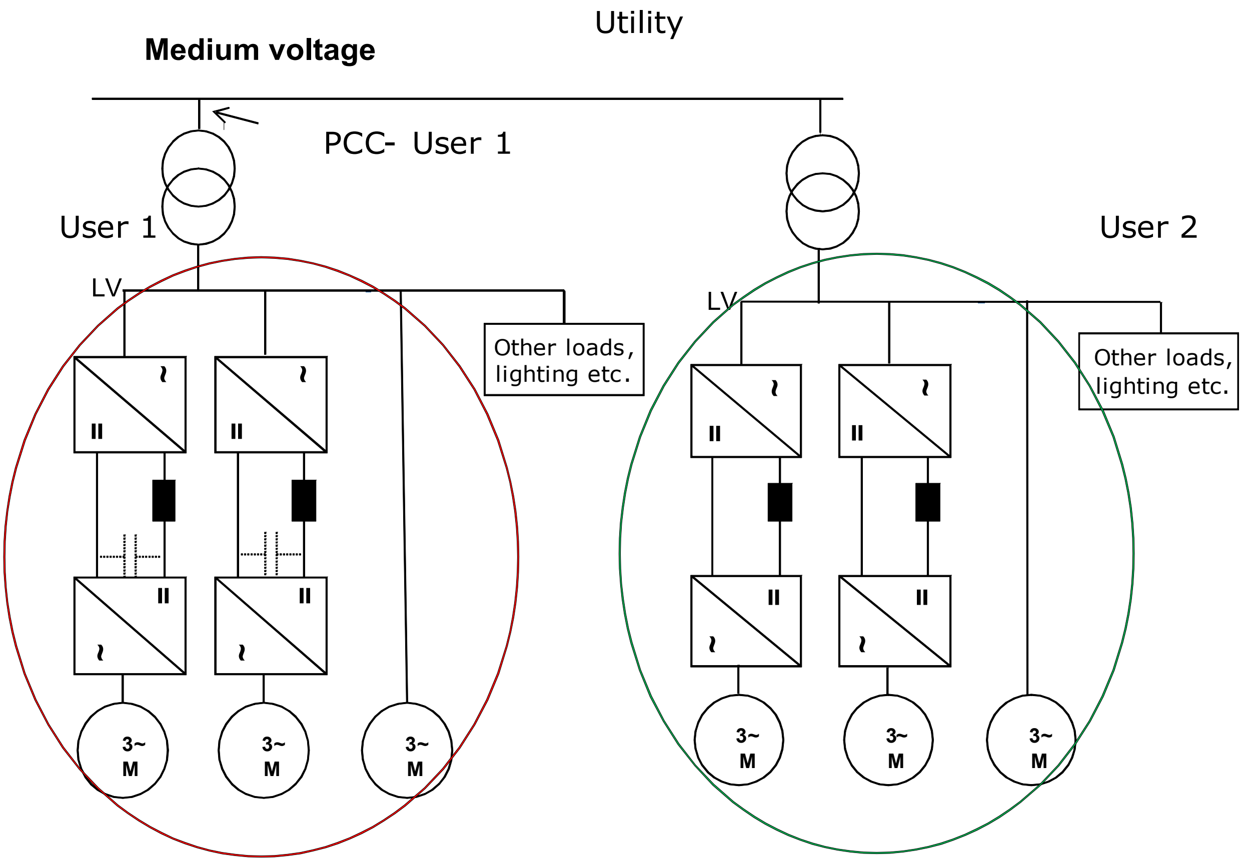



*Figure 37. Point of Common Coupling*

*Table 6. Basics for Harmonic Current Limits*

| SCR at PCC | Maximum individual frequency voltage harmonic (%) | Related assumption |
|---|---|---|
| 10 | 2.5-3.0 | Dedicated system |
| 20 | 2.0-2.5 | 1-2 large customers |
| 50 | 1.0-1.5 | A few relatively large customers |
| 100 | 0.5-1.0 | 5-20 medium size customers |
| 1000 | 0.05-0.10 | Many small customers |

The recommendation starts from the allowed voltage distortion as a function of SCR - the ratio of the short circuit power available at the PCC to the nominal load at the PCC.

These voltage requirements are translated into current requirements: The higher is the ratio of short circuit power to rated power, the higher is the allowed current emission.

*Table 7. Current distortion limits for general distribution systems (120v Through 69 000V), from the* standard IEEE 519:1992

| **Maximum harmonic current distortion on percent of $I_L$** | | | | | | |
|---|---|---|---|---|---|---|
| Individual harmonic order (Odd harmonics) | | | | | | |
| $I_{SC}/I_L$ | < 11 | 11 <= *h* < 17 | 17 <= *h* < 23 | 23 <= *h* < 35 | 35 <= *h* | TDD |
| <20* | 4.0 | 2.0 | 1.5 | 0.6 | 0.3 | 5.0 |
| 25<50 | 7.0 | 3.5 | 2.5 | 1.0 | 0.5 | 8.0 |
| 50<100 | 10.0 | 4.5 | 4.0 | 1.5 | 0.7 | 12.0 |
| 100<1000 | 12.0 | 5.5 | 5.0 | 2.0 | 1.0 | 15.0 |
| >1000 | 15.0 | 7.0 | 6.0 | 2.5 | 1.4 | 20.0 |
| Even harmonics are limited to 25% of the odd harmonic limits above. | | | | | | |
| Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed. | | | | | | |
| *All power generation equipment is limited to these values of current distortion, regardless of actual $I_{SC}/I_L$. | | | | | | |
| where<br>$I_{SC}$ = maximum short-circuit current at PCC.<br>$I_L$ = maximum demand load current (fundamental frequency component) at PCC. | | | | | | |

The demand load current is the total fundamental frequency current (i.e. including all linear and non-linear loads) at the PCC.

## 6.3 Reducing harmonics

### 6.3.1 Chokes

The amplitude of the various frequencies naturally decreases with increasing frequency, so in order to decrease the harmonics further, the impedance at higher frequencies must be increased - a choke must be used. AC or DC - from the point of view of harmonics, their effects are similar. The expected value of THD can change from about 120% (very small or no choke and large transformer) down to about 30% - large choke and small transformer.

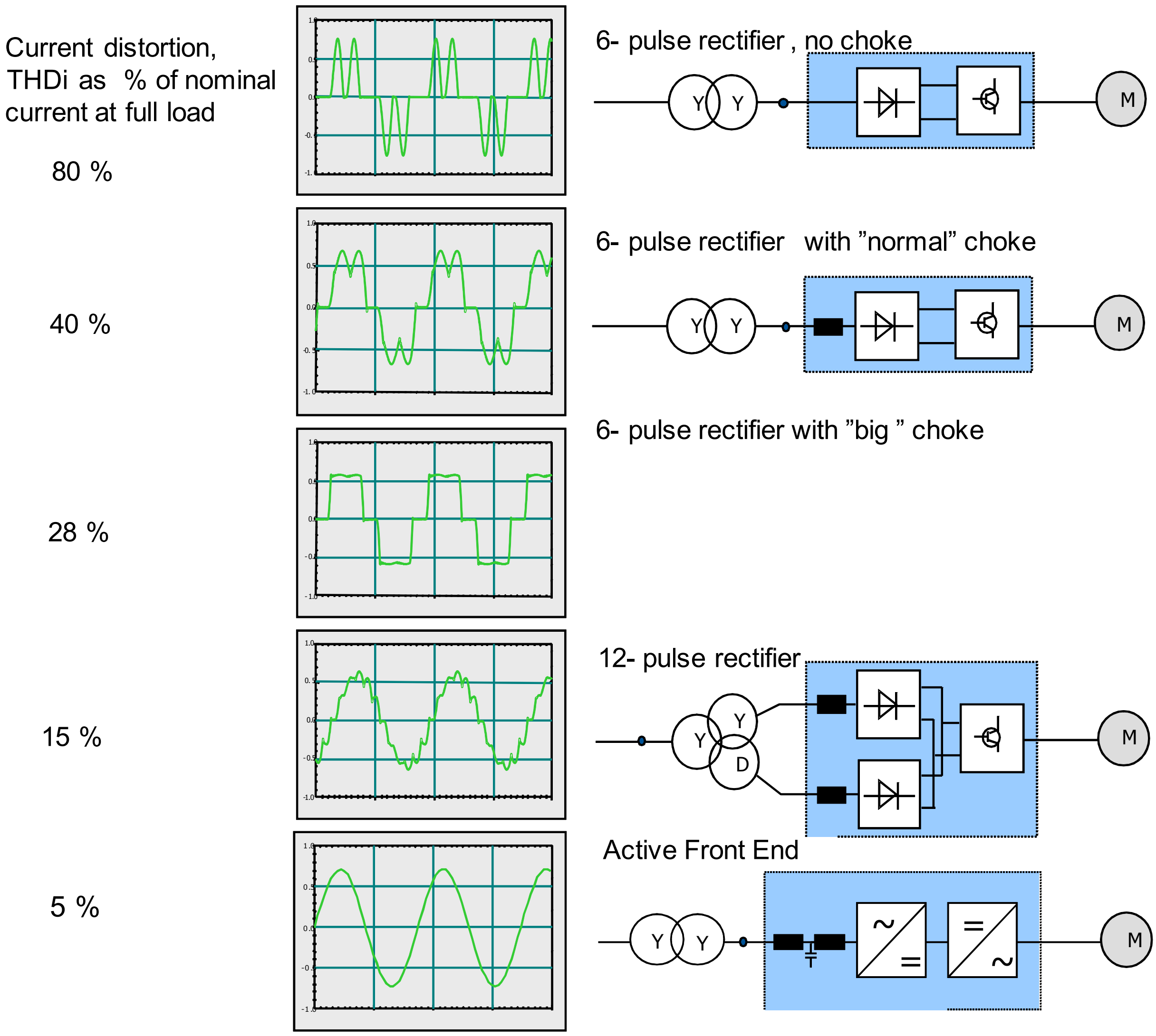



*Figure 38.Typical values for FCs with different rectifier types*

### 6.3.2 Tuned filters

Use a tuned filter (a trap filter) for the 5th and 7th harmonics. This usually requires a system analysis and a stable system, as changes in the supply may cause unwanted resonances.

Tuned filters are available from many suppliers. They usually consist of chokes and capacitors suitably tuned to the harmonic that must be eliminated. Their size is significant, as is the cost associated.

### 6.3.3 Active Front End

An effective way to eliminate harmonic currents is to use an active front end (AFE). It consists of a normal three-phase inverter bridge connected via an LCL filter to the supply. The IGBTs in the inverter bridge are controlled so that a sinusoidal current is drawn from or supplied to the supply - they can thus also regenerate power back into the supply - a feature used in many power generating applications as well as in cases where braking is often required. The power factor of the input current can also be changed, so an AFE can also be used to compensate phase shifts caused by other loads on the supply - within its current rating. An AFE is always sized for the full load current.

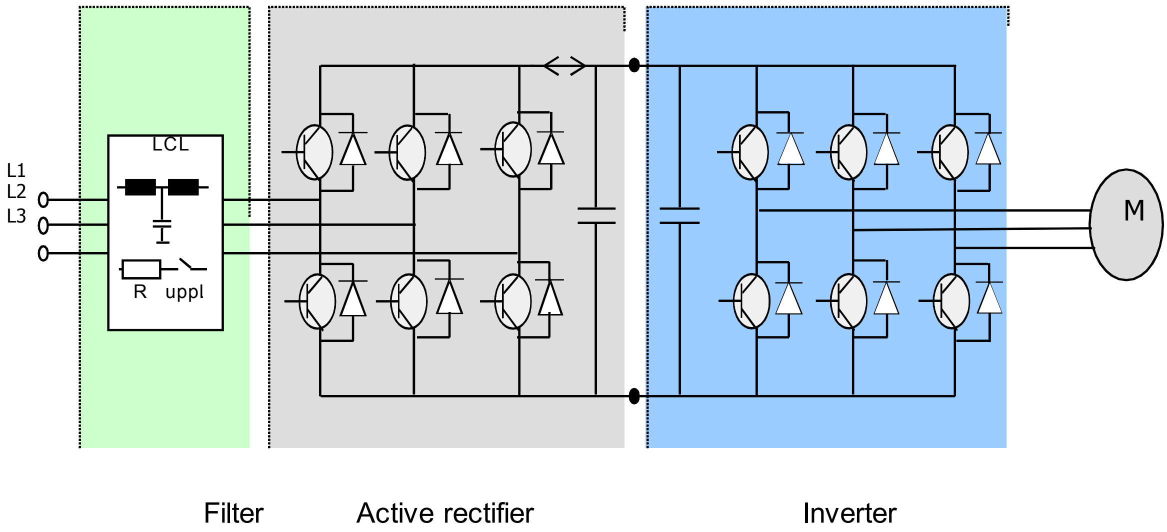



*Figure 39. Active front end*

### 6.3.4 Multipulse connections

A traditional method to reduce harmonics is to use a multipulse transformer, with the windings for multiple three-phase groups arranged in such a manner that the harmonics from the groups cancel in the magnetic circuit of the transformer and are eliminated from the input current of the transformer.

The most common is a 12 pulse system - where two phase groups are connected to the load, eliminating the 5th and 7th harmonic and leaving the $11^{th}$ $13^{th}$ $23^{rd}$ $25^{th}$ etc. The resulting THD in the input current is about 10%. Note that due to challenges in transformer design in balancing the phase groups the cancellation is rarely perfect, some traces of the $5^{th}$ and the $7^{th}$ harmonic remain.

Note that the transformer can be used to change voltage levels from MV to LV at the same time. The main drawback is the size, weight and cost of the required transformer, as well as the need for multiple input rectifiers on the drive. The same effect can also be achieved by distributing equal loads on two windings of your feeding transformer.

Eighteen-pulse systems also exist - with three phase groups - this system eliminates all harmonics up to the 23rd, so the existing ones are 23, 25, 41, 43 etc, and the resulting THD is about 5%.

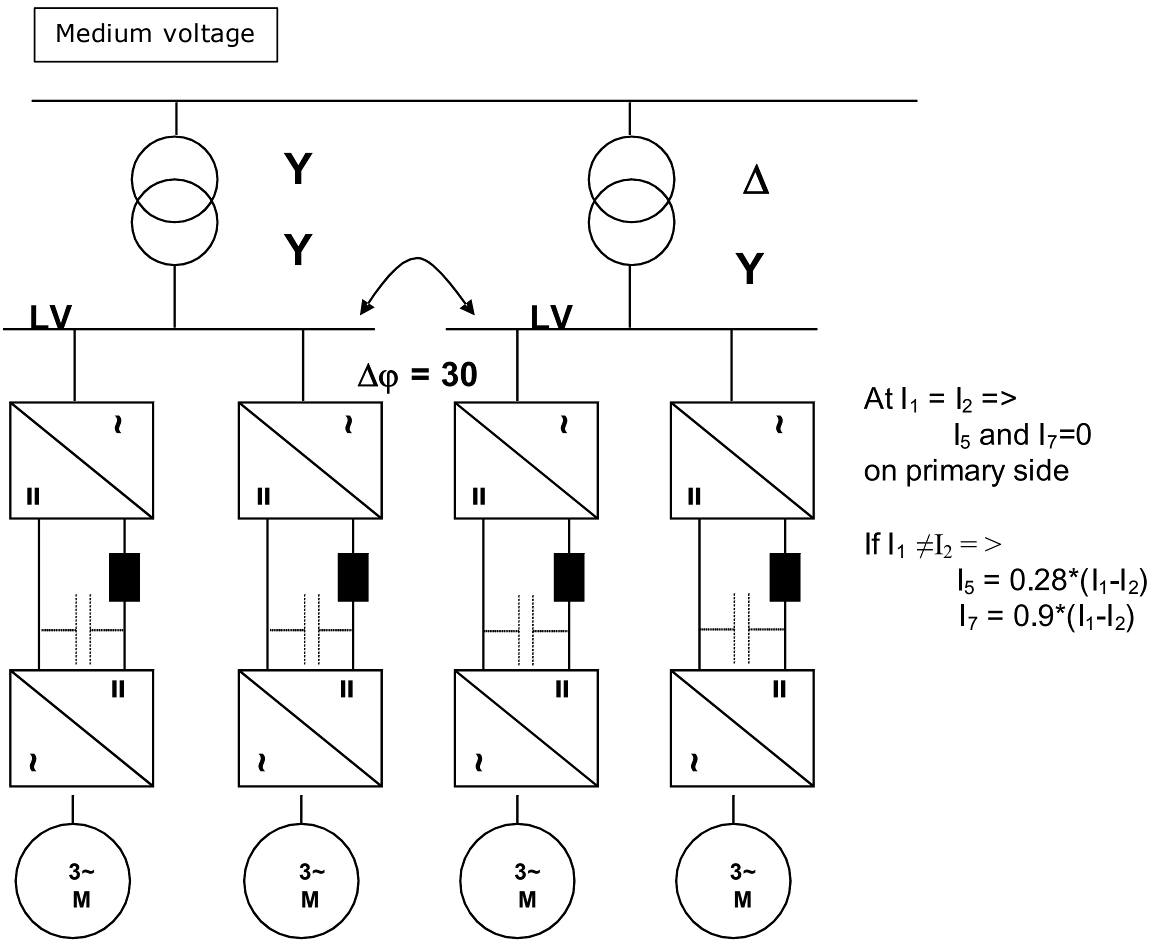



*Figure 40.Using two transformers to cancel harmonics*

### 6.3.5 Passive filters

Some manufacturers offer a passive filter to eliminate the harmonics. The performance of a passive filter is approximately the same as that of a 12 pulse trafo. They consist of chokes and capacitors in a low pass configuration and their size is usually considerable. Passive filters are serial devices and thus sized for the full load current.

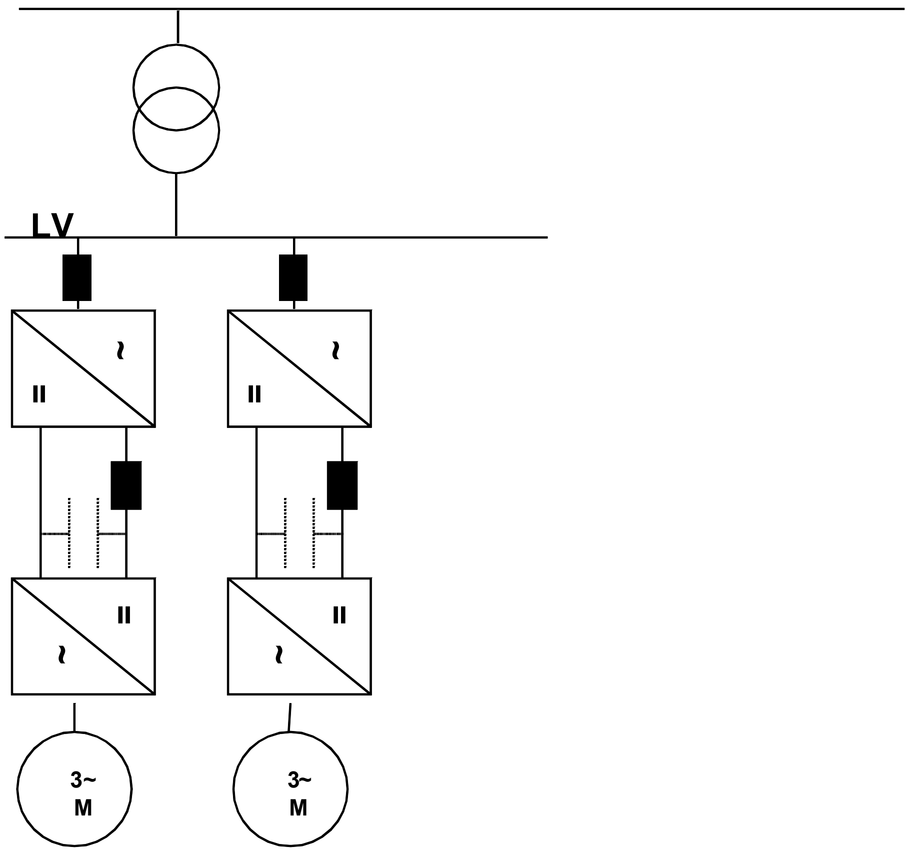



*Figure 41. Passive filter*

#### 6.3.6 Active filters

You can use an active filter to eliminate the harmonics. Active filter diverts the harmonics from the transformer by injecting “anti-harmonics” into the supply. This makes the load on the transformer seem fully linear.

The filter can be sized for the harmonics only, as it is connected in parallel with the load and does not need to handle the full load current.

Note that using active filters will cause the drive to generate higher harmonics, as the filter creates zero impedance spots at the harmonic frequencies (as seen by the drive) and this might overheat the input chokes.

Active filters are available from a number of suppliers.

The resulting THD is about 2-5%, depending on the actual parameters of each specific case.

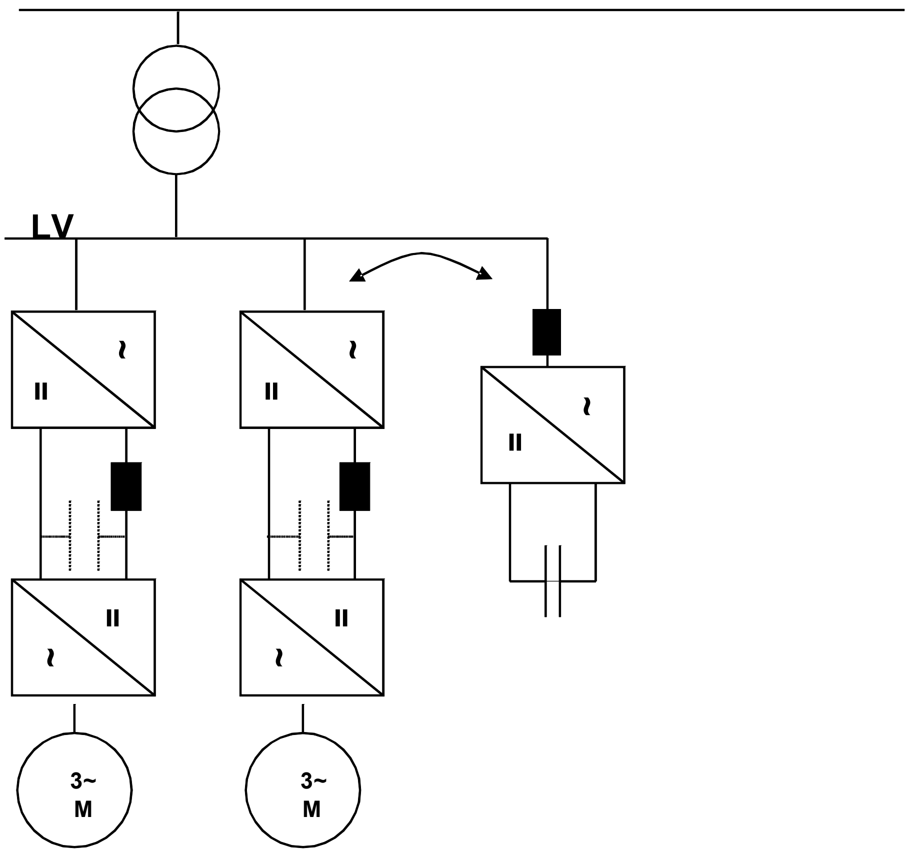



*Figure 42. Active filter*

# 7. Contactors, breakers and fuses

All Vacon AC Drives include internal protection against short circuits taking place at the output of the drive,  for example in motor terminals or motor cables. During a short circuit at the output, mechanical protection devices at the supply, such as circuit breakers, fuses or contactors do not show any high currents flowing through them. Fault current at the output of the drive is turned off by semiconductor transistors (IGBT's) in a few microseconds.

To protect the input cables and also to limit the damages inside the drive in case of an internal failure in the drive, you need to select a proper protective component.

You need to know the approximate short circuit rating of the drive's supply grid to select the right components for the protection of the entire electrical drive system. The short circuit current from the supply must be high enough to burn the fuses in a sufficient time, but it must not be too high. All protective components have limits for maximum short circuit current. For fuses, this value may be from 10kA to 200kA, depending from the fuse series or size, and for some miniature circuit breakers it might be as low as just a few kilo amperes.

It is important to make sure that the short circuit rating of the protective component is high enough. Selecting of an underrated protective component may lead into catastrophic damages.

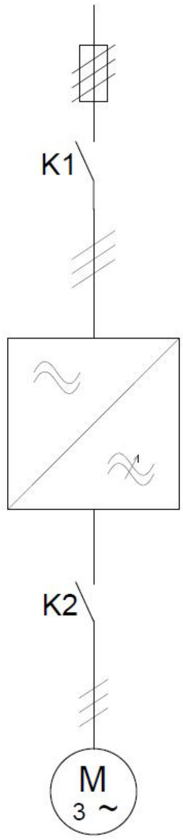
## 7.1 Contactors

You can use a contactor to switch frequency converter's power on and off by local or remote control or by emergency stop. Typically a contactor is used on the AC-power supply side of a frequency converter, but it can also be used on the motor side or even by-pass the converter and connect the motor directly to the mains network. Contactors should have always a protective component in the circuit preventing contacts to be melted in case of short circuit.

A contactor is seldom used in the DC-side of an inverter, but technically it is possible. However DC-contactors with high breaking capacity are rare. In these cases contacting the contactor manufacturer for detailed technical information is highly recommended. When contactors are used in DC-circuit, typically 2 or more contacts are connected series.

*Figure 43. A contactor*

### 7.1.1 Dimensioning




Rating of the contactor is defined by its location in the electric circuit.The current values of AC1 and AC3 are available in technical contactor catalogue. When a contactor is on the network side (K1), dimensioning is based on contactor's AC1 current, because cosφ of input current is close to 1 and frequency is typically 50-60Hz. At motor side cosφ is lower, typically about 0.85, and current has low and high frequencies, so output side contactor (K2) must be dimensioned by the AC3 current with additional current reserve.

A by-pass contactor is dimensioned in the same way as a direct on line (DOL) which is used typically without a frequency converter. Dimensioning is based on the AC3 current and the contactor must be equipped with an overload protection relay.

The control voltage of a contactor can be chosen in accordance with the control voltage of the system, typically 24VDC, 115VAC or 230VAC. Keep in mind that control voltage and main voltage must be properly separated for safety reasons.

### 7.1.2 Auxiliary contacts

Contactors have typically 3 main contacts for switching the power on and off. In addition, they may have a number of auxiliary contacts. These may be normally open or normally closed, and they may be used for other controls which operate simultaneously with the main contacts. Typical use for an auxiliary contact is contactor feedback for the "run" input of the drive or emergency stop relay.

## 7.2 Breakers

Several different types of circuit breakers can be used in the main power circuit and the auxiliary circuit of a frequency converter. In drive systems the most common types are air circuit breakers (ACB) and moulded case circuit breakers (MCCB). In addition, there are vacuum circuit breakers (VCB) and miniature circuit breakers (MCB).


*Figure 44. A moulded case circuit breaker and a single pole MCB*

### 7.2.1 Air circuit breakers

Air circuit breakers can break high voltages and currents (typically up to 6,000 A). Typical application for an air circuit breaker is the main breaker of a switchgear, because it has high short circuit breaking capacity. The dimensioning is based on the capacity of the busbars and thus the power of the whole switchgear. When an ACB is used with a frequency converter, the drive system has to include a device that quickly cuts each frequency converter's power off in case of a short circuit. Usually an ultrafast fuse is used for that purpose since an ACB is not fast enough.

An ACB can be equipped with several types of electronic relays which are used for selecting the breaking curve. Also spring loading motor, opening, closing and under voltage coils are used when ACB opening and closing must be controlled electrically. Opening an ACB by positive electrical pulse (opening coil) is not recommended, as it is not failsafe. In most applications it is even against the rules. Using an undervoltage coil for opening is recommended.

### 7.2.2 Moulded case circuit breakers

Moulded case circuit breakers can break only lower voltages and currents (typically up to 1000 A) and are used in smaller applications. Also, the short circuit capacity may be a limiting factor if you think of using an MCCB as switchgear's main switch. Typical applications include overload and short circuit protection of frequency converter, or main switch of a compact size switchgear. Some MCCB's operate fast and thus ultrafast fuses may not be needed, if only one frequency converter is fed by the MCCB.

Similarly to an ACB, also an MCCB can be equipped with a spring loading motor, opening, closing and undervoltage coils for electrical control of opening and closing. Opening an MCCB by positive electrical pulse (opening coil) is not recommended, as it is not failsafe. In most applications it is even against the rules. Using an undervoltage coil for opening is recommended.

### 7.2.3 Miniature circuit breakers

Miniature circuit breakers (MCBs) can be used to protect low power electric circuits (current ratings up to 100 A). In general, the breakers can be used for overload and short-circuit protection, and mainly in low power main circuit and auxiliary and control circuit. The trip level of an MCB is usually not adjustable but fixed for each breaker. Typical short circuit breaking capacity is up to 6kA. The most important parameters include breaking voltage and current as well as nominal voltage and current.

The choice of an MCB depends on the load type and the MCB's trip characteristics. The most common breaker types are:

**Type B**

Type B is used for resistive loads which do not cause large switching currents. It is suitable for protection of a low power frequency converter.

**Type C**

Type C covers also loads that are slightly inductive or capacitive and can have larger switching currents than type B. It is also suitable for protection of low power frequency converter, but its tripping time is more slow than that of type B. Type C is the most common MCB used to protect auxiliary circuits.

## 7.3 Fuses

Fuses protect electric equipment under overload and short-circuit conditions providing a similar function as circuit breakers. The main benefit of a fuse is that it is usually able to cut off current considerably faster and thus limit overcurrent and subsequent damage better than a circuit breaker. On the other hand, you can reset a circuit breaker after it has tripped, but a fuse is destroyed in the process and has to be replaced.

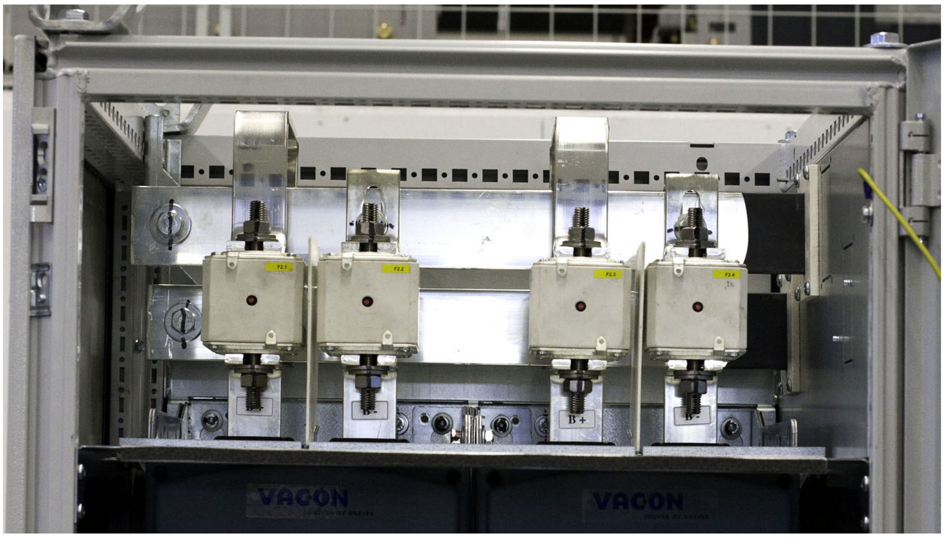
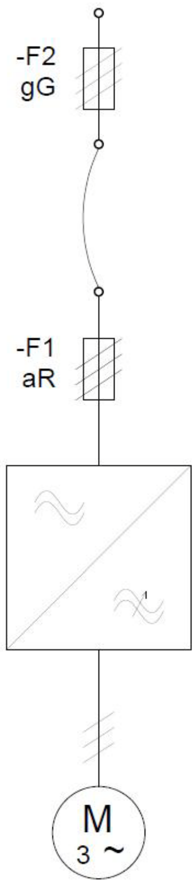



*Figure 45. Bolt type fuses*

In correctly dimensioned frequency converter systems the drive itself provides protection against overloads, but additional short-circuit protection is required. Supply cables should be protected at the supply end against short circuit and overloads.




Typically, ultra fast fuses (aR) are sufficient for protection of frequency converters against short circuit, and they reduce the damage inside the frequency converter in case a short circuit happens inside the drive. Smaller size or low cost frequency converters are protected only with regular speed fuses (gG) as ultra fast fuses are quite expensive and gG fuses ar more affordable. A regular speed fuse (gG) protects from both short circuit and overload, so it is suitable for protecting the supply cables too in the feeding end.

### 7.3.1 Selecting the fuses

See the Vacon product manuals to select the correct fuse type for your frequency converter. Especially with high power frequency converters you may be able to select from several different fuses that are suitable, depending on what kind of fuses are required by the switchgear construction. Usually you can choose between using one set of high current fuses, typically bolt connected, or using parallel smaller knife type fuses. Main parameters for selecting correct fuses are drive's amperage, voltage and required mechanical construction. Also, frequency converters (AC) and inverters (DC) require different fuse types.

# 8. SUPPLY NETWORK AND POWER CABLES

## 8.1 SUPPLY NETWORK TYPES

International standard IEC 60364 distinguishes three families of earthing arrangements, using the two-letter codes TN, TT, and IT. The first letter indicates the connection between earth and the power-supply equipment (generator or transformer):

- T = Direct connection of a point with earth (Latin: terra)
- I = No point is connected with earth (isolation), except perhaps via high impedance.

The second letter indicates the connection between earth and the electrical device being supplied:

- T = Direct connection of a point with earth
- N = Direct connection to neutral at the origin of installation, which is connected to the earth

TN-S and TT networks are more EMC-friendly than IT and especially TN-C networks. In TN-C networks the neutral and PE conductors are the same, which is why unbalanced and circulation currents are common. For the same installation geometry the unbalanced current generates a magnetic field of at least two orders of magnitude higher than of a TN-S network. There is no difference on immunity between networks when faced with high frequency interference.

### 8.1.1 IT NETWORK

IT network is a specific type of network encountered in industry and special environments like ships and hospitals. The main feature of this network is that a short-circuit to ground does not interrupt its operation. The system can continue normal operation, which is essential in some applications.

In an IT network there is no direct connection between active conductors and grounded components as the transformer neutral is not grounded, i.e. the network is floating, unlike in other networks such as TN-C or TN-S. The cases of electrical equipment used in the network are connected to ground.

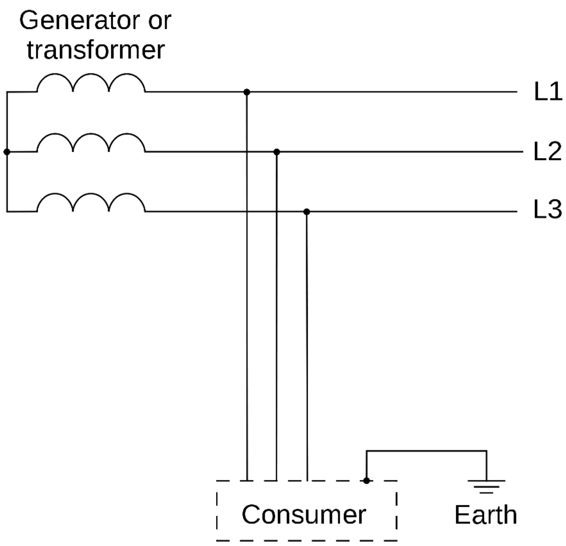



*Figure 46. IT network*

In practice the transformer neutral has a high-impedance connection to ground through the stray capacitances of the system. The stray capacitances have a major impact on the ground currents in the system and thus on the proper functioning of the whole system.

Loads used in the network may contribute to the stray capacitances significantly. Therefore there are restrictions in the use of loads designed to be used in other networks. The increase in capacitive coupling can result in the IT network being practically altered into a different type of a system. Undesired behavior in normal operation or fault situations may follow.

AC drives need to be designed to be used with IT networks. When drives are operated in IT networks it is important that the use does not cause ground currents as this will produce problems with the ground fault monitoring systems of the network. To achieve this, capacitances towards ground need to be minimized in the frequency converter. RFI filters are a significant single source of problems and may not be used. Also the cabling used should be symmetrical to minimize capacitive coupling. Any resistances towards ground need to be on the order of hundreds of megaohms.

Vice versa, the user needs to ensure that fault monitoring systems of the IT network is suitable for AC drives.

Problems may occur if an input phase of the frequency converter gets grounded in the IT network. This will cause modulation frequency component to be seen in the whole network. This can be a problem for low power drives in which a diode pump phenomenon may occur. The phenomenon causes an increase in the DC bus voltage even when the frequency converter is in stop-mode. This can be solved by adding a brake chopper which is active also in the stop-mode.

### 8.1.2 TT NETWORK

In a TT earthing system, the protective earth connection of the consumer is provided by a local connection to earth, independent of any earth connection at the generator.

The big advantage of the TT earthing system is the fact that it is clear of high and low frequency noises that come through the neutral wire from various electrical equipment connected to it. This is why TT has always been preferable for special applications like telecommunication sites that benefit from the interference-free earthing. Also, TT does not have the risk of a broken neutral.

In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

In pre-residual current devices era, the TT earthing system was unattractive for general use because of its worse capability of accepting high currents in case of a live-to-PE short circuit (in comparison with TN systems). But as residual current devices mitigate this disadvantage, the TT earthing system has become attractive for premises where all AC power circuits are protected by a residual current device.

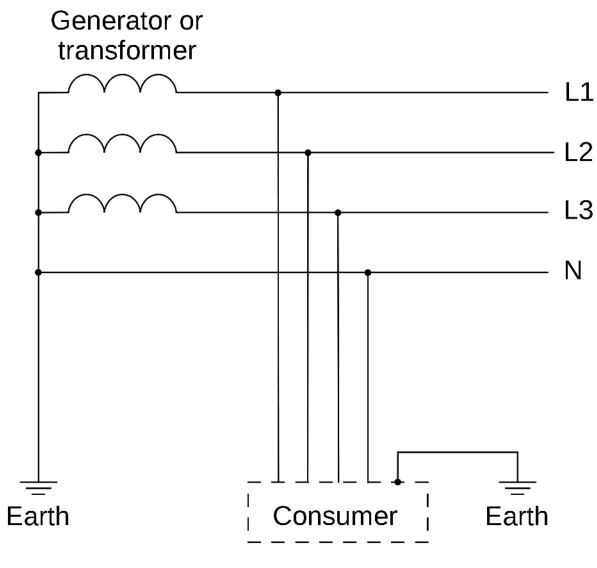



*Figure 47. TT network*

### 8.1.3 TN-S network

A TN-S system is used to separate neutral and protective conductors throughout the system. Electrical installations in buildings used for neutral TN-S system in general. However, in industrial motor drives and other symmetrical loads the neutral wire is usually unnecessary and not used.

PE and N are separate conductors that are connected together only near the power source. Three phase systems have normally five (3L + N + PE) or four (3L + PE) conductors. Single-phase systems have typically three conductors (L + N + PE).

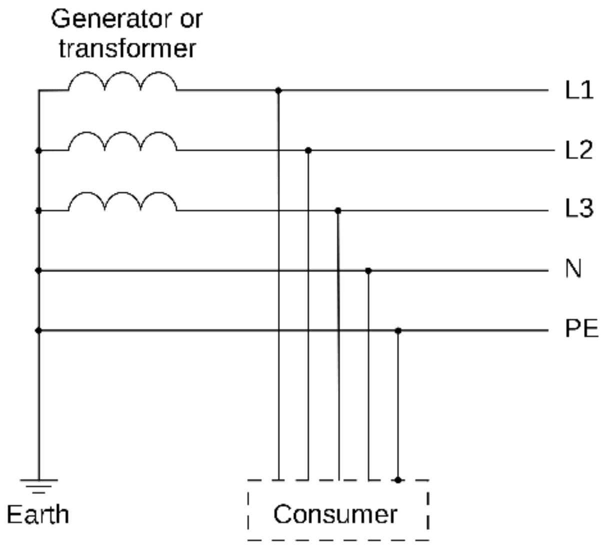



*Figure 48. TN-S network*

### 8.1.4 TN-C network

A combined PEN conductor fulfils the functions of both a PE and an N conductor. This is rarely used. This system is not permitted for conductors of less than 10 mm² or for portable equipment. The TN-C system requires an effective equipotential environment within the installation with dispersed earth electrodes spaced as regularly as possible since the PEN conductor is both the neutral conductor and at the same time carries phase unbalance currents as well as 3rd order harmonic currents and their multiples.

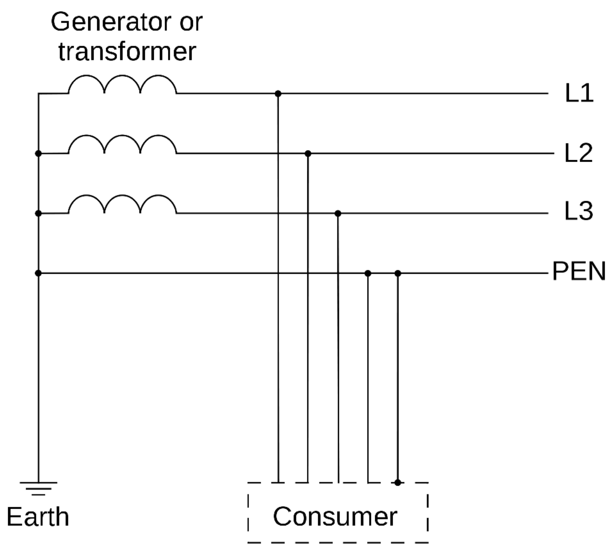



*Figure 49. TN-C network*

### 8.1.5 TN-C-S network

Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, and separated in the service head. In the UK, this system is also known as protective multiple earthing (PME), because of the practice of connecting the combined neutral-and-earth conductor to real earth at many locations, to reduce the risk of broken neutrals - with a similar system in Australia being designated as multiple earthed neutral (MEN).

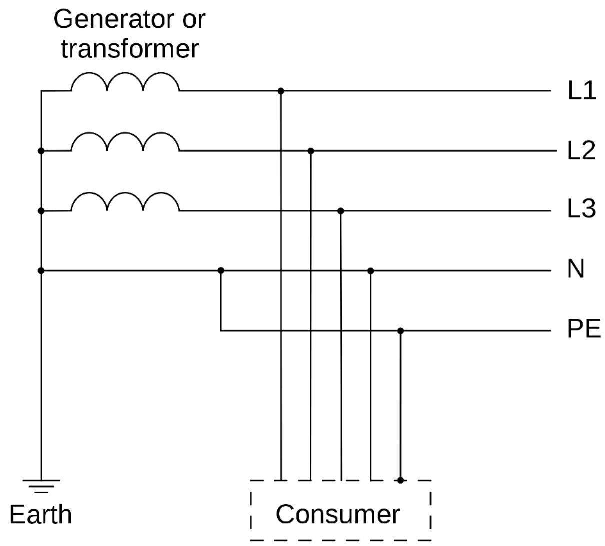



*Figure 50. TN-C-S network*

### 8.1.6 Corner-grounded network

Corner-grounded networks are met mainly in old installations in the US. A corner-grounded network is a system in which one corner of the transformer's delta-connected secondary is grounded. The usage of this network has decreased and is rarely used in modern installations. One of the reasons for the decline is the popularity of delta-wye transformers instead of delta-delta transformers in power transmission systems.

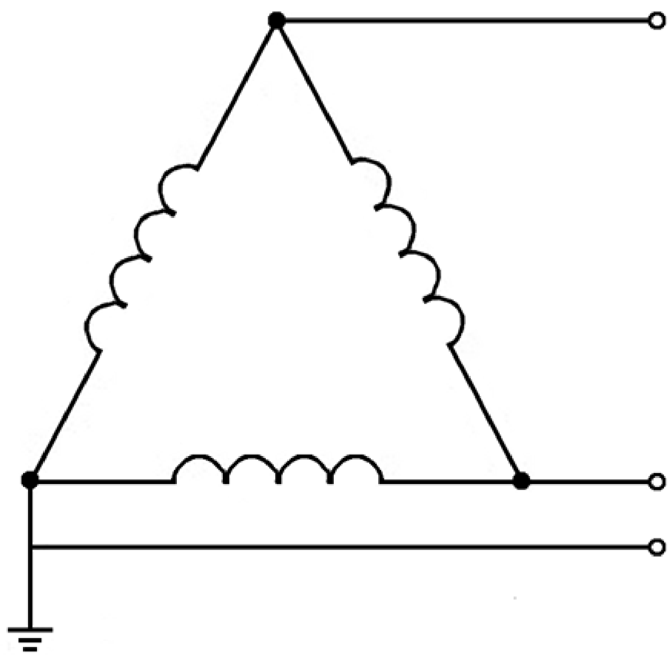


*Figure 51. Corner-grounded network*

Grounding of one phase (usually denoted phase B) stabilizes the voltages of the other phases (A and C) in regard to ground. The phase-to-phase voltage in the system is the same as the phase-to-ground voltages of the ungrounded phases.

When operating in corner-grounded system, user should always ensure that the drive is suitable for use in the particular network, as corner-grounded networks have different voltage levels.

## 8.2 Power cabling

In power drive systems cables are used at the input to connect the power supply to the drive, and at the output to connect the frequency converter to the motor.

The basic parameters for cable selection are voltage rating, and the current the cable is required to carry. Choosing correct voltage rating is straightforward especially for input cables, as the required voltage strength is the supply voltage.

The load current of the drive system defines the required current capacity. Parameters affecting cross-section dimensioning include:

- Conductor material
- Insulation material
- Installation method
- Ambient temperature
- Current harmonics
- Voltage drop
- Short-circuit protection
- Economic considerations

In addition, issues like EMC, grounding, required cable type and safety influence the final decision on the cable type.

## 8.3 Conductor material

Materials used in cables are copper and aluminium. The choice depends on cost and technical requirements, including dimension and weight requirements.

Technically copper is a more suitable material, excluding weight (aluminium is lighter). The resistivity of aluminium is nearly 1.6 times that of copper. However, aluminium is a considerably cheaper metal and thus often is the most cost-efficient solution.

A few general statements regarding aluminium and copper:

- For a fixed cross-section, copper has better conductivity, but aluminium is lighter.
- For a fixed price, aluminium offers larger cross-section and better conductivity.
- For round conductors that heat up to the same temperature, copper has smaller cross-section taking up less space, but aluminium is lighter and cheaper.

Usually, copper is more favour able compared to aluminium, when the cable is small and voltage is large.

When mounting aluminium cables, you must take into account a phenomenon called cold flow. Cold flow is the property of an aluminium conductor to yield due to pressure exerted by terminal on the conductor. This is a problem especially with round conductors. The tightening torque used for mounting the cable must be lower than that used with copper conductors. You must re-tighten the terminal screws after a few days.

## 8.4 Voltage drop

Calculate and check against allowed limits the voltage drop due to the cable resistance at rated current. If cable resistance *R* is known, the line-to-line voltage drop for three-phase system on load current *I* is

$$U_h = \sqrt{3}R$$

Considering the entire drive system, you need to take into account also the voltage drop due to the feeding transformer.

Usually the maximum input voltage for drives is 110% of nominal voltage, and the minimum is 85-90% of nominal voltage.

## 8.5 Insulation material

Insulation material determines the maximum temperature of a cable under normal operation and short-circuits. Cables used with drives should usually withstand at least 70 °C temperature.

The most common insulation material, PVC, limits the temperature to 70 °C in normal operation. XLPE (PEX) materials have 90 °C temperature limit.

Common short-circuit temperature limits are 160 °C for PVC, and 250 °C for XLPE (PEX). Typically this temperature is allowed for a maximum of 5 seconds in short-circuits.

Temperature limits of cables should be verified case by case.

Dielectric strength is usually not of concern with low voltage cables, as only thin insulation layer is needed to achieve the required insulation.

## 8.6 Typical cable type

Recommended cable type in three phase supply is shielded and symmetrical 3 wire cable as shown below. The shield is used for grounding and as it is around the phase wires it beneficial for EMC.

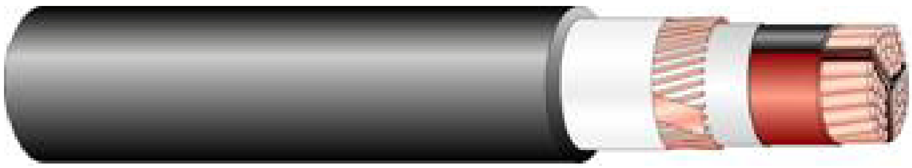


*Figure 52. Shielded and symmetrical 3 wire cable*

## 8.7 Thermal dimensioning of cables

Cables have a temperature limit up to which they are allowed to heat. Cable's insulation material determines its temperature limit. Thermal dimensioning yields the minimum cross-section for specified current rating according to the maximum temperature, or the other way round, it specifies the maximum current rating for a particular cross-section.

### 8.7.1 Thermal dimensioning rules

Environment has a significant effect on cooling of the cable and thus on the level of current that generates the maximum temperature. Cooling is reduced if ambient temperature is increased and cables are installed close to each other.

Manufacturers may define current rating for cables. Selecting cables according to this is easy. However, these current ratings are for normal ambient conditions. The capacity is stated at a certain ambient temperature and with cables having space around them. Correction factors need to be used, if

- ambient temperature is different from the reference temperature
- cables are installed in close proximity to each other
- method of installation reduces cooling

Calculate the current-capacity $I$ using the correction factor $k$ and original load current $I_0$.

$$I = I_0 k$$

### 8.7.2 Ambient temperature

The following table summarises the correction factors for different ambient temperatures presented in the standards EN 60204-1 and IEC 60364-5-523.

40 °C is the default temperature for the standard EN 60204-1 and 25 °C for the standard IEC 60364-5-523.

*Table 8. Correction factors for ambient temperatures*

| Insulation material | PVC | | XLPE (PEX) |
|---|---|---|---|
| Standard | EN 60204-1 | IEC 60364-5-523 | |
| Ambient temperature | Correction factor | | |
| 10 | | 1,15 | 1,11 |
| 15 | | 1,10 | 1,07 |
| 20 | | 1,05 | 1,04 |
| 25 | | 1,00 | 1,00 |
| 30 | 1,15 | 0,94 | 0,96 |
| 35 | 1,08 | 0,88 | 0,92 |
| 40 | 1,00 | 0,82 | 0,88 |
| 45 | 0,91 | 0,75 | 0,84 |
| 50 | 0,82 | 0,67 | 0,79 |
| 55 | 0,71 | 0,58 | 0,73 |
| 60 | 0,58 | 0,47 | 0,68 |
| 65 | | | 0,62 |
| 70 | | | 0,56 |
| 75 | | | 0,48 |
| 80 | | | 0,39 |

### 8.7.3 Installation method

Standards EN 60204-1 and IEC 60364-5-52 present tables with correction factors for various installation methods. Select the standardised method that is most suitable compared with the actual installation.

The following table presents current ratings for copper and aluminium cables when the cables are installed on a tray. The ratings of both standards EN 60204-1 and IEC 60364-5-523 are presented. Insulation material is PVC (temperature limit 70°C).

*Table 9. Current capacities for cables installed on a tray*

| Material | Copper | | Aluminium |
|---|---|---|---|
| Standard | EN 60204-1 | IEC 60364-5-523 | |
| Installation method | E | 52-C3/E | 52-C4/E |
| Ambient temperature | +40 °C | +25°C | |
| Conductor size ($mm^2$) | Current (A) | | |
| 1.5 | 16 | 19 | |
| 2.5 | 22 | 26 | |
| 4 | 30 | 36 | |
| 6 | 37 | 45 | |
| 10 | 52 | 63 | |
| 16 | 70 | 85 | 65 |
| 25 | 88 | 107 | 83 |
| 35 | 114 | 134 | 102 |
| 50 | 123 | 162 | 124 |
| 70 | 155 | 208 | 159 |
| 95 | 192 | 252 | 194 |
| 120 | 221 | 292 | 225 |
| 150 | | 338 | 260 |
| 185 | | 386 | 297 |
| 240 | | 456 | 350 |
| 300 | | 527 | 404 |

### 8.7.4 Cables installed next to each other

The following tables consider the effect of installing cables next to other ones, which reduces cooling. The installation method used is the same as in the previous case. Cables are installed on a tray in one layer and next to other ones with no spacing.

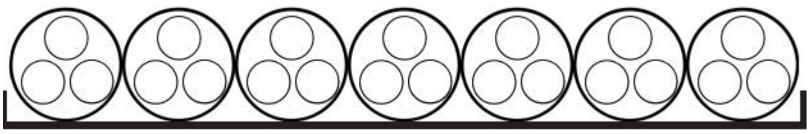


*Figure 53. Cables installed on a tray side by side*

Standard used is IEC 60365-5-523 and insulation material is PVC (temperature limit 70 °C). Ambient temperature is 30 °C which is taken into account.

The first table is presented for copper cables and the latter for aluminium cables.

*Table 10. Current capacities for copper cables installed on a tray and side by side*

| Number of cables | 1 | 2 | 3 | 4 | 6 | 9 |
|---|---|---|---|---|---|---|
| Correction factor *k* due to number of cables | 1.00 | 0.87 | 0.82 | 0.8 | 0.79 | 0.78 |
| Conductor size ($mm^2$) | Loadability of one cable (A) | | | | | |
| 1.5 | 18 | 16 | 15 | 14 | 14 | 14 |
| 2.5 | 24 | 21 | 20 | 20 | 19 | 19 |
| 4 | 34 | 29 | 28 | 27 | 27 | 26 |
| 6 | 42 | 37 | 35 | 34 | 33 | 33 |
| 10 | 59 | 52 | 49 | 47 | 47 | 46 |
| 16 | 80 | 70 | 66 | 64 | 63 | 62 |
| 25 | 101 | 88 | 82 | 80 | 79 | 78 |
| 35 | 126 | 110 | 103 | 101 | 100 | 98 |
| 50 | 152 | 132 | 125 | 122 | 120 | 119 |
| 70 | 196 | 170 | 160 | 156 | 154 | 153 |
| 95 | 237 | 206 | 194 | 190 | 187 | 185 |
| 120 | 274 | 239 | 225 | 220 | 217 | 214 |
| 150 | 318 | 276 | 261 | 254 | 251 | 248 |
| 185 | 363 | 316 | 298 | 290 | 287 | 283 |
| 240 | 429 | 373 | 351 | 343 | 339 | 334 |
| 300 | 495 | 431 | 406 | 396 | 391 | 386 |

*Table 11. Current capacities for aluminium cables installed on a tray and side by side*

| Number of cables | 1 | 2 | 3 | 4 | 6 | 9 |
|---|---|---|---|---|---|---|
| Correction factor *k* due to number of cables | 1.00 | 0.87 | 0.82 | 0.8 | 0.79 | 0.78 |
| Conductor size ($mm^2$) | Loadability of one cable (A) | | | | | |
| 16 | 61 | 53 | 50 | 49 | 48 | 48 |
| 25 | 78 | 68 | 64 | 62 | 62 | 61 |
| 35 | 96 | 83 | 79 | 77 | 76 | 75 |
| 50 | 117 | 101 | 96 | 93 | 92 | 91 |
| 70 | 149 | 130 | 123 | 120 | 118 | 117 |
| 95 | 182 | 159 | 150 | 146 | 144 | 142 |
| 120 | 212 | 184 | 173 | 169 | 167 | 165 |
| 150 | 244 | 213 | 200 | 196 | 193 | 191 |
| 185 | 279 | 243 | 229 | 223 | 221 | 218 |
| 240 | 329 | 286 | 270 | 263 | 260 | 257 |
| 300 | 380 | 330 | 311 | 304 | 300 | 296 |

### 8.7.5 Parallel cables

The following tables consider the effect of parallel connected cables. The installation method, the reference standard and ambient temperature are the same as with previous cases. The number of cables installed in a layer next to each other is nine.

The first table is presented for copper cables and the latter for aluminium cables.

*Table 12. Current capacities for parallel connected copper cables installed on a tray and next to other ones (nine in total)*

| Number of cables in parallel | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Conductor size (mm$^2$) | Combined loadability of cables (A) | | | | | | | |
| 120 | 428 | 642 | | | | | | |
| 150 | 496 | 743 | | | | | | |
| 185 | 566 | 849 | 1132 | 1415 | 1698 | 1981 | 2264 | 2547 |
| 240 | 669 | 1003 | 1337 | 1672 | 2006 | 2340 | 2675 | 3009 |
| 300 | 773 | 1159 | 1546 | 1932 | 2318 | 2705 | 3091 | 3478 |

*Table 13. Current capacities for parallel connected aluminium cables installed on a tray and next to other ones (nine in total)*

| Number of cables in parallel | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Conductor size (mm$^2$) | Combined loadability of cables (A) | | | | | | | |
| 120 | 330 | 495 | | | | | | |
| 150 | 381 | 572 | | | | | | |
| 185 | 436 | 653 | 871 | 1089 | 1307 | 1524 | 1742 | 1960 |
| 240 | 513 | 770 | 1026 | 1283 | 1540 | 1796 | 2053 | 2310 |
| 300 | 592 | 889 | 1185 | 1481 | 1777 | 2073 | 2370 | 2666 |

### 8.7.6 Requirement for PE-cables

The IEC 60204-1 standard sets the following requirement regarding dimensioning PE-cables:

Where electrical equipment has an earth leakage current that is greater than 10 mA AC or DC in any incoming supply, one or more of the following conditions for the associated protective bonding circuit shall be satisfied:

- The protective conductor shall have a cross-sectional area of at least 10mm$^2$ copper or 16 mm$^2$ aluminium, through its total run.
- Where the protective conductor has a cross-sectional area of less than 10 mm$^2$ copper or 16 mm$^2$ aluminium, a second protective conductor of at least the same cross-sectional area shall be provided up to a point where the protective conductor has a cross-sectional area not less than 10mm$^2$ copper or 16 mm$^2$ aluminium
- Automatic disconnection of the supply in case of loss of continuity of the protective conductor.

## 8.8 Effect of harmonics

Drive input current usually includes considerable harmonics. For conventional drives, current THD is about 40%. While harmonic components of current do not contribute to the real power of the drive, they cause additional heating in the cables due to increased resistive losses. Therefore dimensioning of cables has to be done according to the true RMS current, not fundamental current component. Otherwise cables will be overheated.

# 9. NXP-based drive units

## 9.1 The NXP control platform

The Vacon NXP is a common control platform for Vacon's high performance products.

The core of the NXP is a fast microcontroller. The NXP can be used in both open loop applications and in applications requiring encoder feedback. The NXP platform supports fast drive-to-drive communication using System Bus which is an optical bus, and Can Bus which is a normal RS485 bus. Simultaneous monitoring of several drives is possible using the NCDrive tool and a separate monitoring bus based on CAN communication, which allows fast monitoring of dynamic events. Integrated data logger allows saving of specified dynamic events for further analysis using the NC-Drive tool. You can use the NCDrive tool for specifying the event data.

NXP allows control of Permanent Magnet (PM) motors. NXP control platform allows you to use Vacon's Drive Synch control concept, which is a way to parallel high power drives to control an AC motor. See chapter "Drive Synch" on page 76.

A control keypad functions as a link between the user and the frequency converter. You can use the control keypad for setting application parameters, reading status data and giving control commands. The control keypad is detachable and can be operated externally when connected to the frequency converter via a communication cable. Instead of the control keypad, you can use a PC to communicate with the drive, if connected using a similar cable (VACON RS232PC –1.5M).

All Vacon's NXP drives contain the All in One software application package by default. If needed, a process-specific software application can be installed at the factory or later as an update.

Optional I/O expander boards that increase the number of inputs and outputs to be used are also available.

*Table 14. Option boards*

| Type | Card slot | | | | | I / O signal | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | DI | DO | DI DO | AI (mA/ V/±V) | AI (mA) isolated | AO (mA/V) | AO (mA) isolated | RO (NO/ NC) | RO (NO) | +10V$_{ref}$ | Therm | +24V/ EXT +24V | pt100 | 42-240 VAC input | DI/DO ⊓⊔ (10...24V) | DI/DO ⊓⊔ (RS422) | DI ~ 1Vp-p | Resolver | Out +5V/ +15V/ +24V | Out +15V/ +24V | Out +5V/ +12V/ +15V | Note |
| Basic I/O cards (OPT-A) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| OPT-A1 | ■ | | | | | 6 | 1 | | 2 | | 1 | | | | 1 | | 2 | | | | | | | | | | |
| OPT-A2 | | ■ | | | | | | | | | | | 2 | | | | | | | | | | | | | | |
| OPT-A3 | | ■ | | | | | | | | | | | 1 | 1 | | 1 | | | | | | | | | | | |
| OPT-A4 | | | ■ | | | 2 | | | | | | | | | | | | | | | 3/0 | | | 1 | | | |
| OPT-A5 | | | ■ | | | 2 | | | | | | | | | | | | | | 3/0 | | | | | 1 | | |
| OPT-A7 | | | ■ | | | | | | | | | | | | | | | | | 6/2 | | | | | 1 | | 2 enc. input + 1 enc. output |
| OPT-A8 | ■ | | | | | 6 | 1 | | 2 | | 1 | | | | 1 | | 2 | | | | | | | | | | 1) |
| OPT-A9 | ■ | | | | | 6 | 1 | | 2 | | 1 | | | | 1 | | 2 | | | | | | | | | | 2.5 mm$^2$ terminals |
| OPT-AE | | | ■ | | | | 2 | | | | | | | | | | | | | 3/0 | | | | | 1 | | DO=Divider+Direction |
| OPT-AF | | ■ | | | | 2 | | | | | | | 1 | 1 | | 1 | | | | | | | | | | | EN954-1, cat 3 / ATEX therm. |
| OPT-AK | | | ■ | | | | | | | | | | | | | | | | | | | 3 | | | 1 | | Sin/Cos/ Marker |
| OPT-AN | ■ | | | | | 6 | | | 2 | | 2 | | | | | | | | | | | | | | | | Limited support |
| I/O expander cards (OPT-B) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| OPT-B1 | | ■ | ■ | ■ | ■ | | | 6 | | | | | | | | | 1 | | | | | | | | | | Selectable DI/DO |
| OPT-B2 | | ■ | ■ | ■ | ■ | | | | | | | | 1 | 1 | | 1 | | | | | | | | | | | |
| OPT-B4 | | ■ | ■ | ■ | ■ | | | | | 1 | | 2 | | | | | 1 | | | | | | | | | | 2) |
| OPT-B5 | | ■ | ■ | ■ | ■ | | | | | | | | | 3 | | | | | | | | | | | | | |
| OPT-B8 | | ■ | ■ | ■ | ■ | | | | | | | | | | | | 1 | 3 | | | | | | | | | |
| OPT-B9 | | ■ | ■ | ■ | ■ | 2 | | | | | | | | 1 | | | | | 5 | | | | | | | | |
| OPT-BB | | | ■ | | | 2 | | | | | | | | | | | | | | | 0/2 | 2 | | | | 1 | Sin/Cos+EnDat |
| OPT-BC | | | ■ | | | | | | | | | | | | | | | | | 3/3 | | | 1 | | | | Encoder out=Resolver simulation |
| OPT-BE | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | EnDat/SSI |
| Fieldbus cards (OPT-C) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| OPT-C2 | | | | ■ | ■ | RS-485 (Multiprotocol) | | | | | | | | | | | | | | | | | | | | | Modbus, N2 |
| OPT-C3 | | | | ■ | ■ | Profibus DP | | | | | | | | | | | | | | | | | | | | | |
| OPT-C4 | | | | ■ | ■ | LonWorks | | | | | | | | | | | | | | | | | | | | | |
| OPT-C5 | | | | | ■ | Profibus DP (D9-type connector) | | | | | | | | | | | | | | | | | | | | | |
| OPT-C6 | | | | ■ | ■ | CANopen (slave) | | | | | | | | | | | | | | | | | | | | | |
| OPT-C7 | | | | ■ | ■ | DeviceNet | | | | | | | | | | | | | | | | | | | | | |
| OPT-C8 | | | | ■ | ■ | RS-485 (Multiprotocol, D9-type connector) | | | | | | | | | | | | | | | | | | | | | Modbus, N2 |
| OPT-CG | | | | ■ | ■ | SELMA 2 protocol | | | | | | | | | | | | | | | | | | | | | |
| OPT-CI | | | | ■ | ■ | Modbus/TCP (Ethernet) | | | | | | | | | | | | | | | | | | | | | |
| OPT-CJ | | | | ■ | ■ | BACNet, RS485 | | | | | | | | | | | | | | | | | | | | | |
| OPT-CP | | | | ■ | ■ | ProfiNet I/O (Ethernet) | | | | | | | | | | | | | | | | | | | | | |
| OPT-CQ | | | | ■ | ■ | Ethernet/IP (Ethernet) | | | | | | | | | | | | | | | | | | | | | |
| Communication cards (OPT-D) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| OPT-D1 | | | | ■ | ■ | System Bus adapter (2 x fiber optic pairs) | | | | | | | | | | | | | | | | | | | | | |
| OPT-D2 | | | | ■ | ■ | System Bus adapter (1 x fiber optic pair) & CAN-bus adapter (galvanically decoupled) | | | | | | | | | | | | | | | | | | | | | |
| OPT-D3 | | | | ■ | ■ | RS232 adapter card (galvanically decoupled), used mainly for application engineering to connect another keypad | | | | | | | | | | | | | | | | | | | | | |
| OPT-D6 | | ■ | | ■ | ■ | CAN-bus adapter (galvanically decoupled) | | | | | | | | | | | | | | | | | | | | | |
| OPT-D7 | | | ■ | | | Line voltage measurement | | | | | | | | | | | | | | | | | | | | | |

Allowed slots for the board are marked in blue. 1) analogue signals galvanically isolated as a group. 2) analogue signals galvanically isolated separately

The following table is only an approximation. The values presented in the table are valid under normal conditions, with an optimal system configuration.

*Table 15. Vacon drives based on the NXP platform*

| Parameters | Open loop | Closed loop |
|---|---|---|
| Frequency resolution | 0.01 Hz | 0.01 Hz |
| Torque resolution | 0.1% of $T_N$ motor | 0.1% of $T_N$ motor |
| Speed accuracy | < 10% of motor nominal slip | 0.01% static error (of motor nominal speed |
| Torque accuracy | < 5% static error (of $T_N$ motor) for speed up to motor nominal speed. | < 3% static error (of $T_N$ motor) for speed up to motor nominal speed. Above nominal speed< 5% |
| Speed range | 1:25 (e.g. 2 Hz for 50 Hz motor) | No limit from drive side. |
| Torque step rise time | < 5ms | < 5 ms |
| Dynamic response | 0.3 to 0.5% sec with $T_N$ motor | 0.1 to 0.2% sec with $T_N$ motor |
| Field weakening set point | 8 Hz... 320 Hz | 8 Hz... 320 Hz |
| Field weakening area | -300%...+300% of $n_N$ | -300%...+300% of $n_N$ |

Notes:

- Torque-related data is dependent on drive dimensioning related to the motor.
- The drive needs to be provided with accurate motor name plate data.
- Open loop data is taken after the automatic identification run.
- Closed loop performance is valid for an encoder with PPR ≥ 1024
- Depending on the motor type, the values may deviate slightly from those presented in the table.

## 9.2 Drive Synch

Vacon Drive Synch is a control concept for paralleling high power drives to control an AC motor. The concept is suitable for single or multiple winding motors. DriveSynch allows you to build high power AC drives of up to 5MW using standard low voltage drive modules.

Vacon Drive Synch can be used with both air cooled and liquid cooled drives. Frequency converters, or inverters in a common DC bus configuration can be used with the Vacon DriveSynch concept. Using Drive Synch you can synchronise up to 4 drives that have identical power ratings to produce the same PWM pattern at the output to control a single AC motor.

Use a dU/dt filter at the output of each individual drive to ensure further load balancing. DU/dt filter's inductance must be at least 1,5%. Filters with lesser inductance values must not be used in DriveSynch installations. In case of a multiple winding motor, a dU/dt filter may not be required.

Vacon DriveSynch works in both open loop and closed loop motor control modes. With closed loop motor control, the encoder feedback needs to be wired only to the master drive. In case redundancy is required, it may be necessary to wire the encoder feedback also to an alternative master using double encoder option board OPTA7 as a repeater.

System bus communication over optical bus is typically used with NXP drives for load sharing between master and follower drives. Since DriveSynch uses this optical bus for the PWM synchronization of the paralleled drives, the master-follower load sharing feature is not available with drives using DriveSynch.

Maximum switching frequency for drives using DriveSynch is 3.6 kHz

NXP control card must be VB00661 or later.

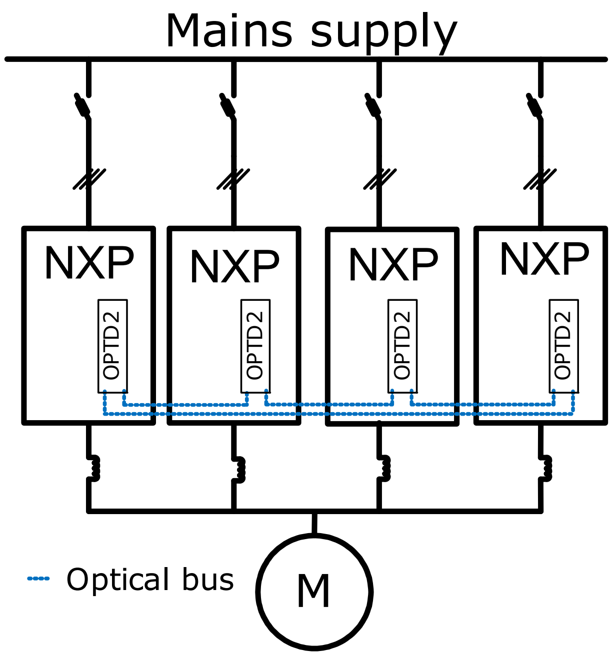



*Figure 54. NXP frequency converters are synchronized to control a low voltage high power motor.*

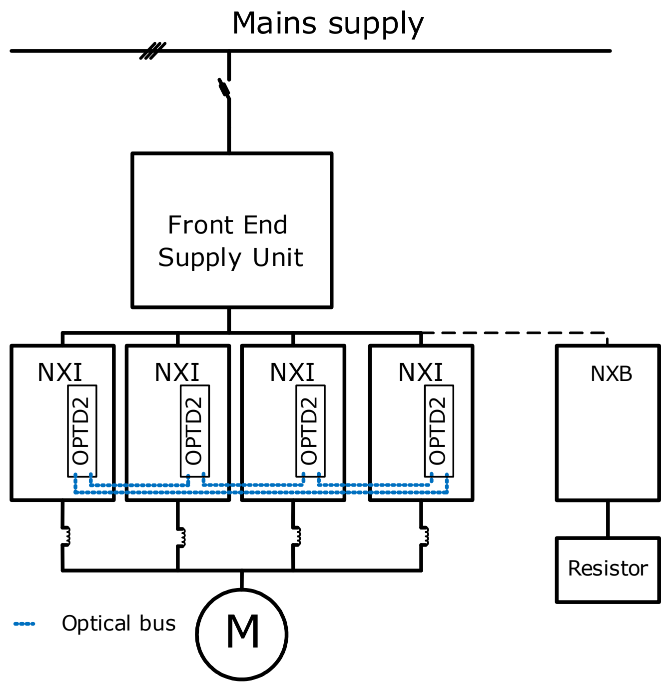



*Figure 55. NXI inverters are synchronized to control a low voltage high power motor in a common DC bus system.*

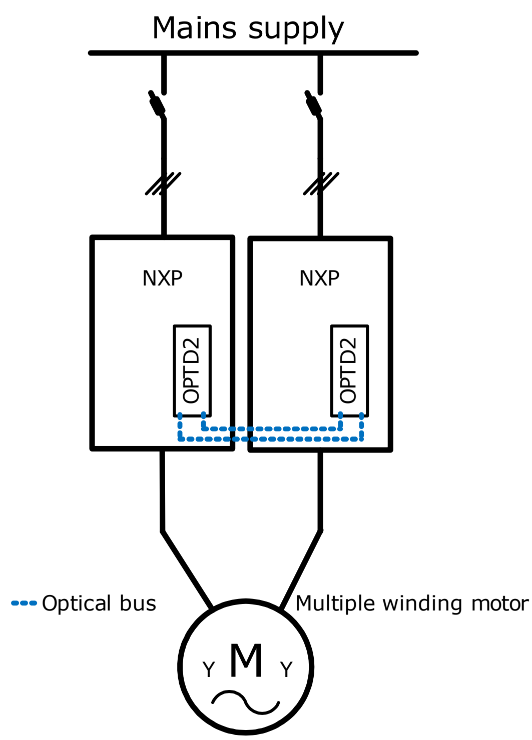



*Figure 56. Individual NXP frequency converters are synchronized to control a low voltage high power multiple winding motor*

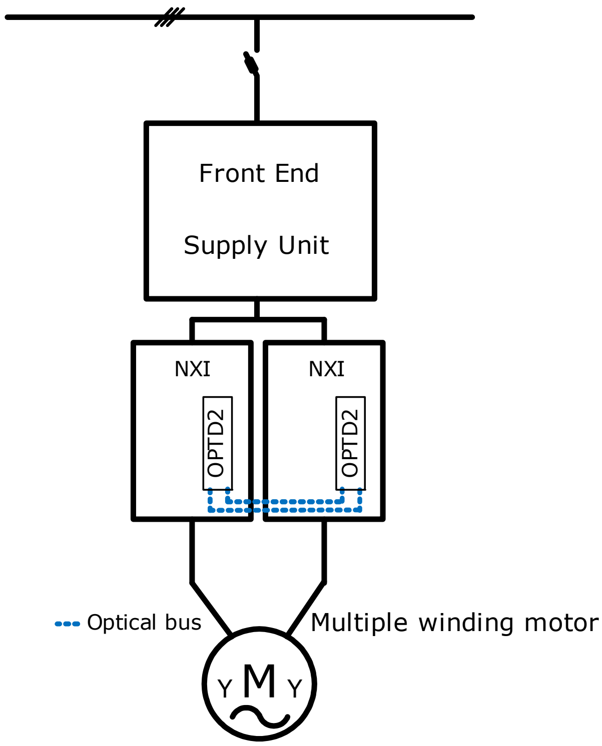



*Figure 57. NXI inverters are synchronized to control a low voltage high power multiple winding motor in a common DC bus system*

Use the DriveSynch with the following hardware and software components:

- Standard frequency converter or inverter (identical power ratings, max 4 pieces)
- DU/dt filter for each frequency converter or inverter
- OPT-D2 (system bus + CAN bus adapter) card for fast drive-to-drive communication
- System software NXP00002V171 or later

Application software:

- Marine application APFIFF09V100 or later, available on the internet
- Multi-Purpose application APFIF166V423, available on request
- System Interface application APFIFF10V228 or later

### 9.2.1 Engineering notes

Consider the following points when dimensioning and designing the system:

- $I_{L\ Total}$ = 0.95 X N X $I_{L(unit)}$
- $I_{HTotal}$ = 0.95 X N X $I_{H\ (unit)}$

where:
$I_{L\ Total}$ = Total low overload current for the complete drive system
$I_{HTotal}$ = Total high overload current for the complete drive system
N = Number of drive units in parallel in DriveSynch
$I_{L\ (unit)}$ = Low overload current of individual drive unit
$I_{H\ (unit)}$ = High overload current of individual drive unit

- The 2% voltage loss caused by the du/dt filter needs to be considered while designing the system
- In order to ensure load balancing, the supply connection to the individual drives and the connection from the drives to the motor must be symmetrical. The supply cables or busbars for the individual units must be of equal size and length from the source. Also, the cable and busbar size and length from the drive unit to motor should be equal. In a common DC bus configuration the supply side connections need not be symmetrical. Tolerance of 2% in the impedance is usually acceptable.
- Fast drive-to-drive communication through optical bus is essential for the DriveSynch. The control box must be supplied with an external uninterrupted +24V supply. This way the DriveSynch communication is always active, and redundancy is achieved.
- Maximum length of optical cable between the units is 10 meters.

For installation and commissioning, see Vacon NX User's Manual.

### 9.2.2 Motor with isolated and multiple windings

If the motor has isolated multiple windings, a du/dt filter is not required. The du/dt filter may still be necessary to limit the instability caused by the mutual impedance of the winding. This is a project-specific solution. If two drives are connected in parallel for one winding, a du/dt filter is required at each drive output.

Winding insulation has to be suitable for frequency converter usage in general. In addition, the insulation level between the winding sets (which are wound in parallel) has to be at least the same as between the phases.

A phase difference can exist between the motor windings. The DriveSynch technology provides a possibility to program the phase difference in the individual unit supplying each set of winding.

### 9.2.3 System redundancy

Paralleled drive units operated using DriveSynch provide a high level of redundancy. The system can be made to continue its operation even if one or more of the drive units is not functioning. The actual level of redundancy is project-specific, and must be defined in accordance with the requirements of the motor, the load and the process.

The master unit, and the fast optical drive-to-drive communication must be functional for the DriveSynch to work. Auxiliary power (+24V) must be continuously provided for all the control units, including any non-functional drive units.

It is also a common practice to use n+1 units, where n is the number of units required for the full functionality of the system. This way, 100% redundancy is possible even if any one of the follower drives is not functioning. Maximum number of units in the DriveSynch is four.

*Table 16.*

| | | Master (1) | Follower (2) | Follower (3) | Follower (4) |
|---|---|---|---|---|---|
| **Hardware settings** | | | | | |
| OPTD2: Jumper | X5 | TX1 | TX2 | TX2 | TX2 |
| OPTD2: Jumper | X6 | ON | ON | ON | ON |
| | | | | | |
| **Expander board parameters** | | | | | |
| OPTD2 | SystemBus in use | YES | YES | YES | YES |
| OPTD2 | System Bus speed | 12 Mbaud | 12 Mbaud | 12 Mbaud | 12 Mbaud |
| OPTD2 | System Bus ID | 1 | 2 | 3 | 4 |
| OPTD2 | System Bus next ID | 2 | 3 | 4 | 1 |
| OPTD2 | System Bus Last ID | 4 | 4 | 4 | 4 |

| Parameter settings | Master (D1) | Follower (D2) | Follower (D3) | Follower (D4) |
|---|---|---|---|---|
| | | | | |
| Motor's nominal voltage | Motor's nominal voltage from its nameplate | Motor's nominal voltage from its nameplate | Motor's nominal voltage from its nameplate | Motor's nominal voltage from its nameplate |
| Motor's nominal frequency | Motor's nominal frequency from its nameplate | Motor's nominal frequency from its nameplate | Motor's nominal frequency from its nameplate | Motor's nominal frequency from its nameplate |
| Motor's nominal current | Motor's nominal current from its nameplate / Number of drives in parallel using Vacon Drive Synch | Motor's nominal current from its nameplate / Number of drives in parallel using Vacon Drive Synch | Motor's nominal current from its nameplate / Number of drives in parallel using Vacon Drive Synch | Motor's nominal current from its nameplate / Number of drives in parallel using Vacon Drive Synch |
| Motor's COS PHI (Motor's nominal power factor) | Motor's COS PHI from its nameplate | Motor's COS PHI from its nameplate | Motor's COS PHI from its nameplate | Motor's COS PHI from its nameplate |
| Master-Follower mode | Master, DriveSynch | Follower, Drive Synch | Follower, Drive Synch | Follower, Drive Synch |
| | | | | |
| Motor Control Mode (Open Loop) | Open Loop Frequency | If used as Secondary Master: Open Loop Frequency. If used as Follower: no meaning | No meaning, internally handled. Recommended to use same setting as in the Master. | No meaning, internally handled. Recommended to use same setting as in the Master. |
| Motor Control Mode (Closed Loop) | Closed Loop Speed / Torque | If used as Secondary Master: Closed Loop Speed / Torque. If used as Follower: no meaning | No meaning, internally handled. Recommended to use same setting as in the Master. | No meaning, internally handled. Recommended to use same setting as in the Master. |
| Magnetizing current (needed only for closed loop motor control) | Motor's nominal magnetizing current / Number of drives in parallel using Vacon DriveSynch. | Motor's nominal magnetizing current / Number of drives in parallel using Vacon DriveSynch. | Motor's nominal magnetizing current / Number of drives in parallel using Vacon DriveSynch. | Motor's nominal magnetizing current / Number of drives in parallel using Vacon DriveSynch. |
| Switching frequency | Max. 3.6 KHz | Same as in the Master | Same as in the Master | Same as in the Master |
| Modulator type | 1, software | Same as in the Master | Same as in the Master | Same as in the Master |
| Follower Phase shift (single winding motor) | 0 degrees | 0 | 0 | 0 |
| Follower Phase shift (multiple winding motor) | 0 degrees | As per motor's name plate | As per motor's name plate | As per motor's name plate |

## 9.3 Functional safety

Machinery must be safe to operate. It is the responsibility of the machine builder to try to eliminate all risks by careful and efficient design. However, there is no such thing as totally risk-free machinery. Functional safety refers to dealing with risk of hazards that are caused by functional faults or errors in machinery or its control system.

A frequency converter is not a safety system as such, but it can be used as a part of a safety system. Frequency converter's role in a safety system is to be an actuator. It contains functions that can be certified for use in safety related systems or applications.

This chapter does not contain instructions on how to build a safety system, and neither do other items of Vacon's product documentation. The aim of Vacon's product documentation is to explain how Vacon's products behave, so that the designers of the safety system can apply them in an appropriate way to the actual safety system.

### 9.3.1 Standards

Standards are used to define the risk levels and to determine the sufficient risk reduction measures. Machine builders follow the standards of their own field of expertise in their design. The following two standards are the most important ones for frequency converters:

- EN/IEC 61800-5-2 "Adjustable speed electrical power drive systems - Part 5-2: Safety requirements - Functional" (Product family standard for drives, functional safety requirements)
- EN ISO 13849-1 "Safety of machinery -- Safety-related parts of control systems -- Part 1: General principles for design"

In addition to the above mentioned, the following standards may sometimes be referred to as regards frequency converters.

- EN/IEC 62061 "Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems"
- IEC 61508 "Functional safety of electrical/electronic/programmable electronic safety-related systems"
- EN 954-1 "Safety of machinery - Safety-related parts of control systems" (replaced by EN ISO 13849)

The EN/IEC 61800-5-2 is a product family standard and, as such, takes precedence over the generic standards

In the EU, harmonised standards are used to demonstrate compliance with the Machinery Directive. Outside EU you must always verify that the standards are accepted by the local legislation.

### 9.3.2 Machine design is the starting point

First of all, it is the machine builder's responsibility to use the means of design to make the machine safe to use. After that, a risk analysis has to be carried out and where risks are identified, the risk level must be defined, and the risks must be reduced to an acceptable level. The risk analysis consists of e.g. finding out how severe accidents could happen, what is the likelihood that they happen, and how often the risk situations occur. The required level of the safety function results from the risk analysis.

The performance of the safety system can be evaluated using two different approaches, the SIL level approach as defined in the IEC 61508 or the PL approach as defined in the ISO 13849-1.

- SIL = Safety Integrity Level
- PL = Performance Level

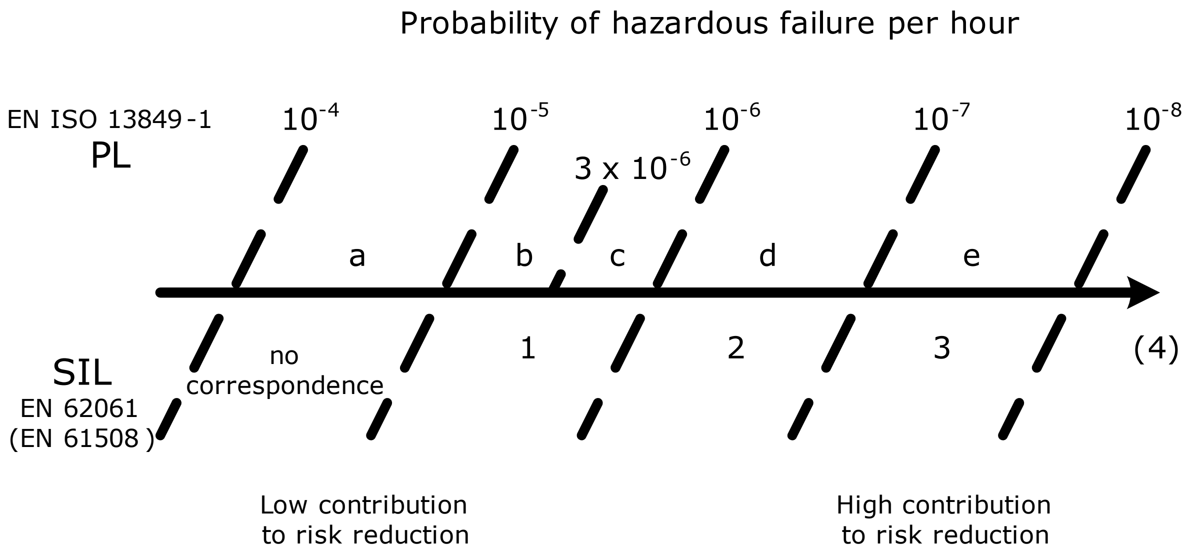



*Figure 58. Comparison of the PL and SIL approaches*

In addition to the required SIL/PL level, it is important to recognise the type of the risk, and thus the required safety function. To be able to define this, it is necessary to understand how the machine behaves, what sort of a process it is used in, and what is the safest way, for example, to stop the machine if a risk has actualised.

### 9.3.3 The safety functions defined for drives

The product standard EN/IEC 61800-5-2 defines the most common functionality needed for frequency converters. The safety functions and their commonly used abbreviations are listed in the table below.

*Table 17. Safety functions as defined in the EN/IEC 61800-5-2*

| Safety function | Abbreviation |
|---|---|
| Safe Torque Off | STO |
| Safe Stop 1 | SS1 |
| Safe Stop 2 | SS2 |
| Safe Operating Stop | SOS |
| Safely-monitored Acceleration/Deceleration | SMA, SMD |
| Safely-limited Acceleration | SLA |
| Safe Acceleration Range | SAR |
| Safely-limited Speed | SLS |
| Safe Speed Range | SSR |
| Safe Speed Monitor | SSM |
| Safe Maximum Speed | SMS[1)] |
| Safely-limited Increment | SLI |
| Safe Direction | SDI |
| Safely-limited Position | SLP |
| Safe Position Switches | SPS[1)] |
| Safe Brake Control | SBC |

*Table 17. Safety functions as defined in the EN/IEC 61800-5-2*

| Safety function | Abbreviation |
|---|---|
| Safe Braking and Holding System | SBS[1)] |
| Safely-limited Torque | SLT |
| Safe Torque Range | STR |
| Safe Motor Temperature | SMT |
| Safe Cam | SCA |

1) Not defined in the IEC 61800-5-2

### 9.3.4 Certified functional safety functions for Vacon NXP AC drives

For other than NXP products, check the availability and instructions for use of the functional safety functions from the product manual.

Together with the NXP control platform, the OPT-AF option board provides the following safety functions: Safe Torque Off (STO), Safe Stop 1 (SS1) and Motor Thermistor Overtemperature protection (in accordance with ATEX). For detailed instructions, see the OPT-AF User's Manual.

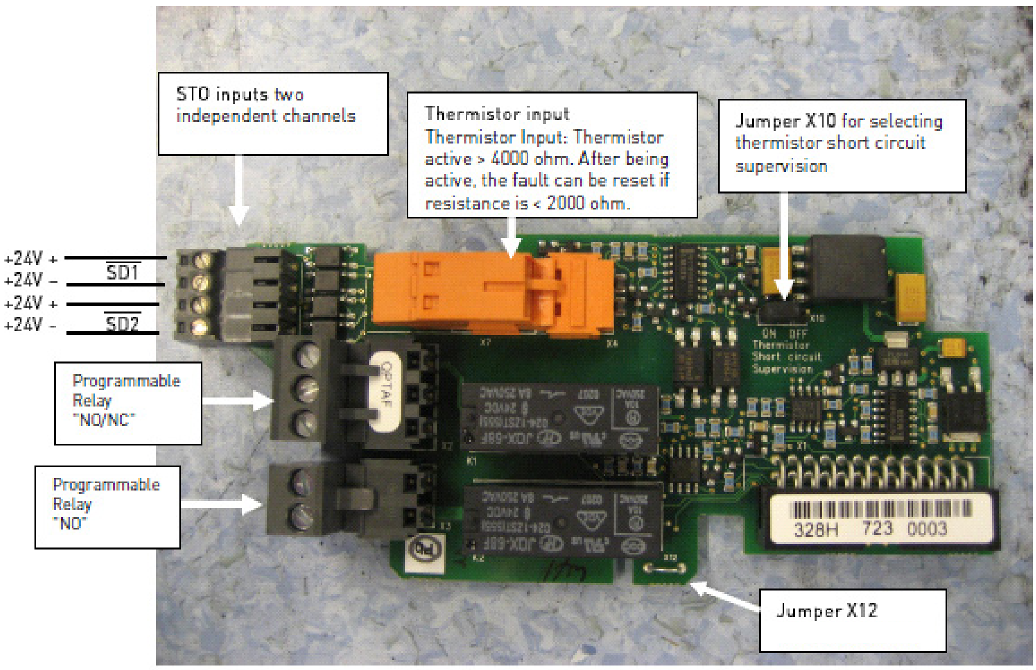



*Figure 59. Layout of the OPT-AF board*

In order to exclude any external influence on the safety circuit, the enclosure class of the control unit, where the OPT-AF board is installed, must be at least IP54 when the safety functions STO or SS1 are used. For the control unit of a frequency converter using only the Motor Thermistor Overtemperature protection function there are no specific IP class requirements.

Choose the correct IP class for the frequency converter, control box or final cabinet assembly in accordance with the guidelines below to comply with the requirements.

*Table 18. IP class requirements for the OPT-AF board*

| FC's IP class | IP class requirements for the Safe Torque Off | IP class requirements for the ATEX Thermistor |
|---|---|---|
| IP00 | IP54 cabinet<br>or<br>IP54 control box | No additional IP class requirements |
| IP21 | IP54 cabinet<br>or<br>IP54 control box | No additional IP class requirements |
| IP54 | No additional<br>IP class requirements | No additional IP class requirements |

#### *9.3.4.1 Safe Torque Off (STO)*

STO is a hardware based Safe Torque Off safety function to prevent the drive from generating torque on the motor shaft. The STO safety function has been designed for use in accordance with the following standards:

- EN 61800-5-2 Safe Torque Off (STO) SIL2
- EN ISO 13849-1: 2006 PL"d" Category 3
- EN 62061: 2005 SILCL2
- IEC 61508: 2000 SIL2
- EN 954-1, Category 3

The function also corresponds to an uncontrolled stop in accordance with stop category 0, EN 60204-1: 2006.

The STO safety function has been certified by the IFA *

The STO safety function of the OPT-AF board allows the drive output to be disabled so that the drive cannot generate torque in the motor shaft. For STO, the OPT-AF board has two separate galvanically isolated inputs: SD1 and SD2.

Vacon OPT-AF board has a dual input solution. This simplifies the work of the system designer, gives built-in fault tolerance and redundance. With the competing single input solutions, the reaching of corresponding safety level requires more evaluation and design work to prove that the system really is safe.

Both SD1 and SD2 inputs are normally closed for the drive to be in enable state. The STO safety function is achieved by disabling the drive modulation. The drive modulation is disabled through two independent paths controlled by SD1 and SD2 so that a single fault in any of the safety related parts will not lead to the loss of the safety function. This is done by disabling the gate driver signal outputs to the driver electronics. The gate drive output signals control the IGBT module. When gate drive output signals are disabled, the drive will not generate torque in the motor shaft. If either of the STO inputs is not connected to a +24V signal, the drive will not go to the RUN state.

* IFA = Instutut für Arbeitsschutz der Deutche Gesetzlichen Unfallversicherung, Germany

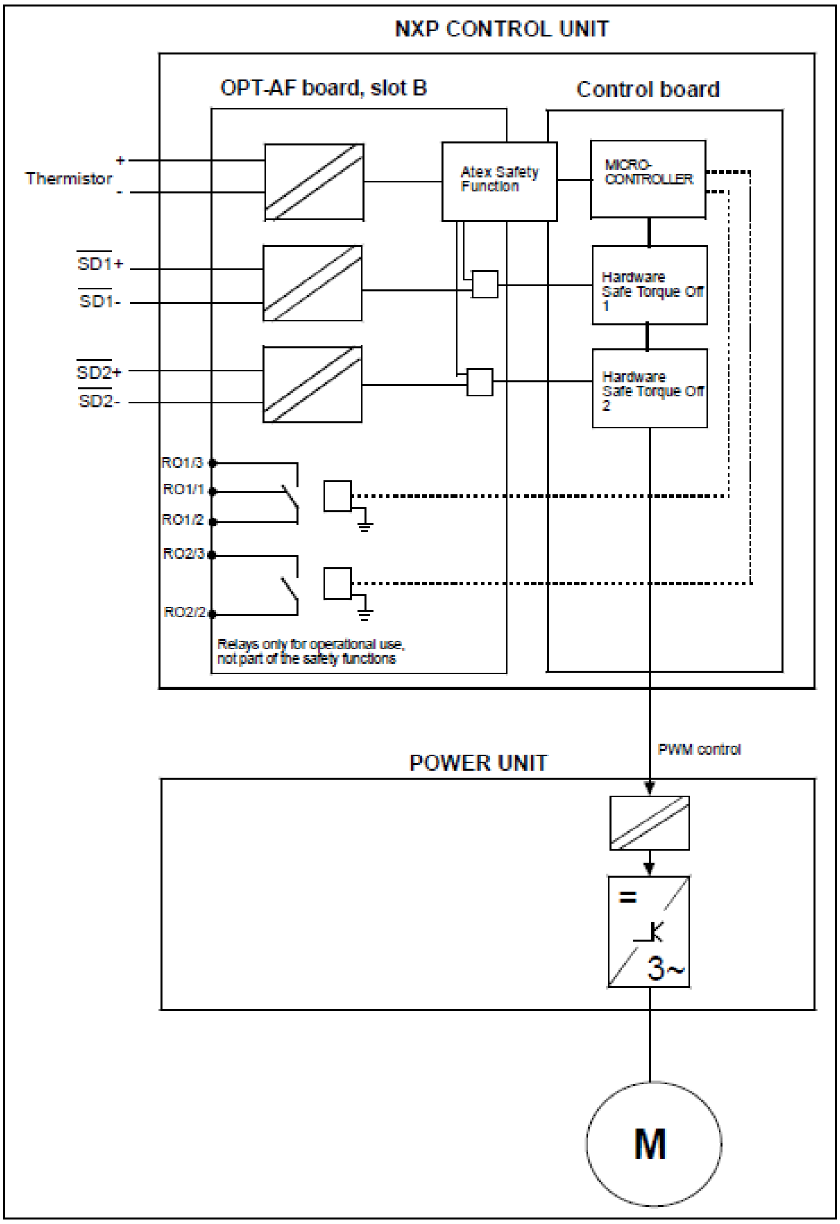



*Figure 60. Operating principle of the STO safety function in an NXP frequency converter with the OPT-AF board*

The figure below shows an example of minimum wiring for the STO function. The key criteria for wiring is that the STO inputs must always be used in parallel. For more wiring examples, see the user's manual of the OPT-AF board. There may also be additional machinery-specific requirements that must be considered.

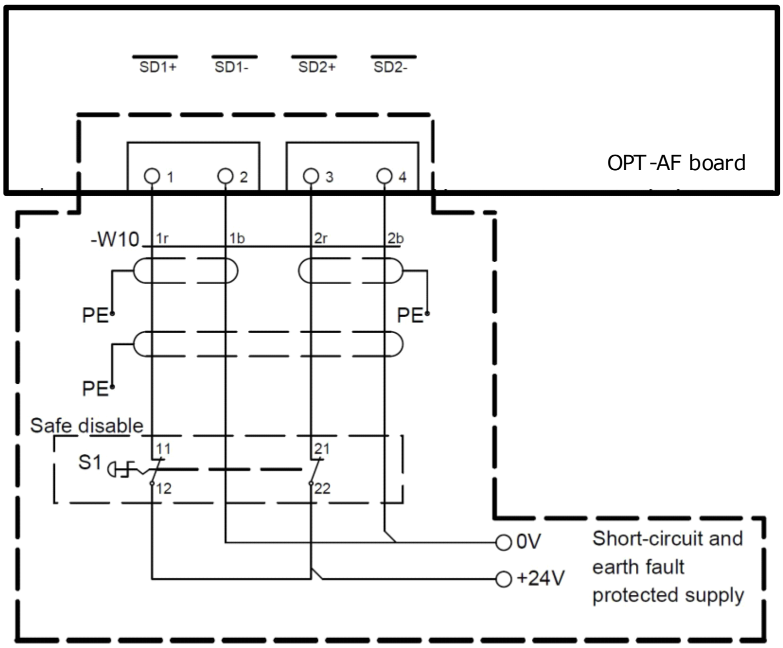



*Figure 61. Partial diagram showing the minimum wiring for the STO function*

### 9.3.4.2 Safe Stop 1 (SS1)

The safe stop function initiates the motor deceleration and initiates the STO function after an application specific time delay set by the user in accordance with the process requirements. The SS1 safety function has been designed for use in accordance with the following standards:

- EN 61800-5-2 Safe Stop 1 (SS1) SIL2
- EN ISO 13849-1: 2006 PL"d" Category 3
- EN 62061: 2005 SILCL2
- IEC 61508: 2000 SIL2

The function also corresponds to a controlled stop in accordance with stop category 1, EN 60204-1:2006.

The SS1 safety function has been certified by the IFA *

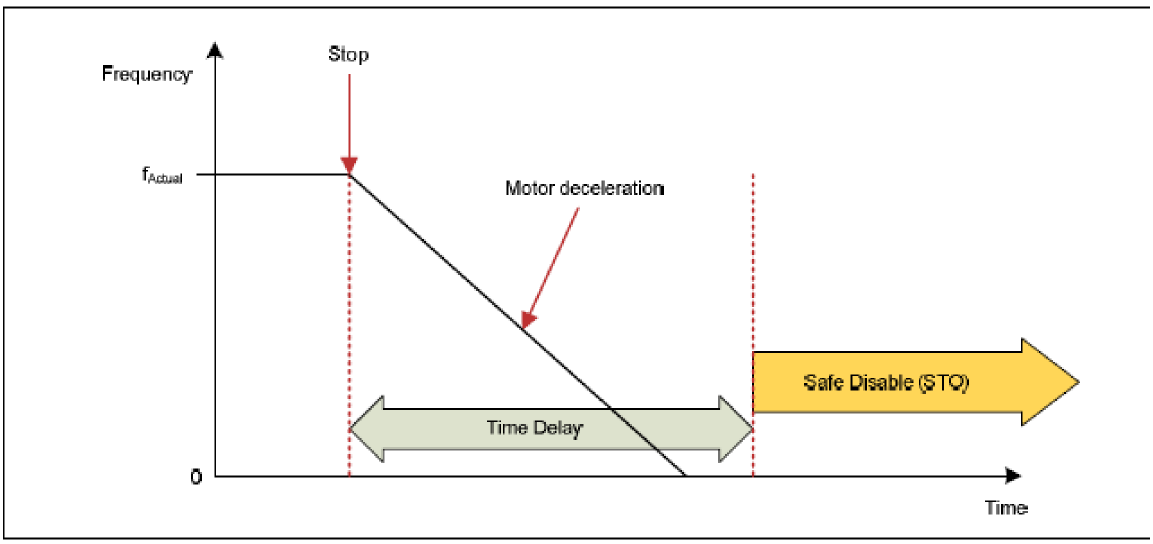



*Figure 62. The principle of Safe Stop 1 (EN 61800-5-2, SS1 type c)*

The Safe Stop 1 (SS1) safety function consists of two safety related subsystems, an external time-delayed safety relay and the STO safety function. These two subsystems together form the Safe Stop 1 safety function as shown in figure Safe Stop 1 (SS1) safety function.

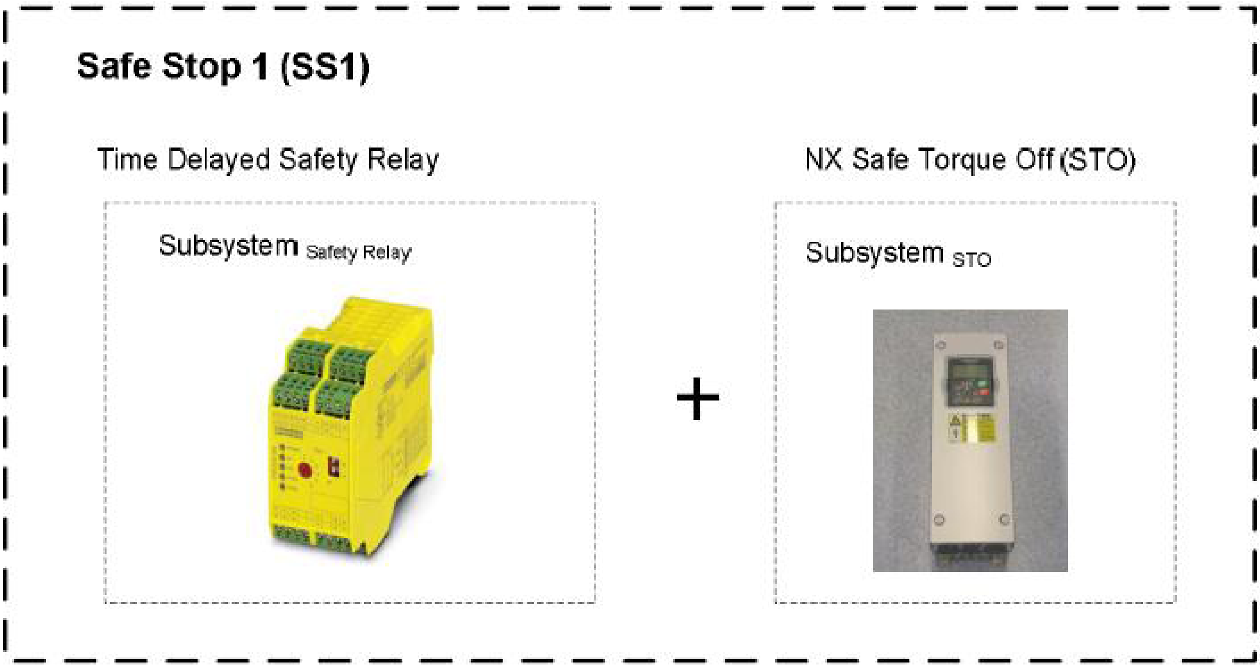



*Figure 63. Safe Stop 1 (SS1) safety function.*

Figure 56 shows the connection principle of Safe Stop 1 safety function.- The time delayed safety relay outputs are connected to the STO inputs.- A separate digital output from the safety relay is connected to a general digital input of the NX drive. The general digital input must be programmed to detect the drive stop command and initiates without time delay the drive stop function (must be set to "stop by ramp") and causes motor deceleration.

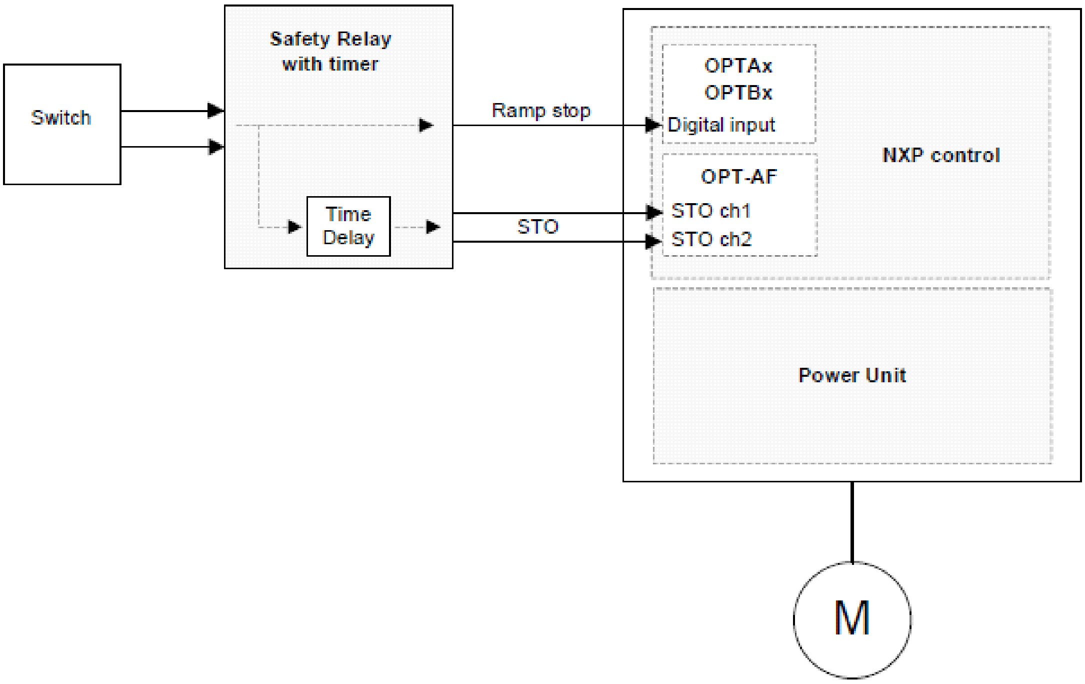



*Figure 64. Connection principle of the SS1 function*

#### *9.3.4.3 Motor Thermistor Overtemperature protection (according to ATEX)*

The Motor Thermistor Overtemperature protection function is an overtemperature detection using thermistor located on the OPT-AF option board. It can be used as a tripping device for ATEX certified motors. The thermistor tripping function is certified by VTT** according to ATEX directive 94/9/EC.

* IFA = Institut für Arbeitsschutz der Deutsche Gesetzlichen Unfallversicherung, Germany

** VTT = Technical Research Centre of Finland

### 9.3.5 Other safety functions

Other safety functions can be implemented by the safety system designer by using external pre-certified third party safety relays. For more information on combining safety-related sub-systems, see the OPT-AF board's user documentation.

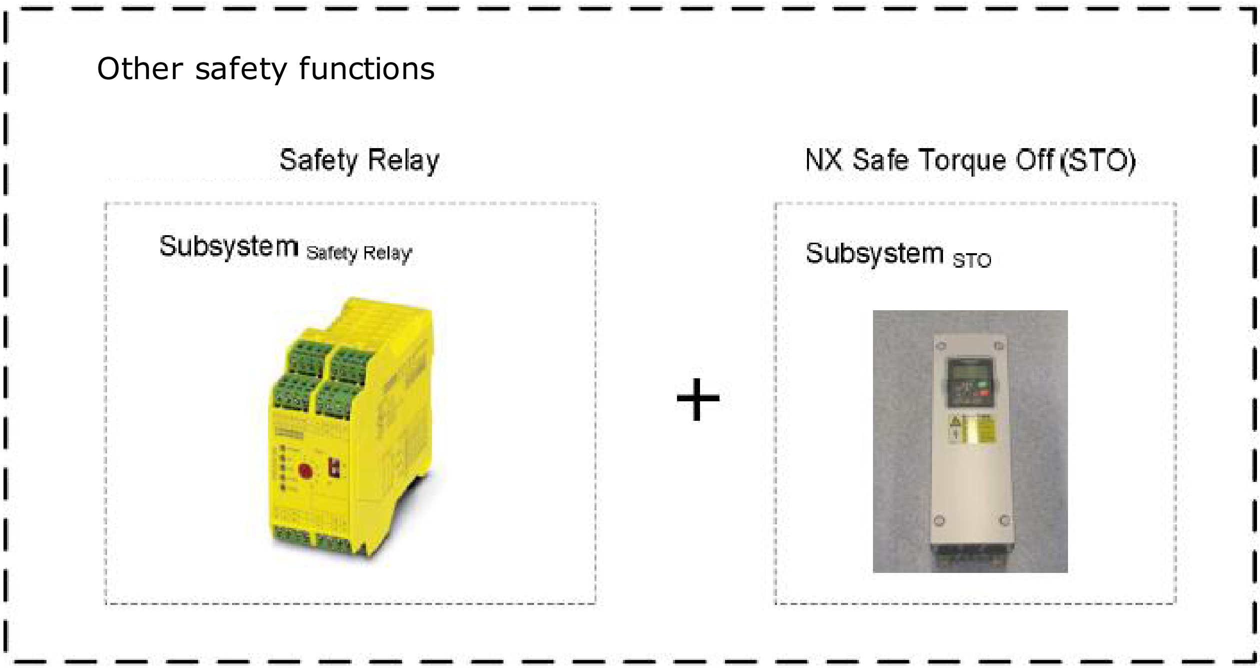



*Figure 65. Other safety functions*

## 9.4 AC supplied IP00 frequency converter modules

AC supplied IP00 frequency converter modules need always cabinet installation. The IP00 frequency converters include both air and liquid cooled drive modules. The product range includes both 6 and12 pulse frequency converters. The IP00 modules are by default delivered with chokes that are separate modules.

For IP00 frequency converter configurations, see chapter “Cabinet installation” on page 109.

*Table 19. Air cooled NXP IP00 frequency converter product range*

| Vacon NXP air cooled IP00 frequency converters | 380 - 500 VAC | 525 - 690 VAC |
|---|---|---|
| 6-pulse | 160 - 1200 kW | 200 - 2000 kW |
| 12-pulse | 160 - 1200 kW | 200 - 2000 kW |

*Table 20. Liquid cooled NXP frequency converter product range*

| Vacon NXP liquid cooled frequency converters | 380 - 500 VAC | 525 - 690 VAC |
|---|---|---|
| 6-pulse | 7,5 - 5150 kW | 110 - 5300 kW |
| 12-pulse | 250 - 5150kW | 200 - 5300 kW |

With the Drive Synch control concept it is possible to increase the total power of the drive system by paralleling up to four drive modules that have identical power ratings. See chapter“Drive Synch” on page 76.

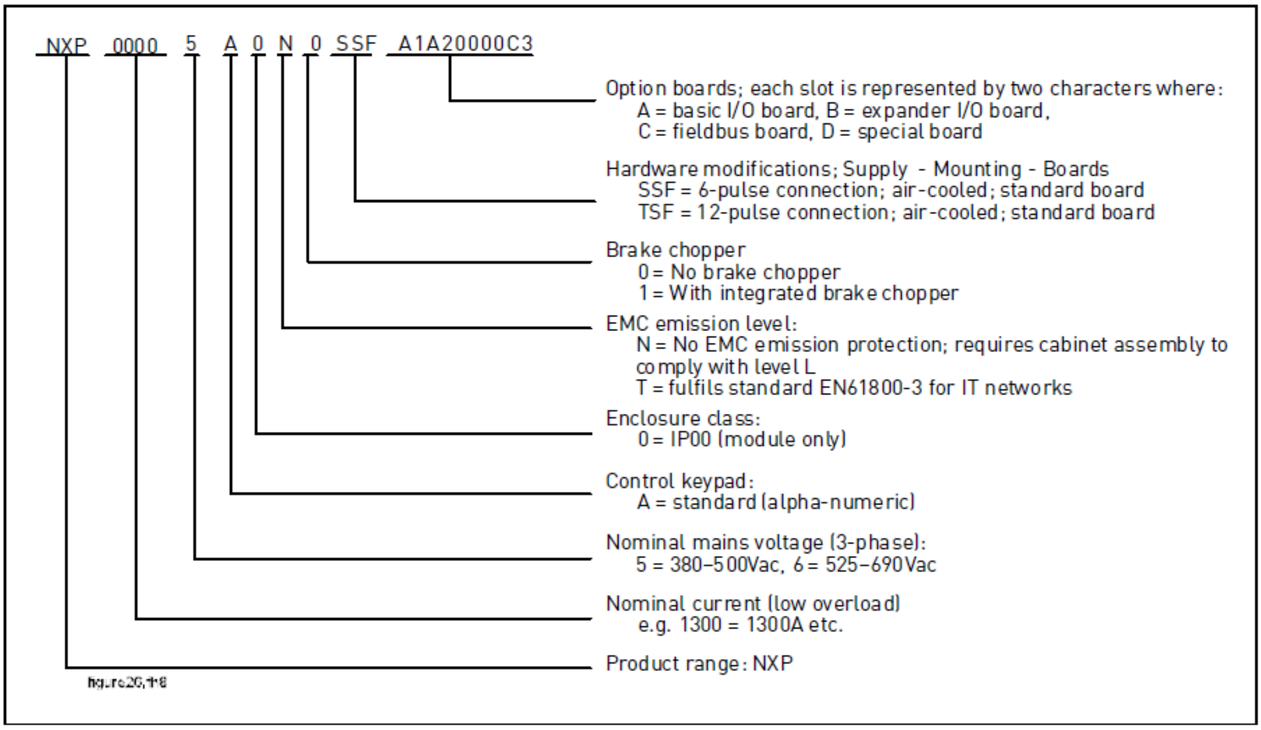



*Figure 66. NXP IP00 type code key*

## 9.5 Common DC bus modules

### 9.5.1 Non-regenerative Front End

Non-regenerative Front End, NFE, is a unidirectional power converter for the front end of a common DC bus drive line-up. Protection class of the NFE module is IP00.

The Non-Regenerative Front End is used to transfer power from the AC input to intermediate DC circuit. Power can only be transferred from the AC input to the intermediate DC circuit. If braking is needed, a brake chopper must be connected to the intermediate DC circuit.

The Non-Regenerative Front End configuration consists of the NFE module and an external AC choke, AC fuses, main contactor and DC fuses, which you must take into account when planning the switchgear configuration. For fuse selection tables, see the product manual.

Vacon's NFE product range includes an air cooled NFE module and a choke. For more details, se the product manual.

*Table 21. NFE current and power ratings*

| Unit | | Low overload (AC current) | DC Power (continuous) | |
|---|---|---|---|---|
| Code | Frame | $I_{Lcont}$ [A] | 400V mains P [kW] | 500V mains P[kW] |
| NXN_0650 6 | FI9 | 650 | 410 | 513 |

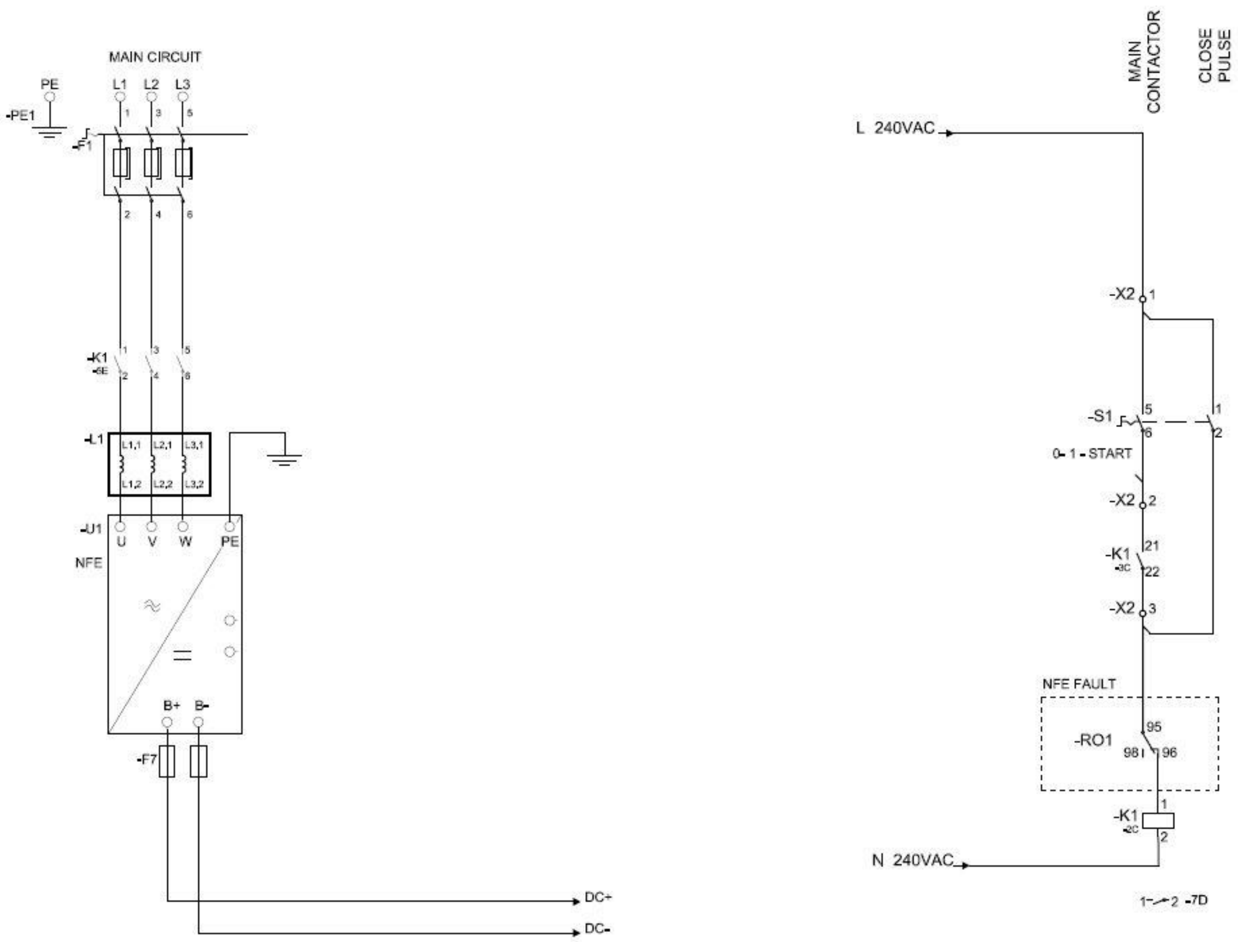



*Figure 67. Non-regenerative front end, single unit connections.*

### 9.5.1.1 NFE unit's type designation code

Vacon type designation code is formed of a nine-segment code and optional +codes. Each segment of the type designation code uniquely corresponds to the product and its options. The code is of the following format:

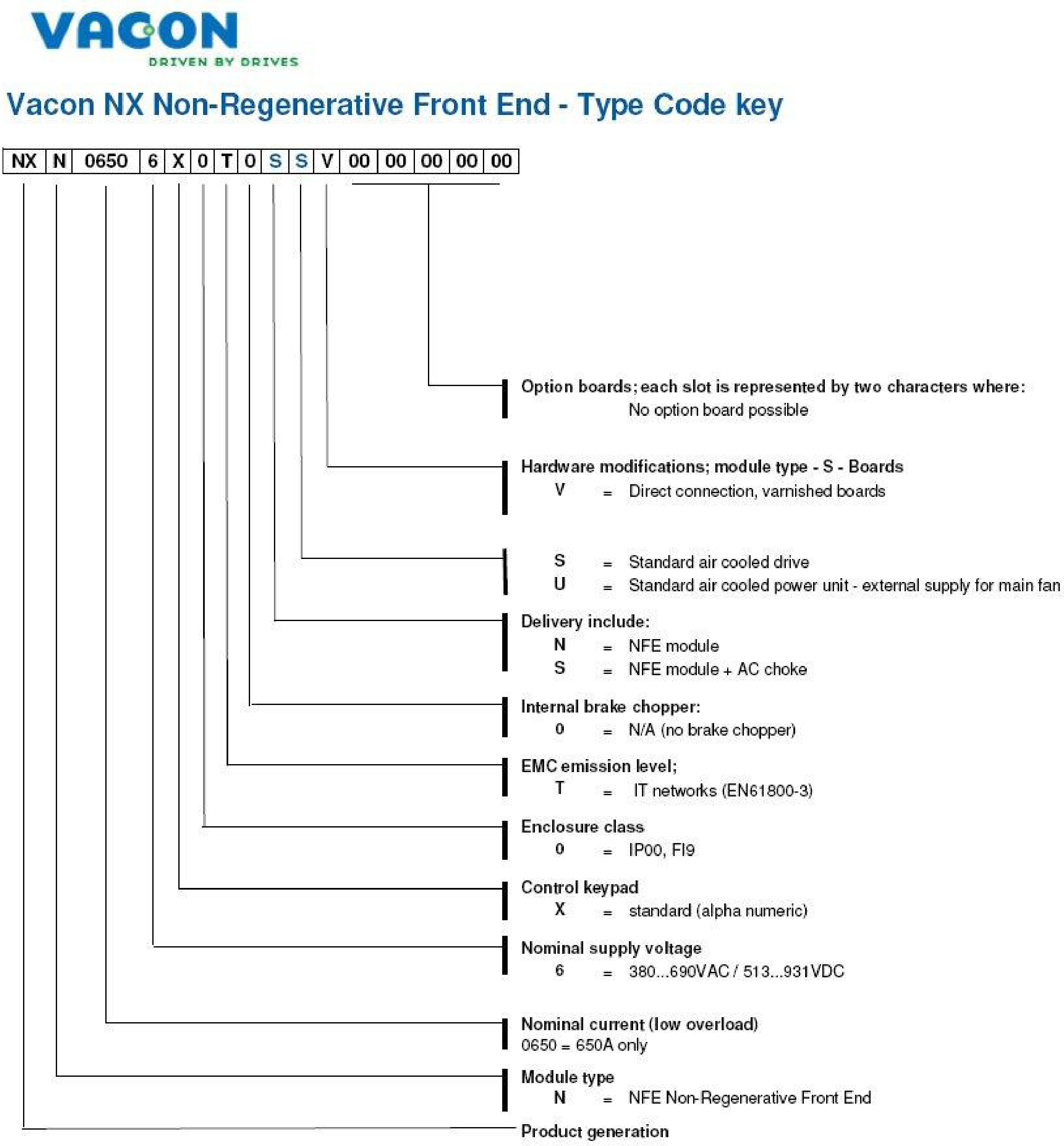



*Figure 68. NFE Type code key*

### 9.5.1.2 Paralleling

You can increase the power of the input group by connecting several Non-Regenerative Front End units that have a common AC supply in parallel. No communication between the units is required; they work independently.

Each Non-Regenerative Front End unit connected in parallel must have its own short-circuit protection on AC and DC sides. Select the fuses in accordance with the instructions in the product manuals. When paralleling, you must pay attention to the sufficient short-circuit capacity of the system.

The derating of Non-Regenerative Front End units connected in parallel is 5% of the DC power; take this into account when dimensioning the front end capacity.

If you need to isolate an NFE unit from the AC and DC voltages, while other Non-Regenerative Front End units are connected in parallel, you must use separate isolators in the AC input and DC output. You can isolate the AC input using a compact circuit-breaker, an ordinary circuit-breaker or a fuse switch. Contactors are not suitable for isolating the AC input because they cannot be locked in the safe position.

You can isolate the DC output using a fuse switch. Both load isolation switch and safety isolation switch are suitable. You can also connect an NFE unit to the mains even when the other NFE units connected in parallel are already connected to the DC bus and running.

### 9.5.2 Active Front End

Active Front End, AFE, is a bidirectional (regenerative) power converter for the front-end of a common DC bus drive line-up. Protection class of all AFE modules is IP00

The Vacon NX Active Front End is used to transfer power between the AC input and intermediate DC circuit. One of the major advantages of using Vacon NX Active Front End is the very low content of harmonic current distortion, THDi.

The Active Front End configuration consists of the AFE module, and a set of external components which you need to take into account when planning the switchgear configuration. Of the external components, LCL filters (both air and liquid cooled) and pre-charging circuit are included in Vacon's product range. For fuse selection tables and circuit breaker guidelines, see the product manual.

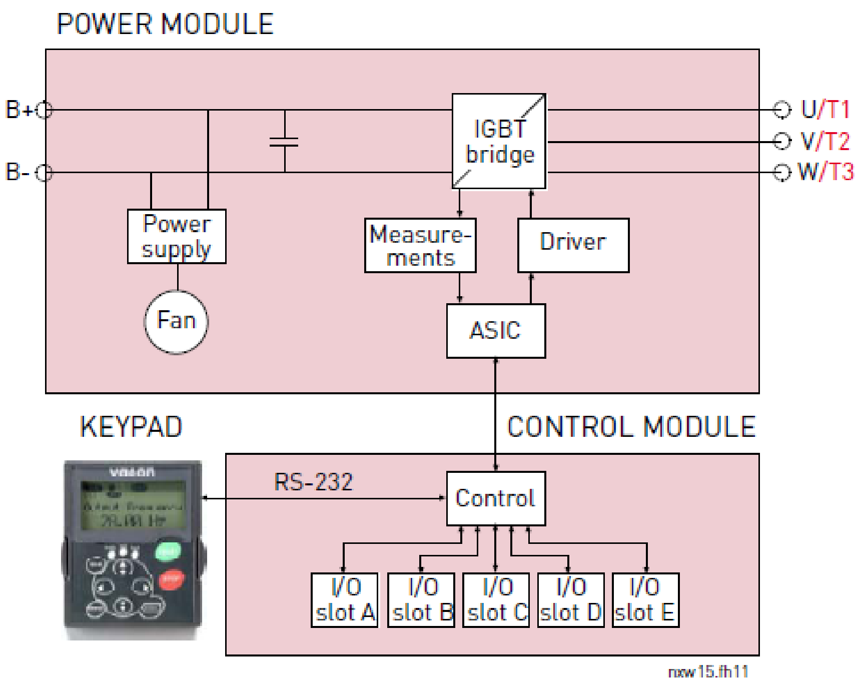



*Figure 69. NXA block diagram*

### *9.5.2.1 AFE unit types*

Vacon type designation code is formed of a nine-segment code and optional +codes. Each segment of the type designation code uniquely corresponds to the product and its options. The code is of the following format:

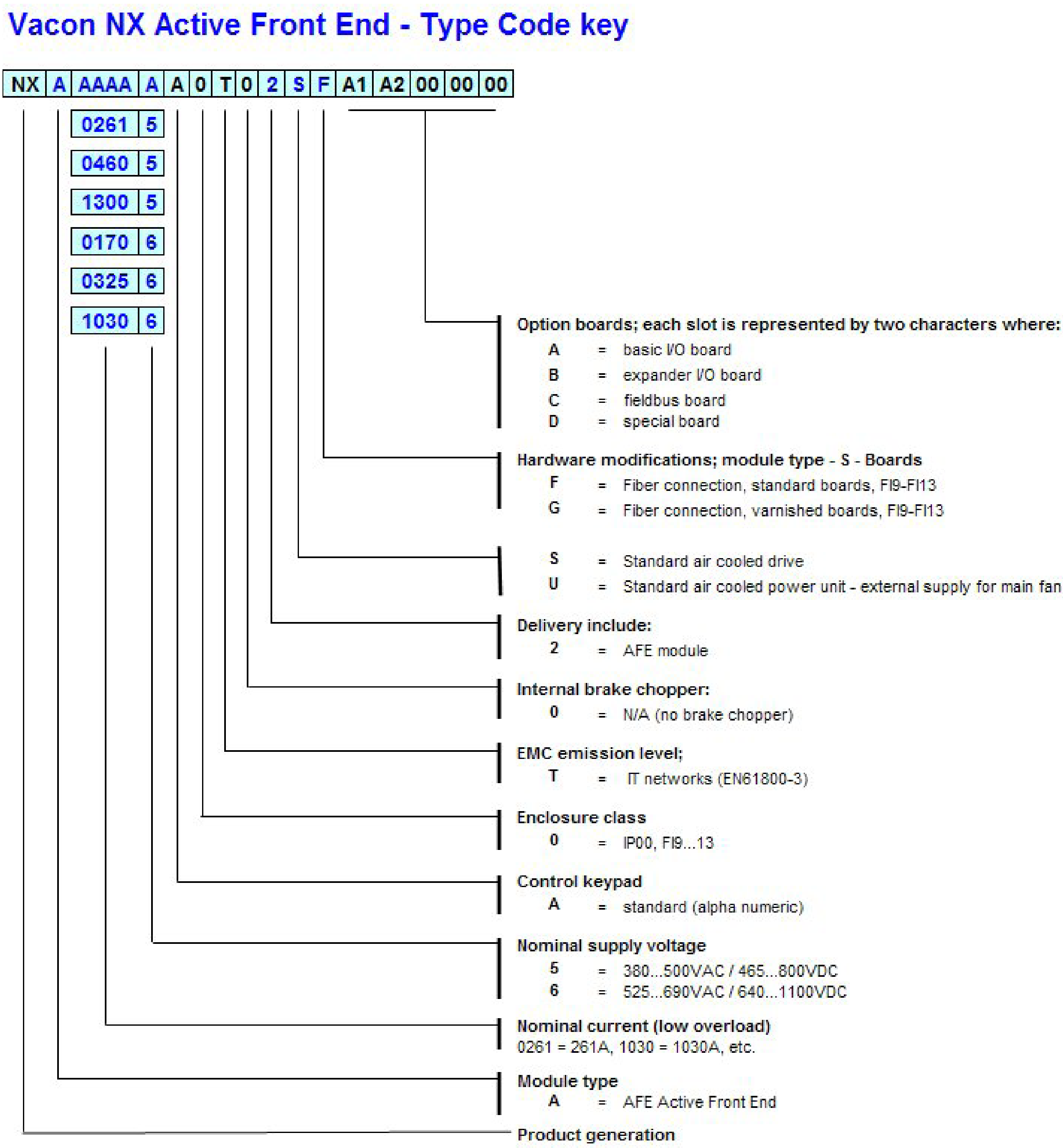



*Table 22. AFE current and power ratings, supply voltages 380-500 VAC*

| Unit | | Low overload (AC current) | DC Power (continuous) | |
|---|---|---|---|---|
| Code | Frame | $I_{Lcont}$ [A] | 400V mains P [kW] | 500V mains P[kW] |
| NXA_0261 5 | FI9 | 261 | 176 | 220 |

*Table 22. AFE current and power ratings, supply voltages 380-500 VAC*

| Unit | | Low overload (AC current) | DC Power (continuous) | |
|---|---|---|---|---|
| Code | Frame | $I_{Lcont}$ [A] | 400V mains P [kW] | 500V mains P[kW] |
| NXA_0460 5 | FI11 | 460 | 310 | 388 |
| NXA_1300 5 | FI13 | 1300 | 876 | 1095 |

*Table 23. AFE current and power ratings, supply voltages 525-690 VAC*

| Unit | | Low overload (AC current) | DC power (continuous) |
|---|---|---|---|
| Code | Frame | $I_{Lcont}$ [A] | 690V mains P [kW] |
| NXA_0170 6 | FI9 | 170 | 198 |
| NXA_0325 6 | FI10 | 325 | 378 |
| NXA_1030 6 | FI13 | 1030 | 1199 |

#### *9.5.2.2 Pre-Charging circuit*

An Active Front End unit requires an external pre-charging circuit. The purpose of the pre-charging unit is to charge the capacitance in the intermediate circuit to a voltage level sufficient for connecting the Active Front End unit to the mains. The charging time depends on the capacitance of the intermediate circuit and the resistance of the charging resistors. Technical specifications of Vacon's standard pre-charging circuits are shown in table Pre-charging circuit's Min and Max capacitance below. Pre-charging circuits are suitable for 380-500VAC and 525-690VAC.

An Active Front End unit must not be connected to mains without pre-charging. In order to ensure the correct operation of the pre-charging circuit, the Active Front End must control the input circuit-breaker or contactor, as well as the precharging circuit contactor. Circuit diagram showing typical connections.

*Table 24. Pre-charging circuit's Min and Max capacitance*

| Frame size | Resistance | Capacitance | |
|---|---|---|---|
| | | Min | Max |
| FI9 | 2x47R | 4950 µF | 30000 µF |
| FI10 | 2x20R | 9900 µF | 70000 µF |
| FI13 | 2x11R | 29700 µF | 128000 µF |

The Active Front End's application software controls the main contactor of the system using the relay output RO2, see the wiring diagram in the figure below. When the intermediate circuit becomes pre-charged, the relay output RO2 closes the main contactor. A digital input (by default DIN4) monitors the status of the main contactor. The monitoring of main contactor is ON by default. It must not be possible to close the main contactor or breaker before the pre-charging is finished. Opening of the contactor is only allowed when there is no load.

**NOTE**: Wirings used for connecting the pre-charging circuit to the intermediate circuit have to be double insulated.

#### *9.5.2.3 Paralleling*

The power of a supply section can be increased by connecting several Active Front End units in parallel, to the same input transformer. No communication between the units is required; they work independently.

Vacon's standard LCL filters must be used for paralleling. If filters other than Vacon's standard LCL filters are used in Active Front End units connected in parallel, too large circulation currents may be generated between the Active Front End units. See the Application manual for specific parameter settings.

Each Active Front End unit connected in parallel must have its own short-circuit protection on both AC and DC sides. When paralleling, attention must be paid to the sufficient short-circuit capacity of the entire system.

Derating of Active Front End units connected in parallel is 5% of the DC power; take this into account when selecting the input units.

If you want to isolate an AFE unit from the AC and DC voltages, while other Active Front End units connected in parallel are in use, you need separate isolators in the AC input and DC output.

The AC input can be isolated using a compact circuit-breaker, an ordinary circuit-breaker or a fuse switch. Contactors are not suitable for isolating the AC input, because they cannot be locked in the safe position. The DC output can be isolated using a fuse switch.

You must also isolate the pre-charging circuit from the AC input. A load isolation switch or safety isolation switch can be used for this.

An Active Front End unit can also be connected to the mains even when the other Active Front End units connected in parallel are already connected and running. In such a case, the isolated AFE unit must first be pre-charged. When that is done, the AC input can be switched on. After this, the device can be connected to the intermediate DC circuit.

#### *9.5.2.4 Common pre-charging circuit*

In case of paralleled Active Front End units, one common pre-charging circuit can be used. Standard pre-charging circuits can be used if the capacitance of the intermediate circuit does not exceed the maximum value. For example, if you connect three FI10 Active Front End units in parallel, you can use the pre-charging circuit for FI13 Active Front End unit.

If all paralleled Active Front End units have a common circuit breaker, the breaker can be controlled by one of the Active Front End units. If each paralleled Active Front End unit has its own circuit breaker, each Active Front End controls it’s own breaker. See the figure below.

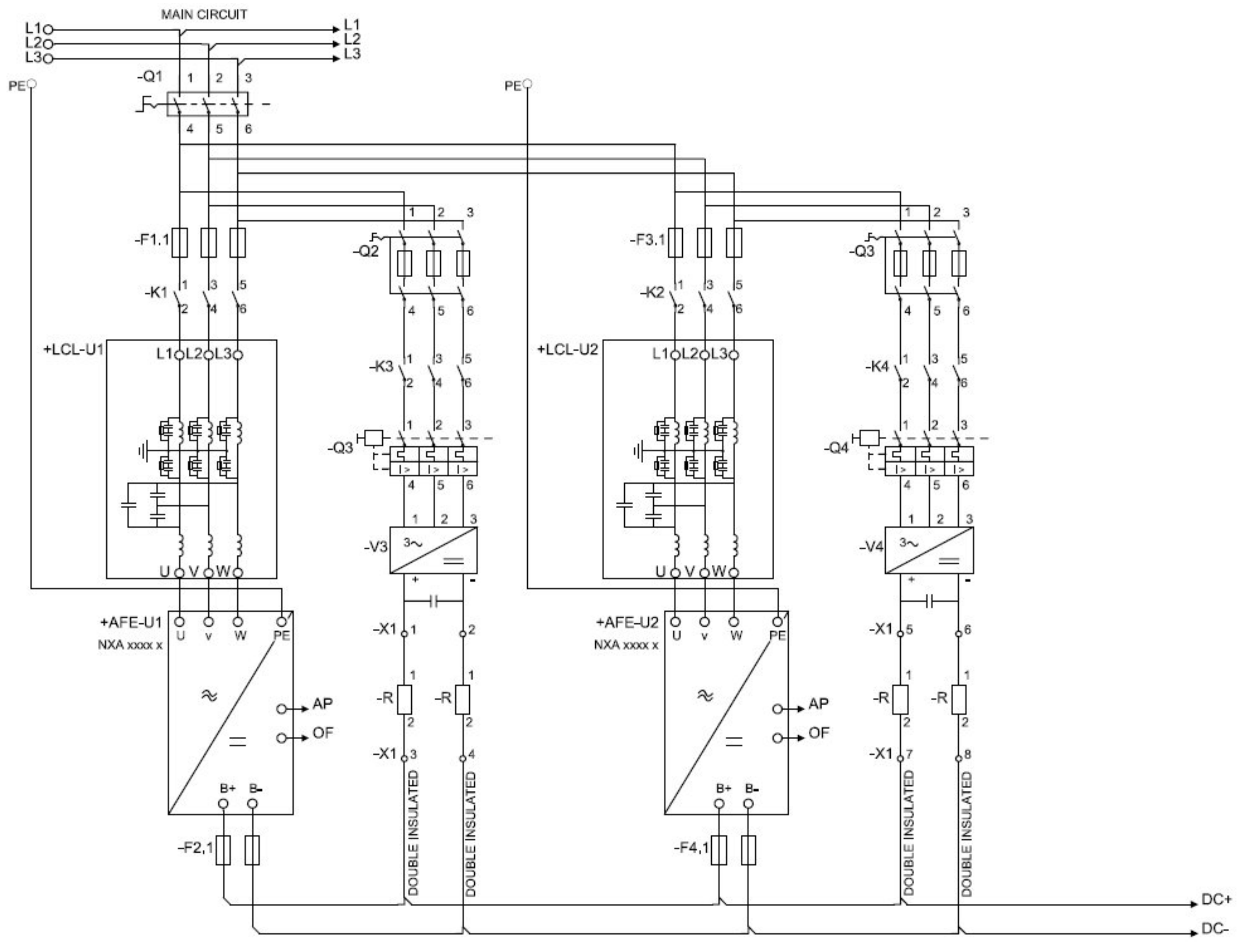



*Figure 70. Active Front End units connected in parallel, with own pre-charging circuits*

### 9.5.3 LCL filter

An AFE needs always a dedicated LCL filter on the mains side. Vacon's product range includes both air and liquid cooled LCL filters.

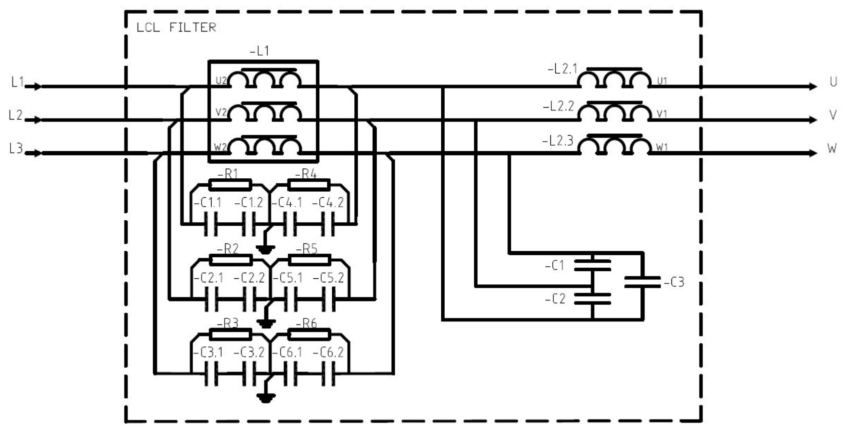



*Figure 71. Main circuit of an LCL filter*

## Vacon LCL filters for AFE - Type code

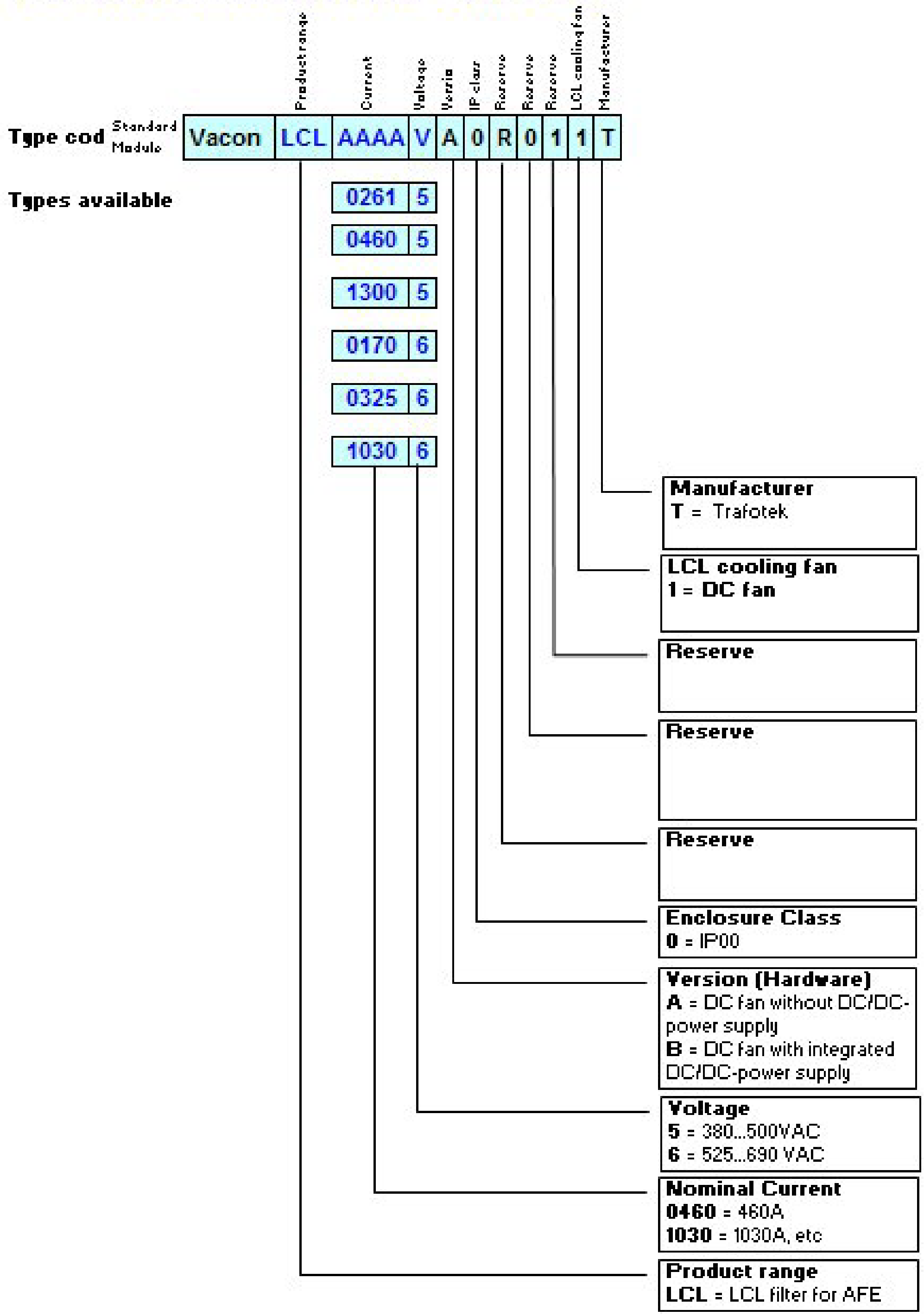


*Table 25. Dedicated LCL filter product range, supply voltage 380-500VAC, air cooled*

| Unit | | Low overload (AC current) | DC Power (continuous) | | Dedicated LCL filter's code |
|---|---|---|---|---|---|
| Code | Frame | $I_{L-cont}$ (A) | 400V mains P (kW) | 500V mains P (kW) | |
| NXA_0261 5 | FI9 | 261 | 176 | 220 | LCL02615 A/B* 0R011T |
| NXA_0460 5 | FI10 | 460 | 310 | 388 | LCL04605 A/B* 0R011T |
| NXA_1300 5 | FI13 | 1300 | 876 | 1095 | LCL13005 A/B* B0R011T |

*A = DC fan without DC/DC power supply
B = DC fan with integrated DC/DC power supply

*Table 26. Dedicated LCL filter product range, supply voltages 525-690VAC, air cooled*

| Unit | | Low overload (AC current) | DC Power (continuous) | Dedicated LCL filter's code |
|---|---|---|---|---|
| Code | Frame | $I_{L-cont}$ (A) | 690V mains P (kW) | |
| NXA_0170 6 | FI9 | 170 | 198 | LCL01706 A/B* 0R011T |
| NXA_0325 6 | FI10 | 325 | 378 | LCL03256 A/B* 0R011T |
| NXA_1030 6 | FI13 | 1030 | 1199 | LCL10306 A/B* 0R011T |

*A = DC fan without DC/DC power supply
B = DC fan with integrated DC/DC power supply

*Table 27. Dedicated LCL product range, liquid cooled*

| Vacon type | Current/A | Usability | |
|---|---|---|---|
| | | 400-500V | 525-690V |
| RCL-0385-6-0 | 385 | | x |
| RCL-0520-6-0 | 520 | x | x |
| RCL-0750-6-0 | 750 | x | x |
| RCL-0920-6-0 | 920 | x | x |
| RCL-1180-6-0 | 1180 | x | x |
| RCL-1640-6-0 | 1640 | x | x |
| RCL-2300-5-0 | 2300 | x | |

*Figure 72. An LCL filter*

### 9.5.4 Inverter unit

Inverter unit is a bidirectional DC-fed power inverter for the supply and control of AC motors. Protection class of air cooled inverter units up to FR 7 is IP21 or IP54. Bigger air cooled and all liquid cooled inverters are IP00.

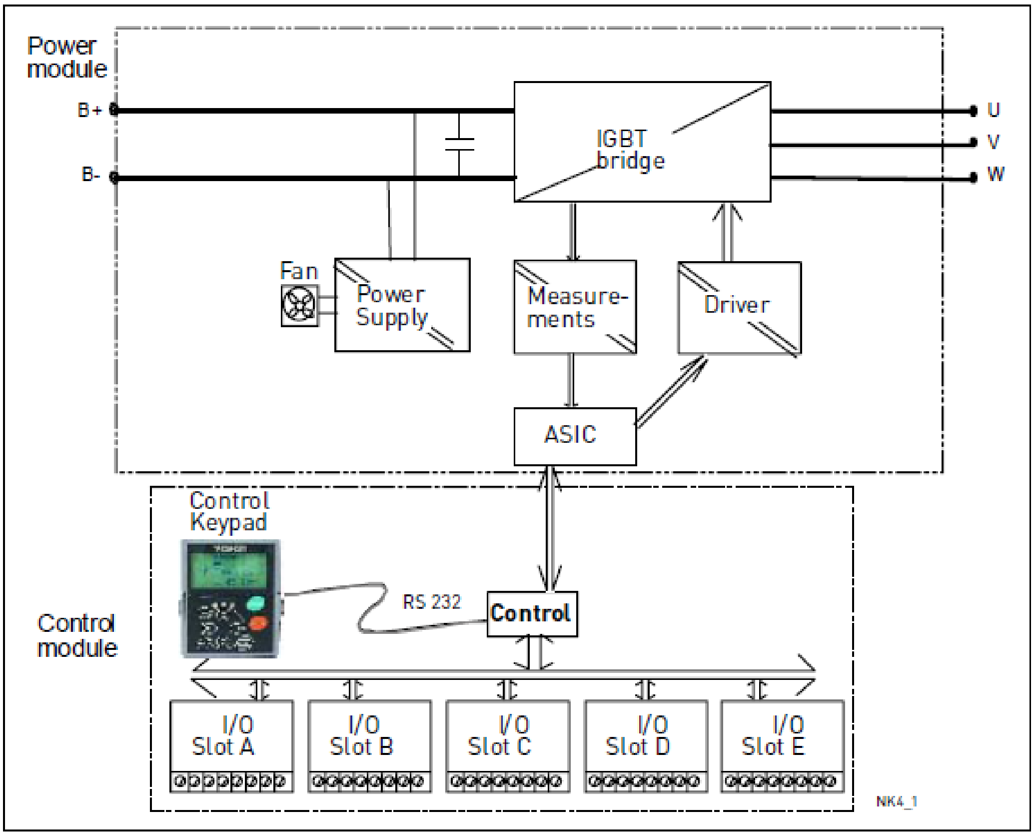



*Figure 73. NXI block diagram*

#### *9.5.4.1 Fuses and pre-charging*

Inverter units from FR4 to FR8 contain an integrated pre-charging circuit. Bigger units and all liquid cooled inverter units do not contain an integrated pre-charging circuit.

Need for disconnection and reconnection of inverters to a live DC bus defines if you need an isolation switch or direct connection with fuses.

- If you need to disconnect and reconnect an inverter that contains integrated pre-charging to a live DC bus, you can use a fuse switch.
- If you need to disconnect and reconnect an inverter that does not contain integrated pre-charging, you need a charging switch, or an alternative pre-charging method.
- If you do not need to disconnect and reconnect the inverter to a live DC bus, direct fuse connection is sufficient.

#### *9.5.4.2 Inverter Pre-charging switches*

Pre-charging switch is used for connecting and disconnecting inverter modules from the live DC busbar. The pre-charging circuit needs also resistors and fuses. Select the fuses for the pre-charging circuit according to the pre-charging currents in tables below.

The pre-charging switches are available with different control voltages. V1 means that control voltage for the coil is 110VAC and V2 that control voltage for the coil is 230VAC.

For connection instructions, see the product manuals.

Pre-charging switch type codes:

- CHAR-SWITCH-INU-FI9-FI10-V1
- CHAR-SWITCH-INU-FI9-FI10-V2
- CHAR-SWITCH-INU-FI12-V1
- CHAR-SWITCH-INU-FI12-V2
- CHAR-SWITCH-INU-FI13-V1
- CHAR-SWITCH-INU-FI13-V2

Charging resistor type codes:

- CHAR-RESIS-INU-11R
- CHAR-RESIS-INU-20R
- CHAR-RESIS-INU-35R
- CHAR-RESIS-INU-47R

*Table 28. Pre-charging components for 380-500VAC inverter units*

| | Pre-charging components | | | Values | | |
|---|---|---|---|---|---|---|
| Frame | OEVA | Resistor* | Resistance | Charging time (s) | Charging current (A) | Peak current (A) |
| FI9 | CHAR-SWITCH-INU-FI9-FI10 | CHAR-RESIS-INU-35R | 35ohm | 0,558 | 3,9 | 7,7 |
| FI10 | CHAR-SWITCH-INU-FI9-FI10 | CHAR-RESIS-INU-35R | 35ohm | 1,115 | 3,9 | 7,7 |
| FI12 | CHAR-SWITCH-INU-FI12 | 2 x CHAR-RESIS-INU-35R | 35ohm | 1,115 | 3,9 | 7,7 |
| FI13 | CHAR-SWITCH-INU-FI13 | CHAR-RESIS-INU-11R | 11ohm | 1,052 | 12,4 | 24,5 |
| FI14 | CHAR-SWITCH-INU-FI13 | 2 x CHAR-RESIS-INU-11R | 11ohm | 1,052 | 12,4 | 24,5 |

*The resistor type code refers to two resistors. Thus a delivery of 2 x CHAR-RESIS-INU-35R contains 4 resistors.

*Table 29. Pre-charging components for 525-690VAC inverter units*

| | Pre-charging components | | | Values | | |
|---|---|---|---|---|---|---|
| Frame | OEVA | Resistor* | Resistance | Charging time (s) | Charging current (A) | Peak current (A) |
| FI9 | CHAR-SWITCH-INU-FI9-FI10 | CHAR-RESIS-INU-47R | 47ohm | 0,565 | 5,0 | 9,9 |
| FI10 | CHAR-SWITCH-INU-FI9-FI10 | CHAR-RESIS-INU-47R | 47ohm | 1,130 | 5,0 | 9,9 |
| FI12 | CHAR-SWITCH-INU-FI12 | 2 x CHAR-RESIS-INU-47R | 47ohm | 1,130 | 5,0 | 9,9 |
| FI13 | CHAR-SWITCH-INU-FI13 | CHAR-RESIS-INU-20R | 20ohm | 1,442 | 11,7 | 23,3 |
| FI14 | CHAR-SWITCH-INU-FI13 | 2 x CHAR-RESIS-INU-20R | 20ohm | 1,442 | 11,7 | 23,3 |

*The resistor type code refers to two resistors. Thus a delivery of 2 x CHAR-RESIS-INU-35R contains 4 resistors.

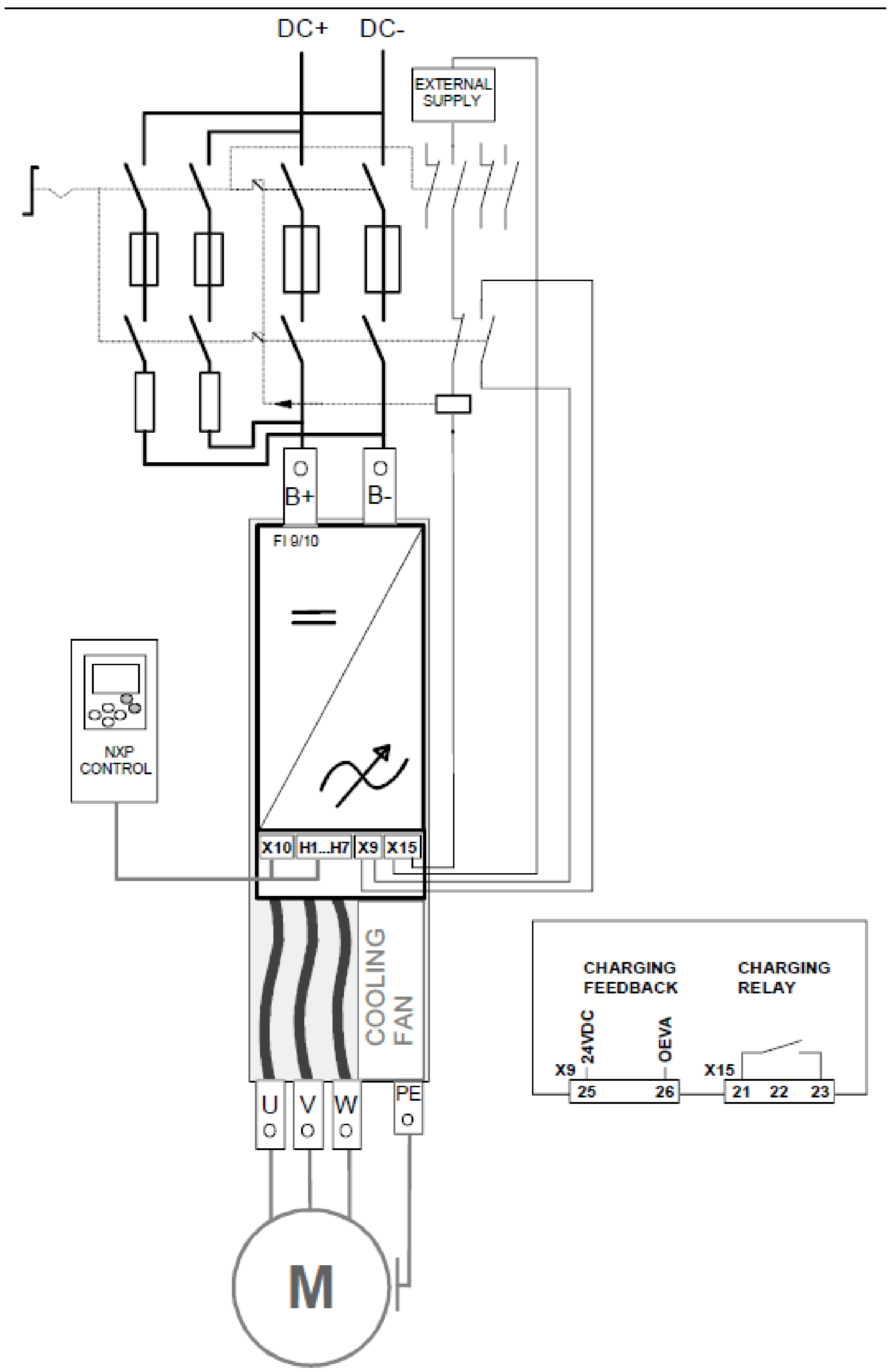



*Figure 74. FI9/FI10 Basic wiring diagram with charging*

### 9.5.4.3 INU unit's type code

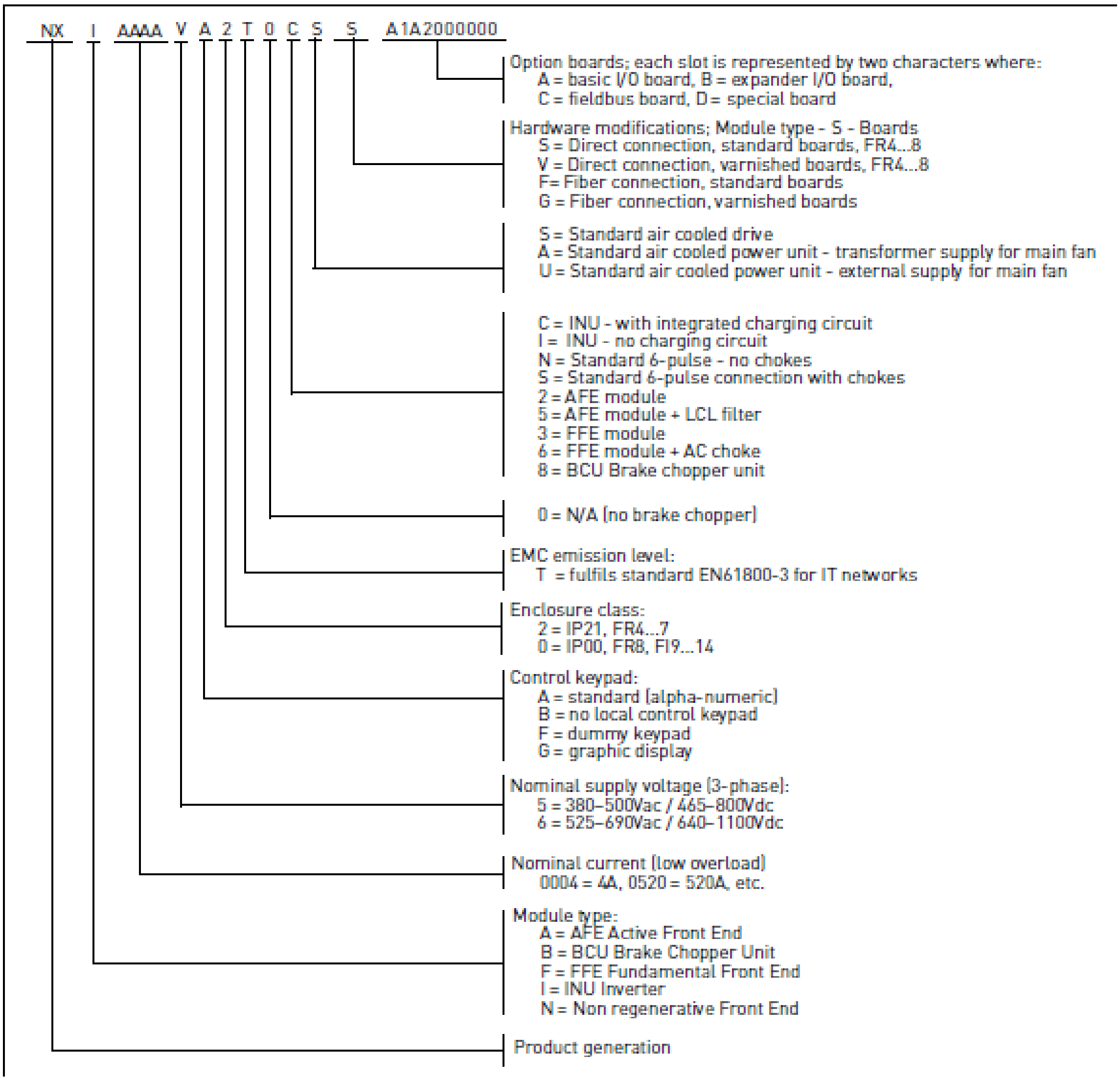



*Figure 75. Air cooled inverter unit's type code, frames FI9 - FI14*

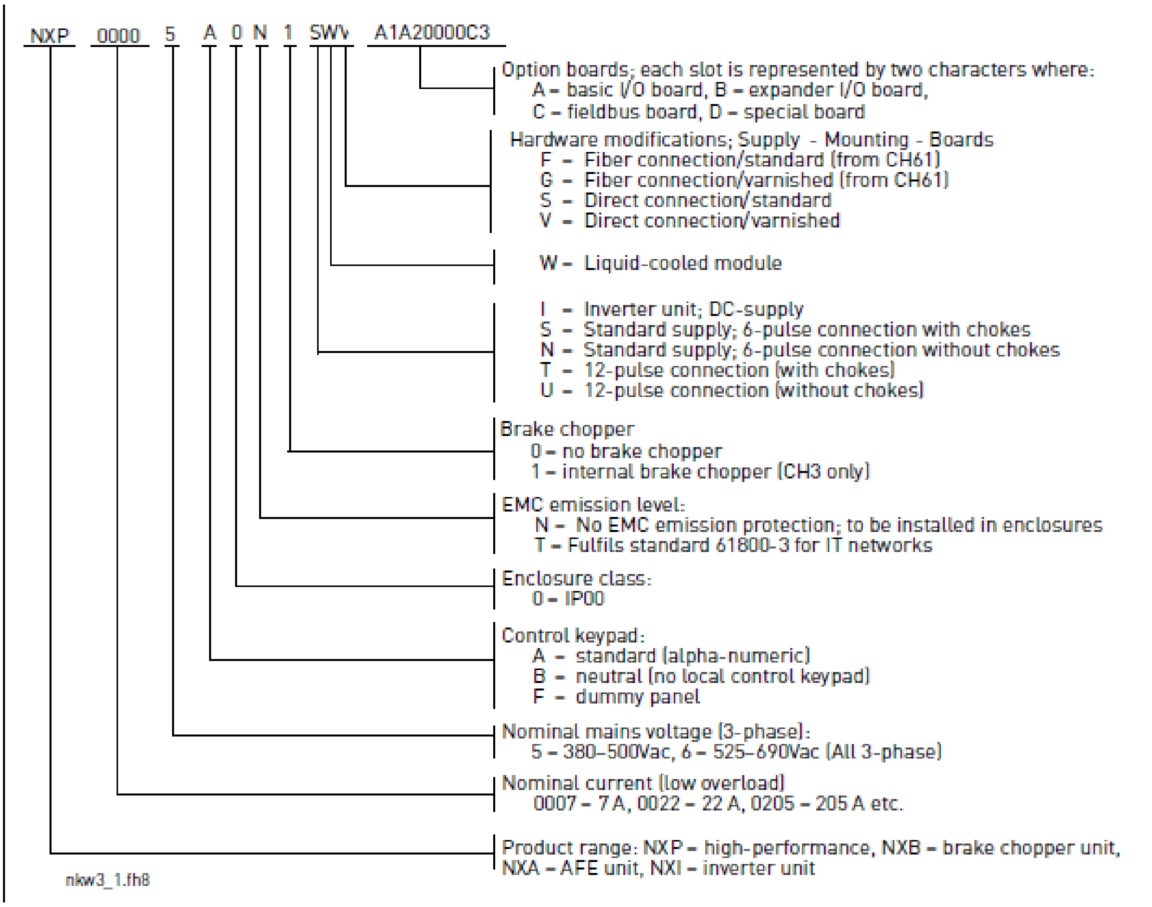



*Figure 76. Liquid cooled inverter unit’s type code*

Inverter product range includes both air and liquid cooled units in two voltage ranges. For detailed information, see the product brochures and manuals.

### 9.5.5 Brake chopper unit & brake resistors

The BCU (Brake chopper unit) is a unidirectional power converter for the supply of excessive energy from a common DC bus drive line-up to resistors where the energy is dissipated as heat. External resistors are needed. By using two brake resistors, the braking power of the brake chopper is doubled.

## 9.6 Wiring diagram examples

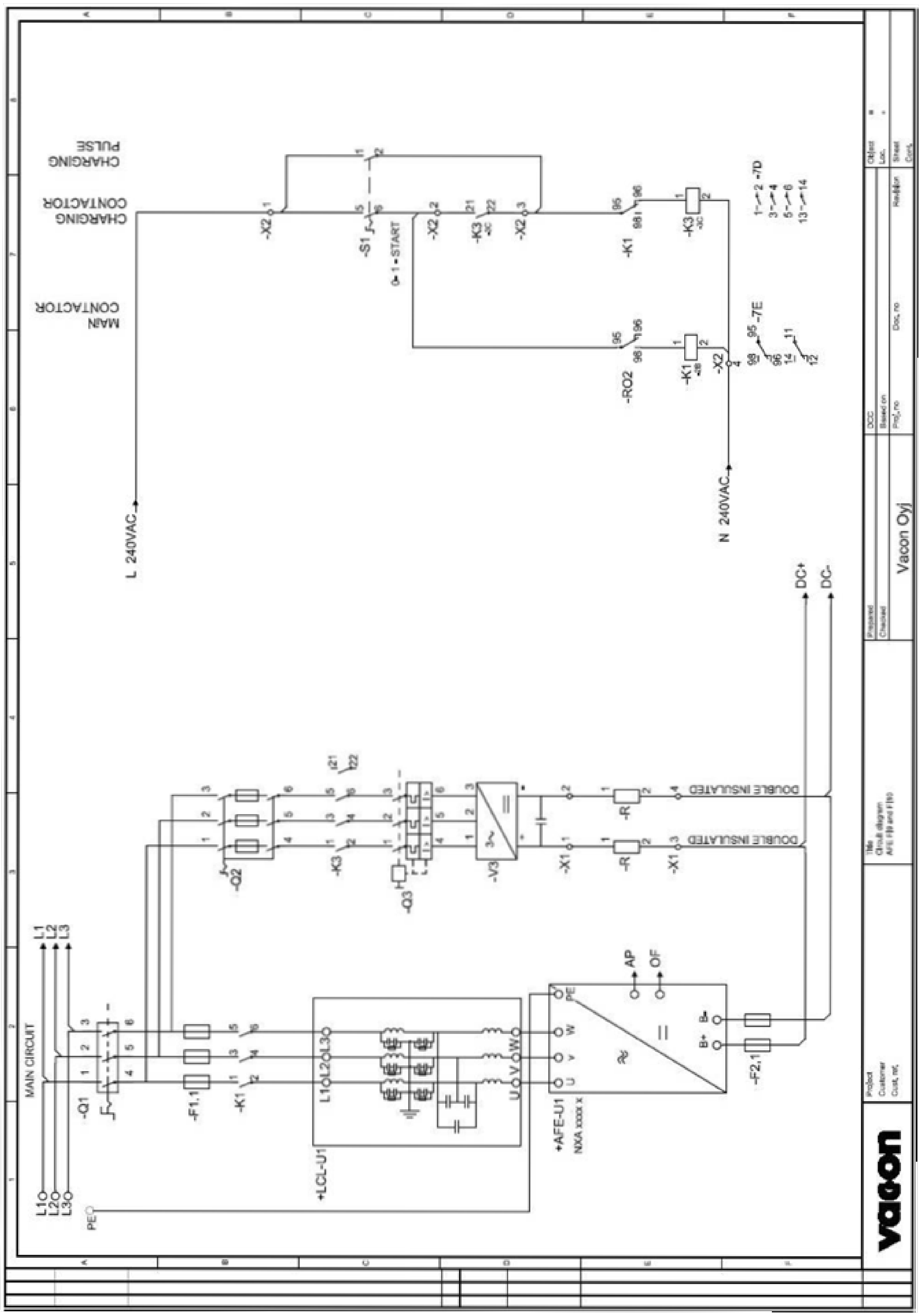



Figure 77. Wiring diagram for FI9 and FI10

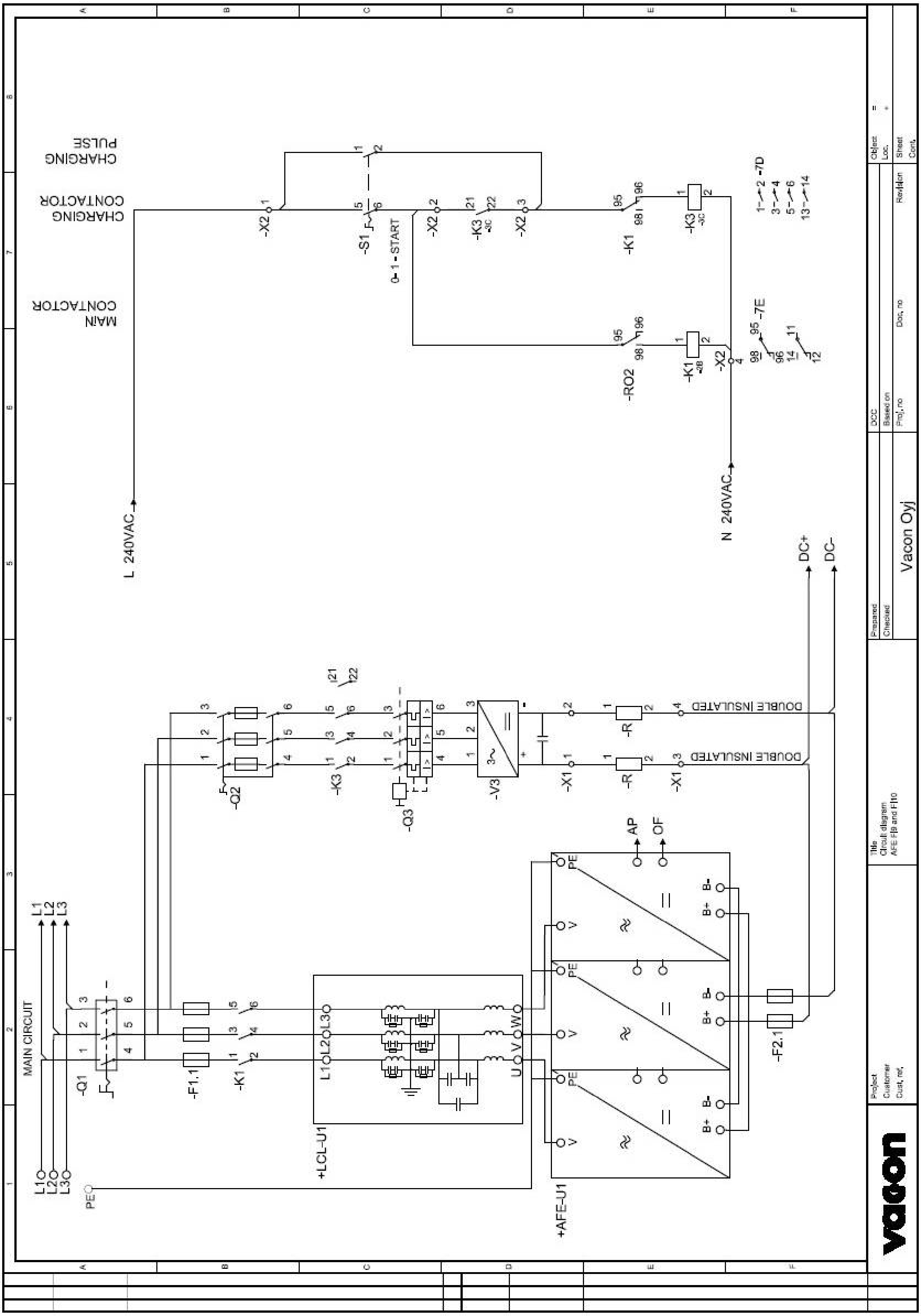



*Figure 78. Wiring diagram for FI13*

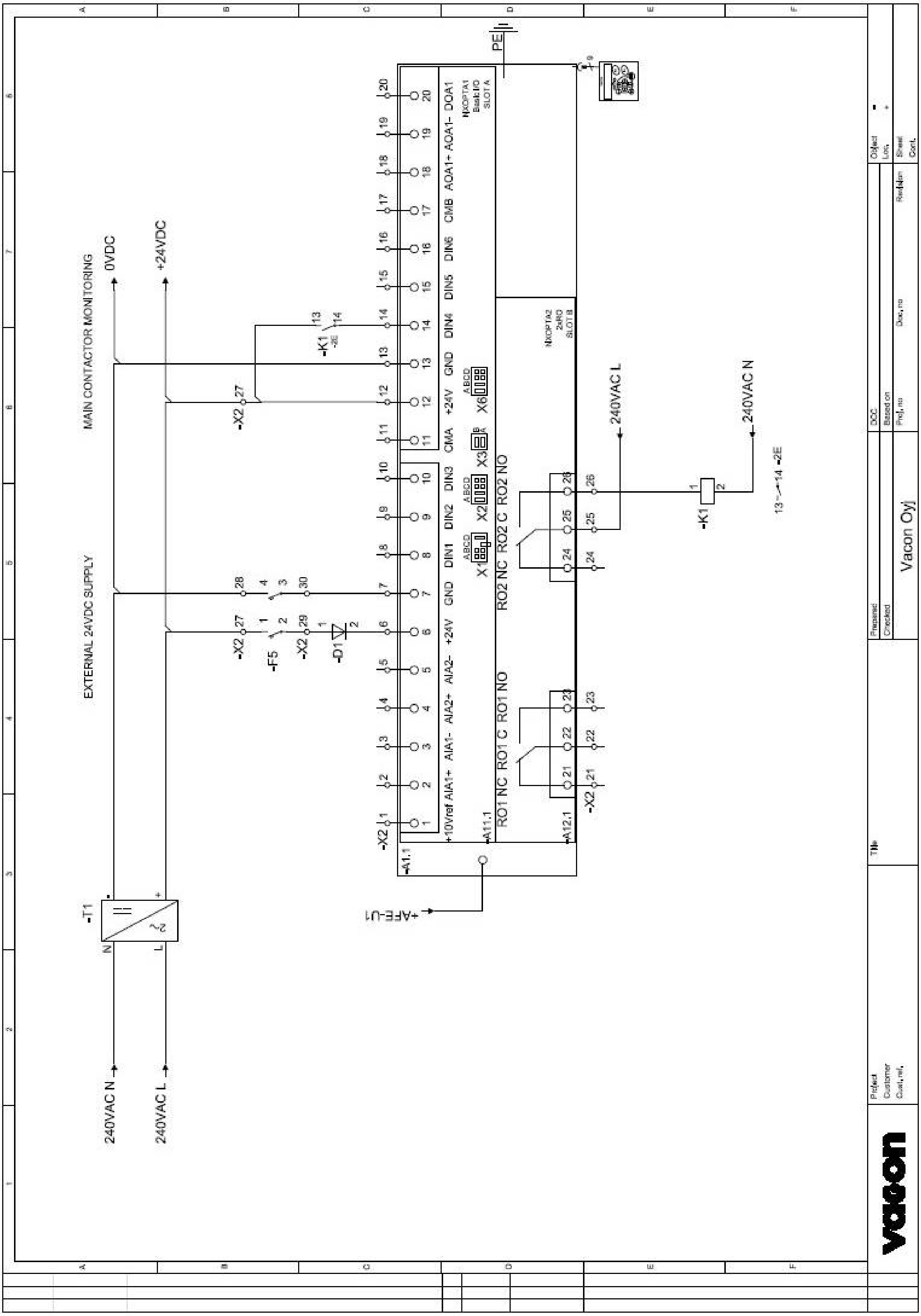



*Figure 79. Wiring diagram for a control unit*

# 10. Cabinet installation

Drive modules of protection class IP00 must always be installed in an installation cabinet or enclosure. The actual protection class of the entire drive system can be adjusted by selecting an appropriate installation cabinet type. The enclosure must provide sufficient shielding for contact of the live parts (IP2x).

The switchgear design must allow enough space for all connection cables and auxiliary devices, for example ferrites. There must also be room for making the cable connections. Module installation within the switchgear must allow service operations, such as changing the fans and external fuses as well as checking and re-tightening of electrical connection points.

The switchgear design, installation and mounting must comply with local laws and regulations. In addition, you need to find out the requirements that the installation premises set to the switchgear configuration. These requirements include ambient conditions and the size of the actual installation space.

The cooling system as well as the busbars and cables need to be dimensioned in accordance with the “worst case scenario” of continuous temperature and load. When choosing the auxiliary components, you need to check the components’ ratings to avoid breakdown due to, for example, too high ambient temperature.

The IP00 modules must be protected from short circuit currents using appropriate AC and/or DC fuses or by circuit breakers. For fuse selection, see the relevant product manuals.

## 10.1 Products included in an IP00 drive delivery

- AC choke (with liquid cooled drives the choke can be excluded from the order, but a choke is compulsory as such)
- The IP00 power module
- Control unit
- Output filter (optional)

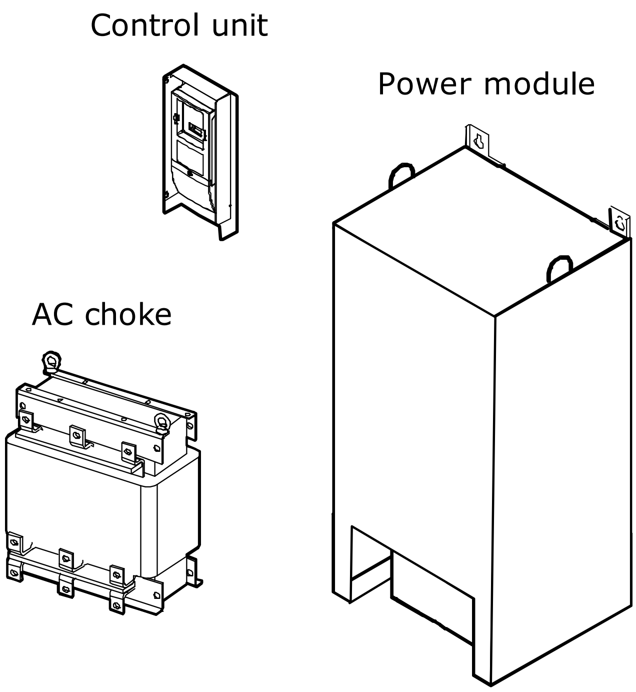



*Figure 80. Main items of an IP00 drive unit delivery*

## 10.2 Air cooled NXP IP00 module configurations

### 10.2.1 Frames 10 and 11

The power units of FR10 and FR11 drives are contained in a single frame. The drive units are available in 6-pulse and 12-pulse versions. The pulse system has no effect on the dimensions of the drive unit. The number of AC chokes depends on the pulse system. A 6-pulse drive needs one AC choke, and a 12-pulse drive needs two AC chokes. The chokes are external, and they are delivered separately. Brake chopper is optional, and it has no effect on the dimensions of the drive unit.

The control unit can be separate, with optical connection to the power unit, or it can be installed on the cover of the power module, as in the figure below. When the control unit is delivered with optical connection, the delivery also contains a fixing plate, that is needed for installing the control unit to, for example, a cabinet door.

*Figure 81. FR10 and FR11*

### 10.2.2 Frame 12

Frame 12 consists of a control unit and two separate power modules that are connected together using a star coupler board. The control unit can be separate, with optical connection to the power unit, or it can be installed on the cover of the power module, as in the figures above and below. AC chokes are delivered separately. Brake chopper is optional, and it can be integrated in the frame. Thus it does have no effect on the dimensions.

Frame 12 is available in 6-pulse and 12-pulse versions, and the pulse system has no effect on the dimensions, or on the amount of chokes. An FR12 drive needs always two AC chokes.

*Figure 82. FR12*

#### 10.2.3 Frames 13 and 14

Frame 13 and 14 drives are based on the common DC bus product range. There is always one control unit. The power module consists of NFE (Non-regenerative Front End) units and INU (Inverter) units. A Frame 13 delivery contains always 1 INU, and a Frame 14 delivery contains 2 INUs, connected using a star coupler board. Depending on the pulse system (6-pulse or 12-pulse), there can be 2, 3 or 4 NFE units. Thus the pulse system has direct effect on the dimensions of the drive system.

The number of AC chokes depends on the number of NFE units, there must be one AC choke for each NFE unit. They are delivered separately.

Brake chopper cannot be integrated, it is always external. There are no frame-specific brake choppers for FR13 and FR14. You can selected the brake chopper unit from the common DC bus brake chopper range. The brake choppers are of different sizes, so they have an effect on the drive system's dimensions.

Control unit is always connected using an optical cable. The delivery contains also a fixing plate, that is needed for installing the control unit to, for example, a cabinet door.

With FR14 two external dU/dt filters are delivered by default. For other frames, they are optional.

For more details on dimensions and product types, IP00 module installation guide.


*Figure 83. Frames 13 and 14*

## 10.3 Liquid cooled NXP IP00 module configurations

All liquid cooled drives use the NXP control platform. The control unit is delivered separately, with optical connection to the power unit. A fixing plate for installing the control unit to, for example a cabinet door, is included in the delivery. The protection class of all liquid cooled drive modules is always IP00, and they must be installed in a cabinet or other enclosure. All liquid cooled drive units that consist of multiple modules are installed in mounting bracket.

A standard liquid cooled drive delivery contains an air cooled AC choke, if a choke is needed.

### 10.3.1 Chassis 3, Chassis 4 and Chassis 5

The CH3, CH4 and CH5 frequency converters are available in 6-pulse versions only. They need an external AC choke.

*Figure 84. CH3, CH4 and CH5 frequency converters*

The CH3, CH4 and CH5 brake chopper units do not need an AC choke, but they need external brake resistors.

The CH3, CH4 and CH5 inverter units need a DC supply.

*Table 30. Power ranges for CH3, CH4 and CH5*

| | 400-500 VAC (465-800 VDC) |
|---|---|
| CH3 | 7,5-37 kW |
| CH4 | 37-90 kW |
| CH5 | 90-160 kW |

### 10.3.2 Chassis 61 and Chassis 63

The CH61 and CH63 frequency converters are available in 6-pulse versions only. They need an external AC choke.

*Figure 85. CH 61 and CH63 frequency converters*

The CH61 and CH63 brake chopper units do not need an AC choke, but they need external brake resistors.

The CH61 and CH63 inverter units need a DC supply.

*Table 31. Power ranges for CH61 and CH63*

| | 400-500 VAC (465-800 VDC) | 525-690 V AC (640-1100 VDC) |
|---|---|---|
| CH61 | 160-250 kW | 110-250 kW |
| CH63 | 450-750 kW | 400-700kW |

### 10.3.3 Chassis 62 and Chassis 64

*Figure 86. CH62 and CH64 inverter units*

The CH62 and CH64 are dedicated inverter units that need a DC supply.

The CH62 and CH64 brake chopper units do not need an AC choke, but they need external brake resistors

*Table 32. Power ranges for CH62 and CH64*

| | 400-500 VAC (465-800 VDC) | 525-690 V AC (640-1100 VDC) |
|---|---|---|
| CH62 | 250-500 kW | 200-450 kW |
| CH64 | 700-1500 kW | 560- 1550 kW |

### 10.3.4 Chassis 72 and Chassis 74

*Figure 87. CH72 and CH74 frequency converters*

The CH72 and CH74 frequency converters are available in both 6- and 12-pulse versions. The CH74 6-pulse version contains three parallel rectifiers, and thus they can be used to compile an 18-pulse solution, too. They need an external AC choke.

The CH72 brake chopper option is available in the 6-pulse version only. The CH74 brake chopper option is available in both 6- and 12-pulse versions.

*Table 33. Power ranges for CH72 and CH74*

| | 400-500 VAC (465-800 VDC) | 525-690 V AC (640-1100 VDC) |
|---|---|---|
| CH72 | 250-500 kW | 200-450 kW |
| CH74 | 700-1500 kW | 560-1550 kW |

### 10.3.5 2 X Chassis 64 and 2 X Chassis 74

The 2 x CH64 and 2 x CH74 frequency converters each consist of one control unit and two power modules that are connected together using a star coupler board.

In case a brake chopper is used in the 2 x chassis 74, the intermediate DC circuits must be connected together, because the brake chopper is not synchronised. This guarantees the operation of the braking system.

For more details, see the product manuals.

*Table 34. Power ranges for 2xCH64 and 2xCH74*

| | 400-500 VAC (465-800 VDC) | 525-690 V AC (640-1100 VDC) |
|---|---|---|
| 2 X CH64 | 1300-2700 kW | 1250-2800 kW |
| 2 X CH74 | 1300-2700 kW | 1250-2800 kW |

## 10.4 AC chokes

The input choke is needed as an essential component for motor control, to protect the input and DC-link components against abrupt changes of current and voltage, as well as to function as a protection against harmonics. Input chokes are included in the standard delivery of Vacon liquid-cooled frequency converters (not inverters). However, you can also order your frequency converter without the choke.

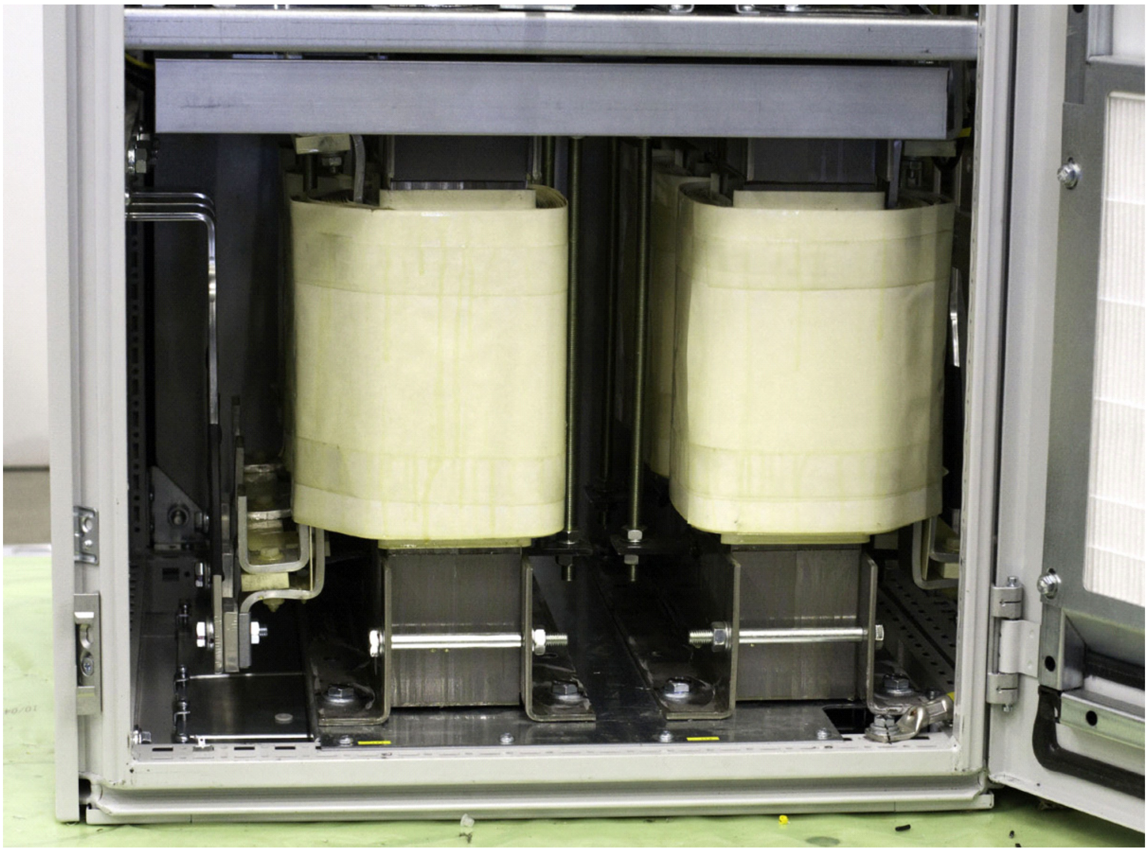


*Figure 88. AC chokes*

*Table 35. Input chokes for 6-pulse supply*

| Converter types (400—500VAC) | Converter types (690VAC) | Choke type | Thermal current (A) | Nominal inductance (μH) A/B* | Calculated loss (W) |
|---|---|---|---|---|---|
| 0016...0022 | 0012...0023 | CHK0023N6A0 | 23 | 1900 | 145 |
| 0031...0038 | 0031...0038 | CHK0038N6A0 | 38 | 1100 | 170 |
| 0045...0061 | 0046...0062 | CHK0062N6A0 | 62 | 700 | 210 |
| 0072...0087 | 0072...0087 | CHK0087N6A0 | 87 | 480 | 250 |
| 0105...0140 | 0105...0140 | CHK0145N6A0 | 145 | 290 | 380 |
| 0168...0261 | 0170...0261 | CHK0261N6A0 | 261 | 139/187 | 460 |
| 0300...0385 | 0325...0385<br>*0820...1180*<br>*1850...2340* | CHK0400N6A0 | 400 | 90/126 | 610 |

*Table 35. Input chokes for 6-pulse supply*

| Converter types (400—500VAC) | Converter types (690VAC) | Choke type | Thermal current (A) | Nominal inductance (μH) A/B* | Calculated loss (W) |
|---|---|---|---|---|---|
| 0460...0520<br>*1370 (CH74)* | 0416...0502<br>*1300...1500*<br>*2700...3100* | CHK0520N6A0 | 520 | 65/95 | 810 |
| 0590...0650<br>*1640* | 0590...0650<br>*1700...1900* | CHK0650N6A0 | 650 | 51/71 | 890 |
| 0730<br>*2060* | 0750 | CHK0750N6A0 | 750 | 45/61 | 970 |
| 0820<br>*2300* | - | CHK0820N6A0 | 820 | 39/53 | 1020 |
| 0920...1030 | - | CHK1030N6A0 | 1030 | 30/41 | 1170 |
| 1150 | - | CHK1150N6A0 | 1150 | 26/36 | 1420 |
| *2470...2950* | | CHK0520N6A0 | 520 | 65/95 | 810 |
| *3710* | | CHK0650N6A0 | 650 | 51/71 | 890 |
| *4140* | | CHK0750N6A0 | 750 | 45/61 | 970 |

**NOTE:** Converter types written in *italics* require three chokes per unit.

*Table 36. Input chokes for 12-pulse supply*

| Converter types (400—500VAC) | Converter types (690VAC) | Choke types (2 chokes needed) | Thermal current (A) | Nominal inductance (μH) A/B* | Calculated loss (W) |
|---|---|---|---|---|---|
| 0460...0520 | 0325...0502 | CHK0261N6A0 | 261 | 139/187 | 460 |
| 0590...0730 | 0590...0750 | CHK0400N6A0 | 400 | 90/120 | 610 |
| 0820...1030 | 0820...1030<br>*1850* | CHK0520N6A0 | 520 | 65/95 | 810 |
| 1150<br>*2300*<br>*2470* | 1180...1300<br>*2120...2340* | CHK0650N6A0 | 650 | 51/71 | 890 |
| 1370<br>*2950* | 1370<br>*2700* | CHK0750N6A0 | 750 | 45/61 | 970 |
| 1640 | 1500<br>*3100* | CHK0820N6A0 | 820 | 39/53 | 1020 |
| 2060<br>*3710* | 1700...1900 | CHK1030N6A0 | 1030 | 30/41 | 1170 |
| *4140* | - | CHK1150N6A0 | 1150 | 26/36 | NA |

**NOTE:** Converter types written in *italics* require two chokes per unit (in total 4)

## 10.5 Lifting the power module

The power module of an air cooled drive unit weighs typically over 100 kg, which means that you need a specific lifting device for lifting and moving it to the place needed. The power module has lifting lugs at the top. See the product manual for more detailed handling instructions.

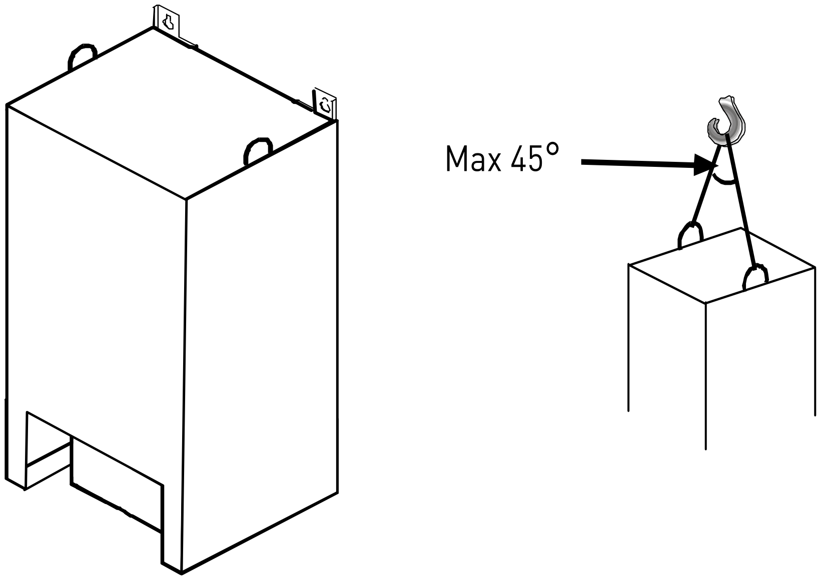



*Figure 89. Lifting angle*

*Table 37. Weight of air cooled drive units*

| Frame | Weight kg |
|---|---|
| FR10 | 123 |
| FR11 | 210 |
| FI9 | 65 |
| FI10 | 100 |
| FI12 | 200 |
| FI13 | 302 |

*Table 38.* Dimensions of liquid cooled NXP drives consisting of one module

| Chassis | Width (mm) | Height (mm) | Depth (mm) | Weight (kg) |
|---|---|---|---|---|
| CH3 | 160 | 431 | 246 | 30 |
| CH4 | 193 | 493 | 257 | 35 |
| CH5 | 246 | 553 | 264 | 40 |
| CH61/62 | 246 | 658 | 372 | 55 |
| CH63 | 505 | 923 | 375 | 120 |
| CH64 | 746 | 923 | 375 | 180 |
| CH72 | 246 | 1076 | 372 | 90 |
| CH74 | 746 | 1175 | 385 | 280 |

Mounting base of the drive unit is included in the dimensions of the above table, but AC chokes are not.

## 10.6 Installing the power module

The power module can be mounted in a vertical position on the back plane of a cubicle. See the product manual for more detailed installation instructions.

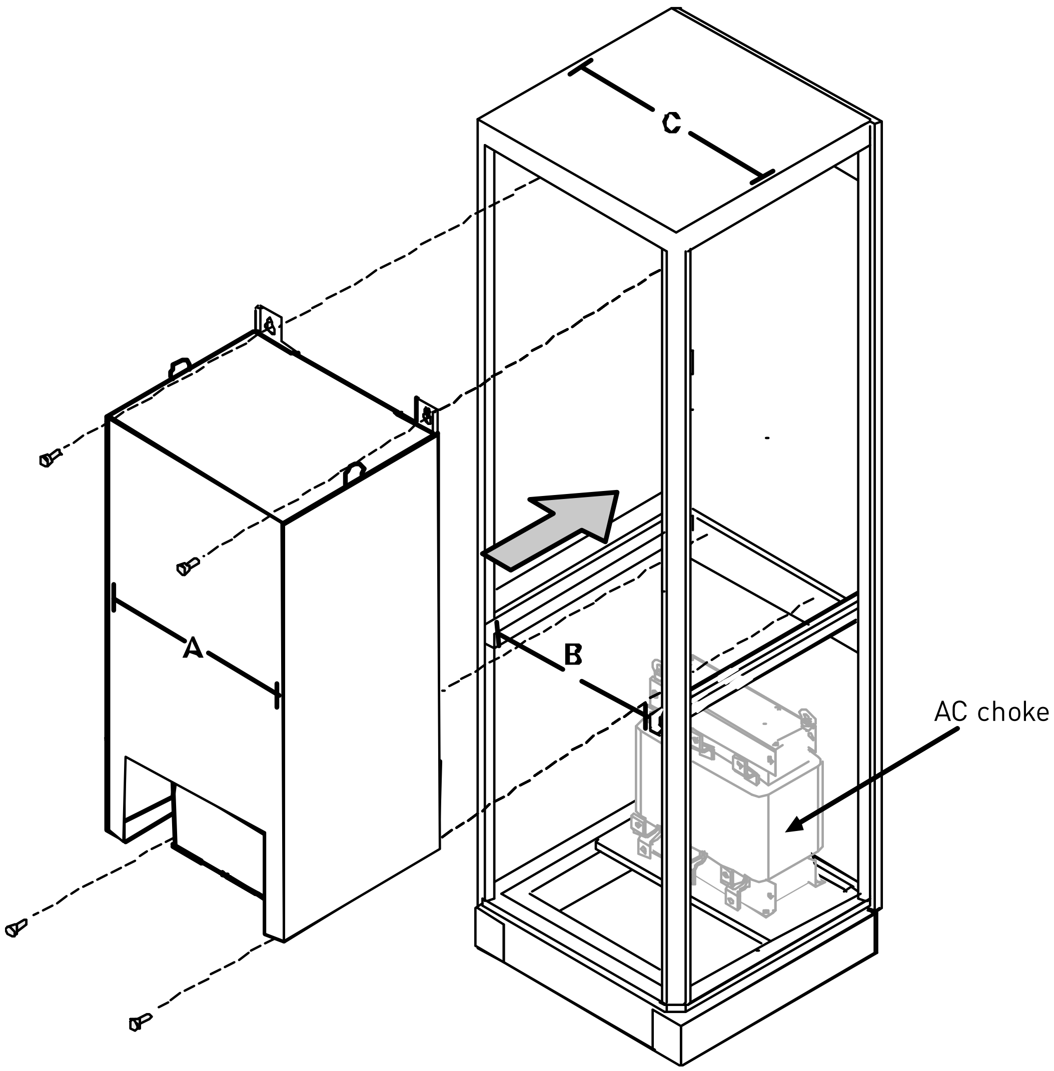



*Figure 90. Installation of the power module*

*Table 39. Cabinet measurements*

| Frame | Device width A/mm | Supporting bar range B/mm | Recommended cabinet width C/mm |
|---|---|---|---|
| FR10 | 500 | A - 50mm | 600 |
| FR11 | 709 | A - 20mm | 800 |
| FI9 | 239 | A - 50mm | 400 |
| FI10 | 239 | A - 50mm | 400 |
| FI12 | 478 | A - 50mm | 600 |
| FI13 | 708 | A - 50mm | 800 |

## 10.7 Cooling - air cooled units

When planning the placement of the drive unit and auxiliary components to the sections of a drive line-up, you must carefully consider the ventilation and cooling of each section. The drive unit as well as the auxiliary components of a drive heat up the space they are installed in.

The drive line-up must be designed so that the ambient conditions inside each section are in accordance with Vacon's specifications for Vacon products. Temperature within each section must stay below the maximum operating temperature. Repeated overheating will compromise the operation and shorten the lifetime of the frequency converter.

The need of cooling of the frequency converter varies greatly with load and output frequency as well as with the switching frequency used. For dimensioning of cooling or ventilation equipment for electrical rooms, the following generic formula gives a good approximation of the heat losses for standard 6- and 12- pulse frequency converters at nominal conditions:

$$P_{loss}\ [kw] = P_{mot}\ [kW] \times 0{,}025$$

**NOTE!** Always check the heat loss data from the relevant product manuals.

Ventilation and air flow are important both within the cabinet, and outside the cabinet. You can use either a duct or an air barrier to make sure that the outgoing air does not mix with incoming cooling air.

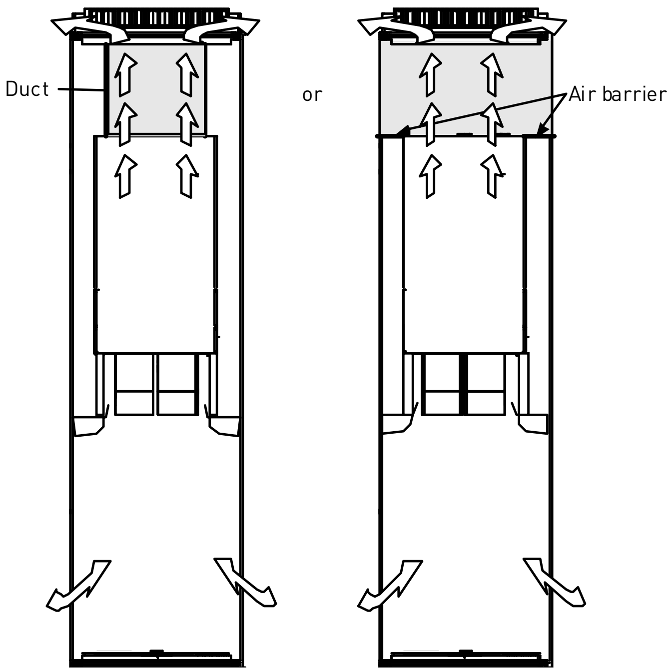



*Figure 91. Steering the internal air flow*

In the sections containing drive module/modules, the module's own fan is usually enough to provide sufficient cooling air flow within that section, when the openings for inlet and outlet of air are designed in accordance with the requirements. In sections that do not contain a drive module, but for example a choke and/or an output filter, you must check how much heat is produced, and whether a door fan or other separate ventilation system is needed.

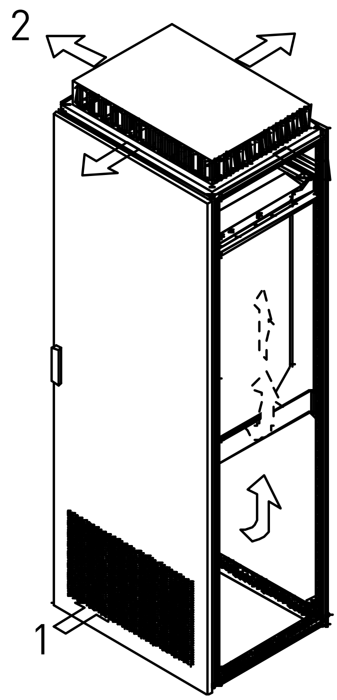



*Figure 92. Ventilation of the cabinet*

Table below states the required cooling air quantities and the sizes of the openings for inlet and outlet of air. These values (table below) are achieved with the unit's own fan, when the openings are in accordance with the product-specific requirements.

*Table 40. Ventilation requirements*

| | | Minimum air hole on switchgear/$dm^2$ | |
|---|---|---|---|
| **Frame** | **Cooling air required $m^3/h$** | **1) Inlet** | **2) Outlet** |
| FR10 | 2800 | 13 | 7 |
| FR11 | 4200 | 19,5 | 10,5 |
| FI9 | 1150 | 5,5 | 3 |
| FI10 | 1400 | 6,5 | 4 |
| FI12 | 2800 | 13 | 7 |
| FI13 | 4200 | 19,5 | 10,5 |

## 10.8 Cooling - liquid cooled units

In liquid cooled units, most of the excess heat is cooled by the liquid cooling system. However, in a liquid cooled drive system, there are always some heat losses to the air, too. The heat losses originate from the busbars, filters, chokes and other auxiliary components.

The drive line-up must be designed so that the ambient conditions inside each section are in accordance with Vacon's specifications for Vacon products. Temperature within each section must stay below the maximum operating temperature. Repeated overheating will compromise the operation and shorten the lifetime of the frequency converter.

The need of cooling of the frequency converter varies greatly with load and output frequency as well as with the switching frequency used. You must check how much the heat losses are in each section of the drive line-up, and whether a door fan or other separate ventilation system is needed to keep the temperature of the section within the limits.

A completely air-tight cabinet is possible if there is a radiator (liquid to air) heat exchanger inside the drive cabinet.

## 10.9 Dimensions and layout examples

### 10.9.1 Dimensions of the supply section

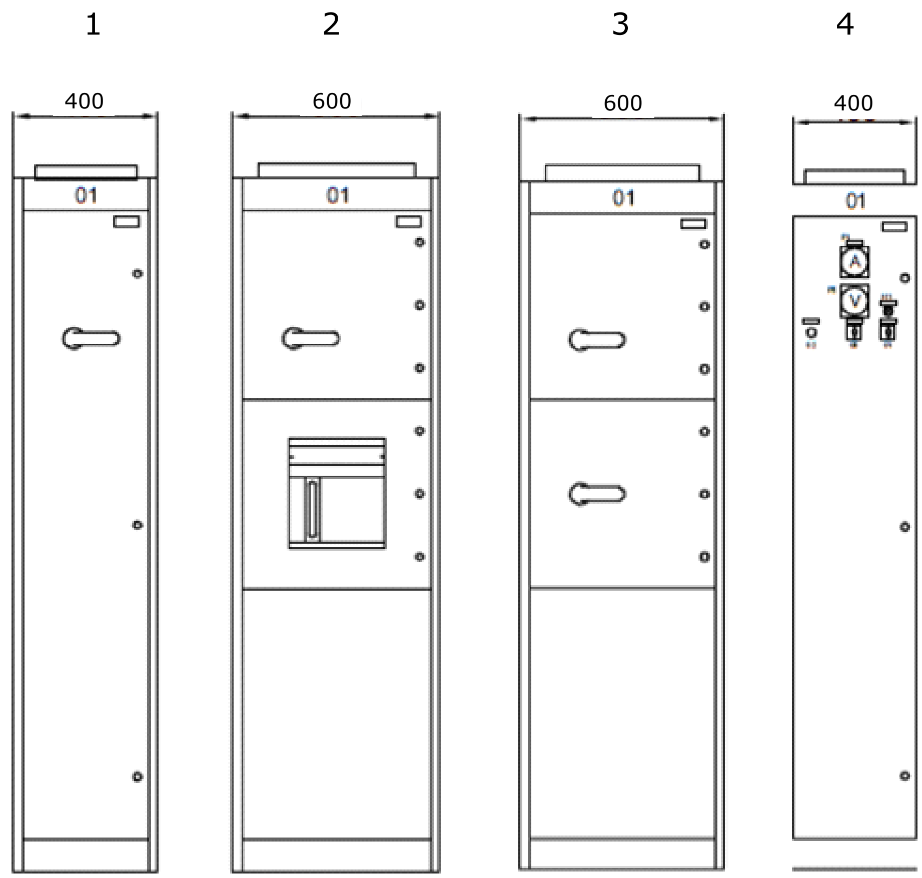



*Figure 93. Supply section, dimensions*

**Example 1**: With a supply unit of under 1000A, it is possible to use a switch fuse, or if the supply system has adequate overload and short circuit protection, a load switch can be used. The cabinet width is typically 400mm.

**Example 2**: With a supply unit of over 1000A, both a breaker (ACB) and an earthing switch can be used. The use of an earthing switch depends on the local legislation. The cabinet width depends on the size of the switch. Typical cabinet widths are as follows:

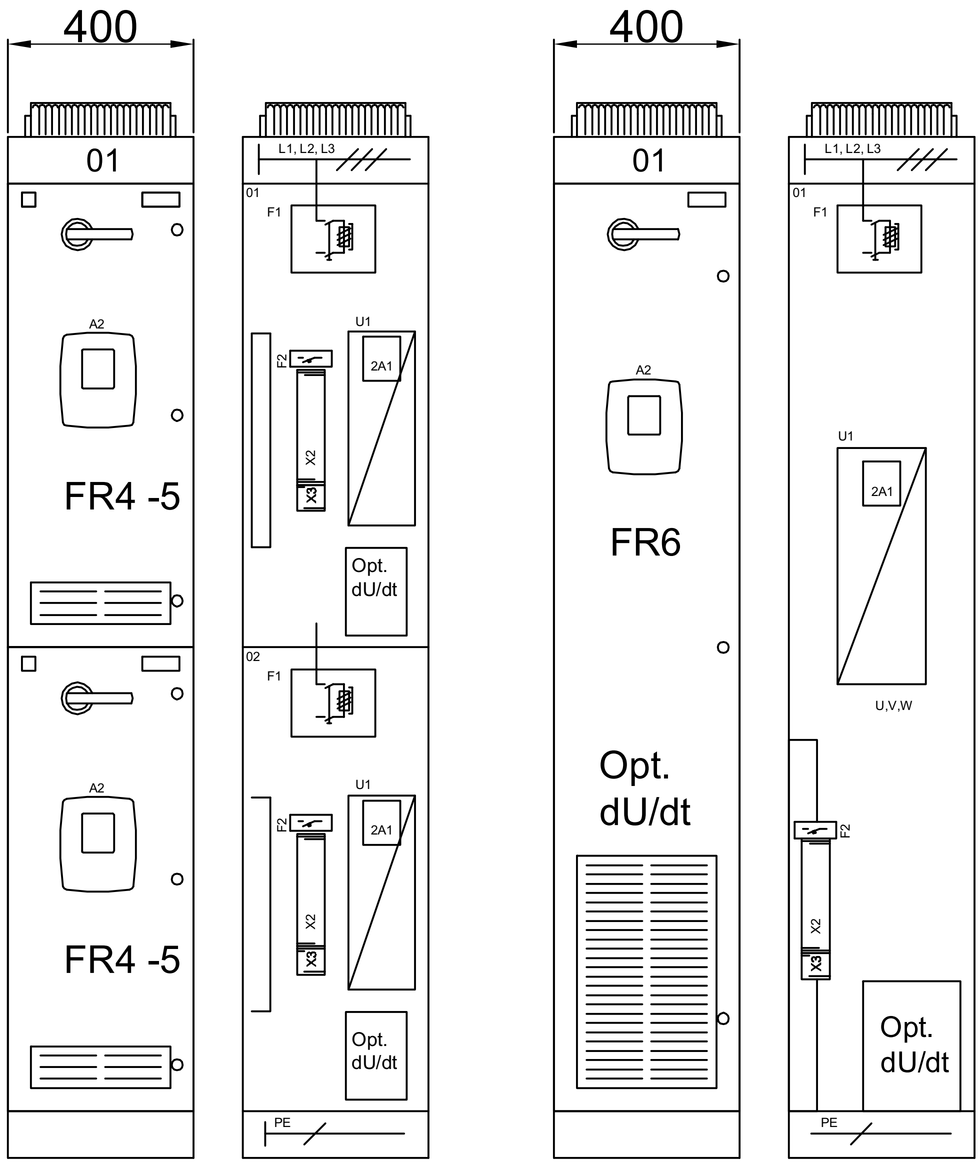
*Table 41.*

| A | Cabinet width |
|---|---|
| 1600A-3200A | 600mm |
| 4000A | 800mm |
| 5000A | 1000mm |

**Example 3**: With a supply unit of over 1000A, the supply section typically contains an earthing switch (with a typical exception of marine drives), or if the supply system has adequate overload and short circuit protection, a load switch can be used.

**Example 4**: An auxiliary cabinet can contain various components needed in the drive system, such as components needed for control voltage distribution, measurement and indication of voltage and current, DC charging components, arc protection relays and other control components that are common to the entire drive system.

### 10.9.2 Dimensions and layout of FR4, FR5 and FR6 frequency converters




Two FR4/FR5 frequency converters can be installed in one full height cabinet. FR6 requires an entire cabinet.

A dU/dt filter is optional, and usually fits in the same cabinet with the frequency converter, depending on the cabinet type and height.

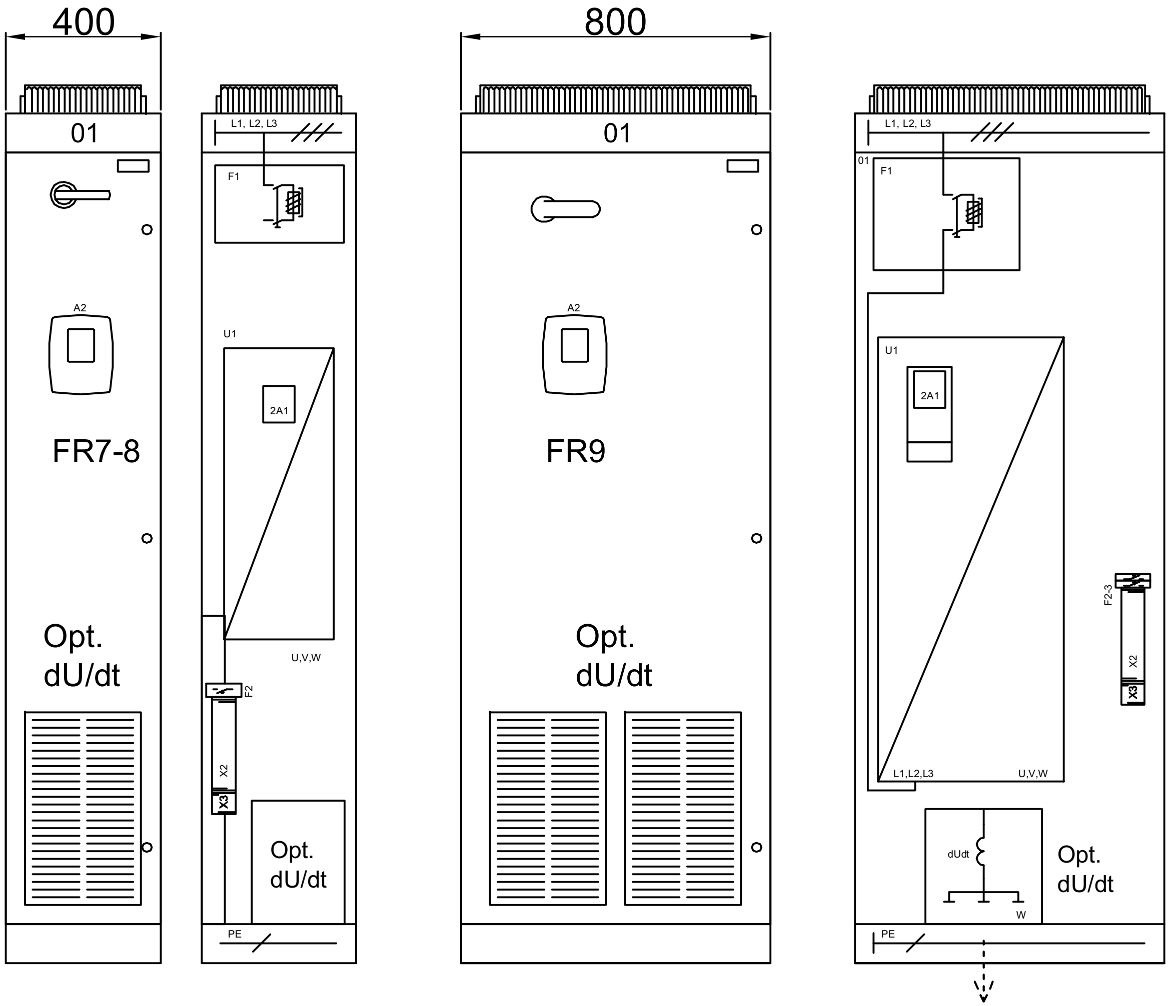
Proper ventilation of the cabinet is important. Cooling air must be conducted out of the cabinet. Inside the cabinet there must normally be an air barrier that keeps the incoming and outgoing air from getting mixed. The incoming air must come from the lower part of the cabinet (usually cabinet door), so that the airflow goes past the dU/dt, cooling it on the way.

In case the cabinet contains two frequency converters, it is even more important to see that the air goes out from the lower part of the cabinet and does not heat up the devices in the upper part of the cabinet. See chapter "Cooling - air cooled units" on page 119.

On the supply side there is a lockable switch fuse for protection of the frequency converter and for safe voltage separation. If there is no dU/dt filter, the motor cables are connected directly to the frequency converter's output terminals. If a dU/dt is used, the motor cables are connected either directly to the filter terminals or separate terminals. The motor cables must be 360° grounded for elimination of EMC disturbance. The motor and supply cables must be kept separate from the control cables, to avoid disturbance in the control cables.

Auxiliary components and terminals and cable trays, if they are used, must be placed so that they do not get heated up and can be safely reached for measurement purposes. Different voltages (wires, cables and components) must be separated, due to safety reasons and to avoid disturbances.

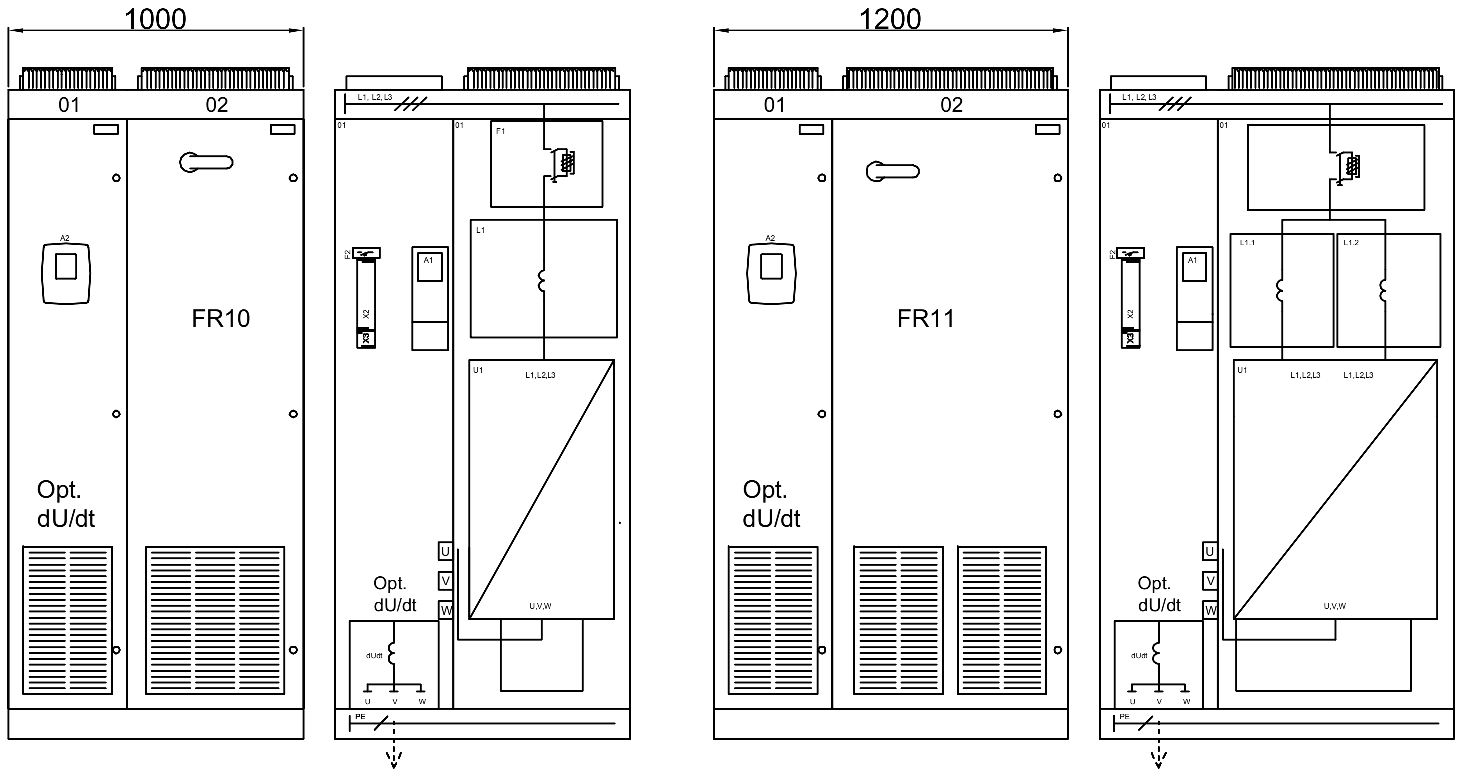
### 10.9.3 Dimensions and layout of FR7, FR8 and FR9 frequency converters




FR 7, FR8 and FR9 all require one full height cabinet. FR9 without auxiliary components and dU/dt filter can be fitted in a 600mm, but otherwise it requires approximately 800mm wide cabinet as in the drawing, or a separate auxiliary cabinet.

For cooling, switch fuse and cabling, see chapter "Dimensions and layout of FR4, FR5 and FR6 frequency converters" on page 123.

## 10.9.4 Dimensions and layout of FR10 and FR11 frequency converters

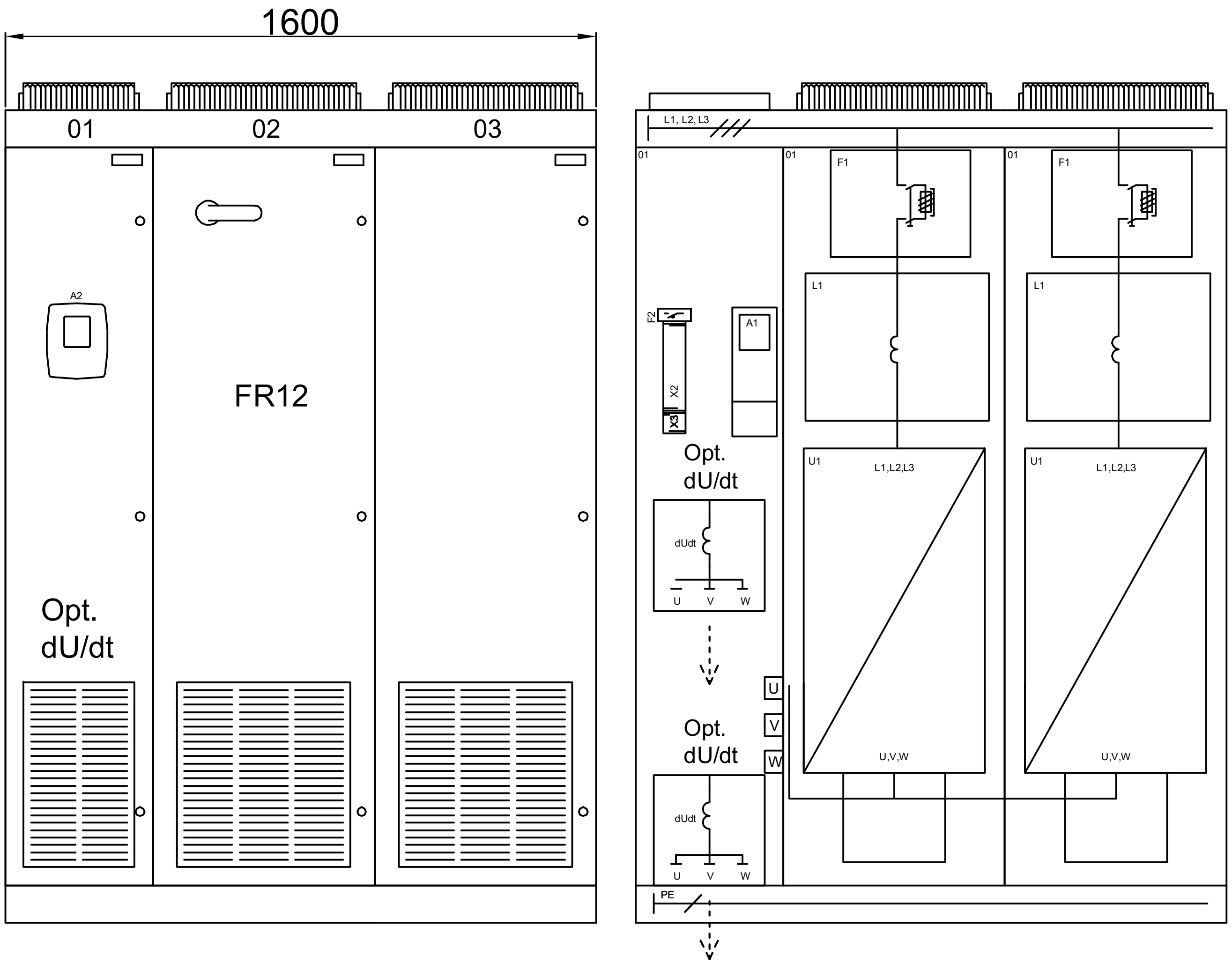



FR10 has one external choke, FR11 can have one or two external chokes. Choke is positioned on top of the frequency converter where it is cooled by the airflow coming from the frequency converter's cooling fan.

DU/dt filter is in these installations in an auxiliary cabinet. If the auxiliary cabinet's protection class is IP23, there is no need for a separate cooling system to cool the filter. If the cabinet's protection class is higher than IP21, a fan is needed to cool the filter.

For cooling, switch fuse and cabling, see chapter “Dimensions and layout of FR4, FR5 and FR6 frequency converters” on page 123.

### 10.9.5 Dimensions and layout of FR12 frequency converter



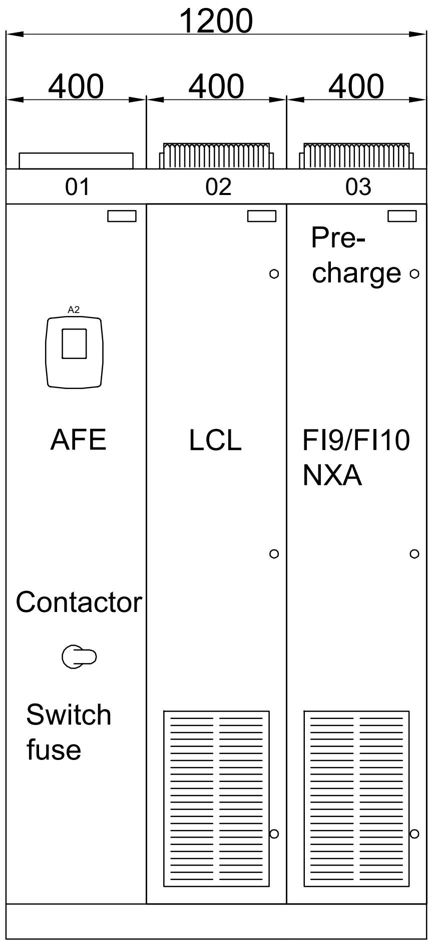

FR12 has always two chokes. Chokes are positioned on top of the frequency converter where they are cooled by the airflow coming from the frequency converter's cooling fan.

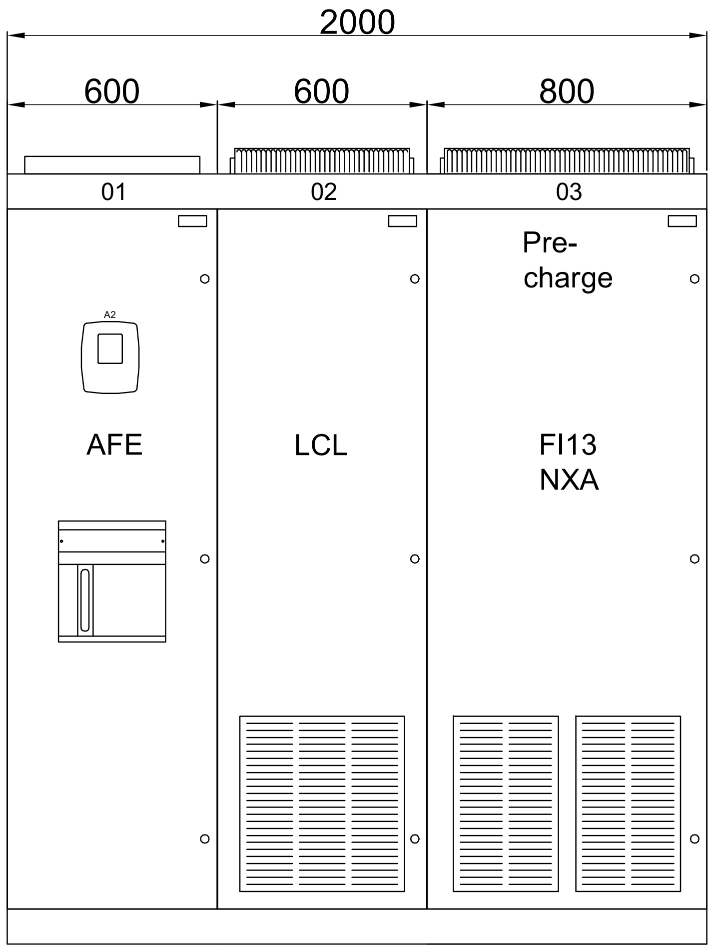
DU/dt filter is in these installations in an auxiliary cabinet. If the auxiliary cabinet's protection class is IP23, there is no need for a separate cooling system to cool the filter. If the cabinet's protection class is higher than IP23, a fan is needed to cool the filter.

FR12 consists of two parallel connected FR10 modules. Regardless of the supply voltage, two dU/dt filters are needed in most installations.

For cooling, switch fuse and cabling, see chapter "Dimensions and layout of FR4, FR5 and FR6 frequency converters" on page 123.

### 10.9.6 Dimensions and layout of the FI9, FI10 and FI13 active front end units




The switchgear's power capacity can be increased by adding AFE modules. Each AFE module requires a dedicated LCL filter. It is recommended to use also a dedicated pre-charging circuit with each AFE module. This improves the system redundance . In case one AFE unit is being serviced, the rest of the switchgear can still be used, as long as the AFE that is out of use is electricaly isolated.

For cooling, switch fuse and cabling, see chapter "Dimensions and layout of FR4, FR5, FR6 and FR7 inverter units" on page 128.

If there is no requirement for regeneration and/or low harmonics content, it is possible to use (NFE) Non-regenerative Front End units. The switchgear's power capacity can be increased by adding NFE modules. Each NFE requires dedicated AC and DC fuses and a choke. NFE units have an integrated pre-charging circuit.

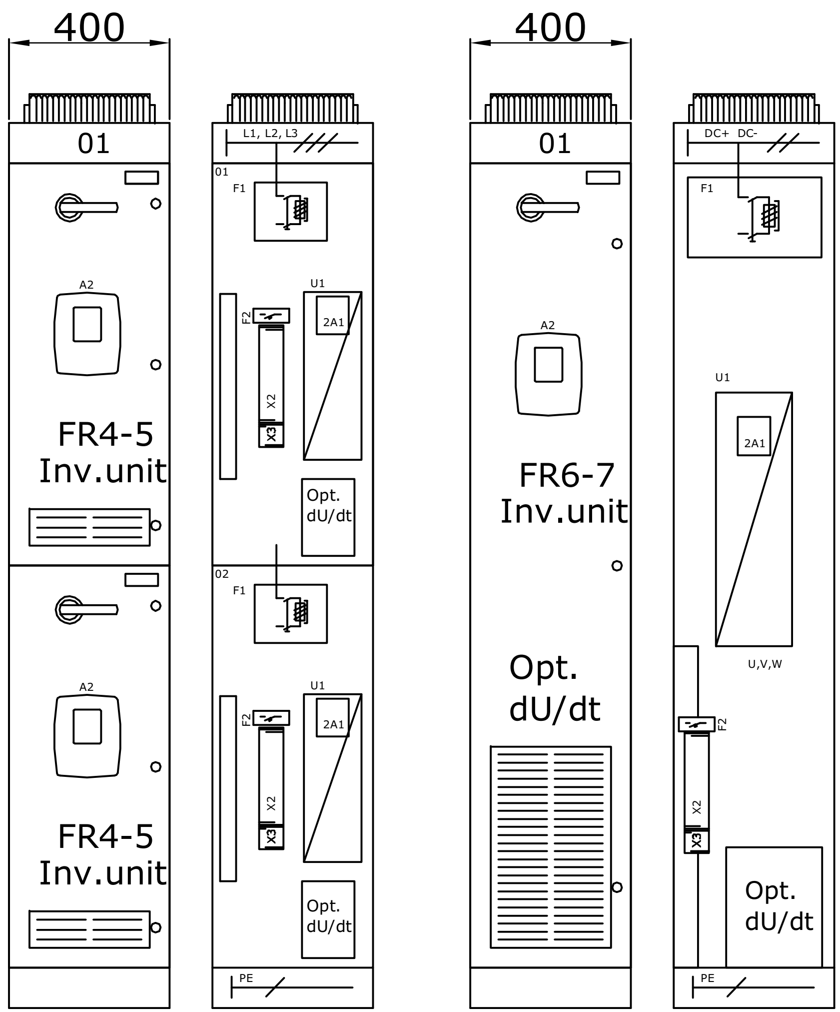
1 x NFE fits in a 400mm cabinet

2 x NFE fit in a 600mm cabinet

3 x NFE fit in a 800mm cabinet

It is also possible to place the fuses and chokes to a separate cabinet.

### 10.9.7 Dimensions and layout of FR4, FR5, FR6 and FR7 inverter units




Two FR4/FR5 inverters can be installed in one full height cabinet. An FR6 requires an entire cabinet.

A dU/dt filter is optional, and usually fits in the same cabinet with the inverter, depending on the cabinet type and height.

Proper ventilation of the cabinet is important. Cooling air must be conducted out of the cabinet. Inside the cabinet there must normally be an air barrier that keeps the incoming and outgoing air from getting mixed. The incoming air must come from the lower part of the cabinet (usually cabinet door), so that the airflow goes past the dU/dt, cooling it on the way.

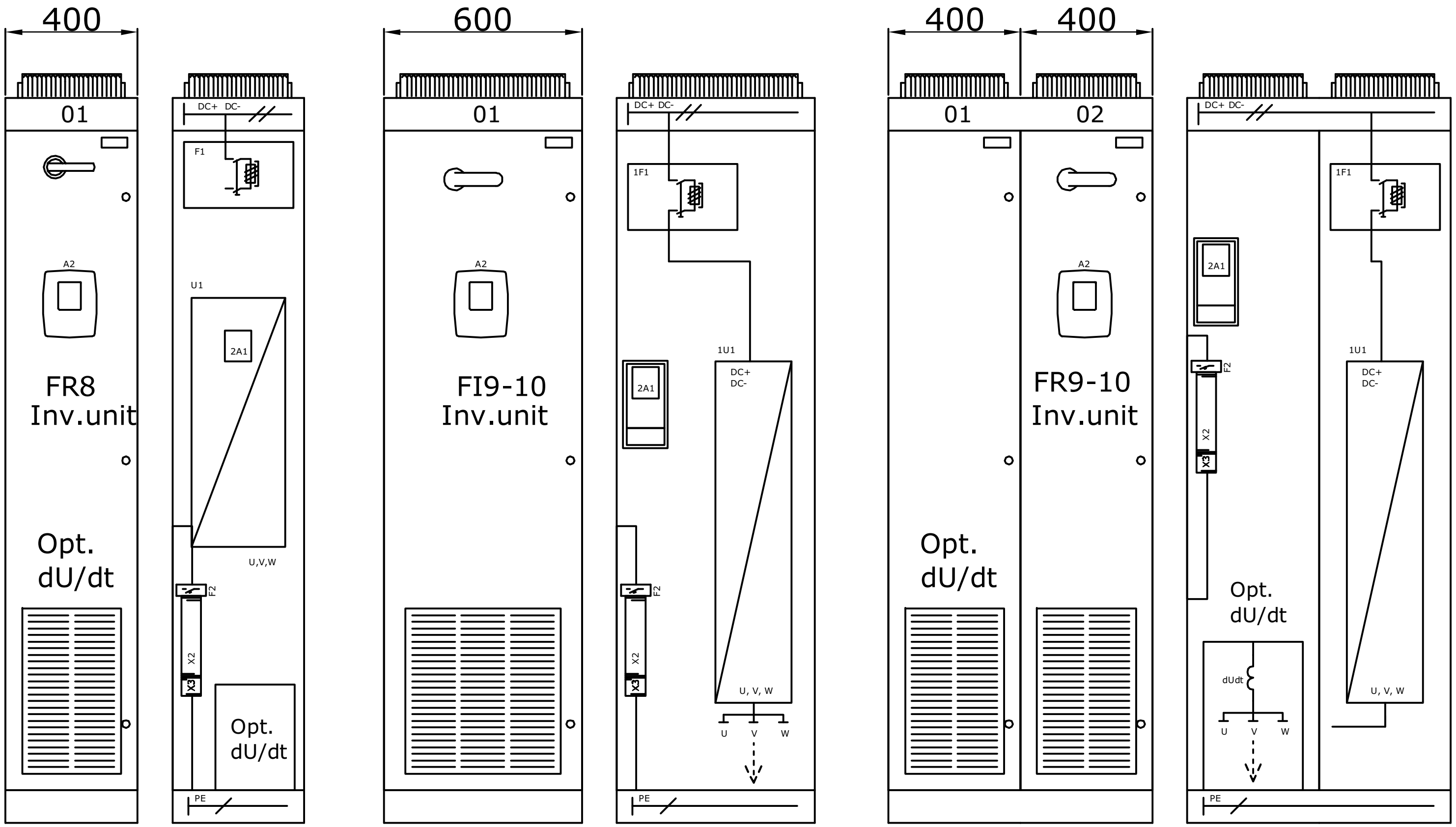
In case the cabinet contains two inverters, it is even more important to see that the air goes out from the lower part of the cabinet and does not heat up the devices in the upper part of the cabinet. See chapter Cooling - Air cooled units on “Cooling - air cooled units” on page 119.

On the supply side there is a lockable switch fuse for protection of the inverter and for safe voltage separation. If there is no dU/dt filter, the motor cables are connected directly to the frequency converter’s output terminals. If a dU/dt is used, the motor cables are connected either directly to the filter terminals or separate terminals. The motor cables must be 360° grounded for elimination of EMC disturbance. The motor and supply cables must be kept separate from the control cables, to avoid disturbance in the control cables.

Auxiliary components and terminals and cable trays, if they are used, must be placed so that they do not get heated up and can be safely reached for measurement purposes. Different voltages (wires, cables and components) must be separated, due to safety reasons and to avoid disturbances.

FR4 - FR8 inverters have integrated pre-charging circuit.

### 10.9.8 Dimensions and layout of FR8, FR9 and FR10 inverter units

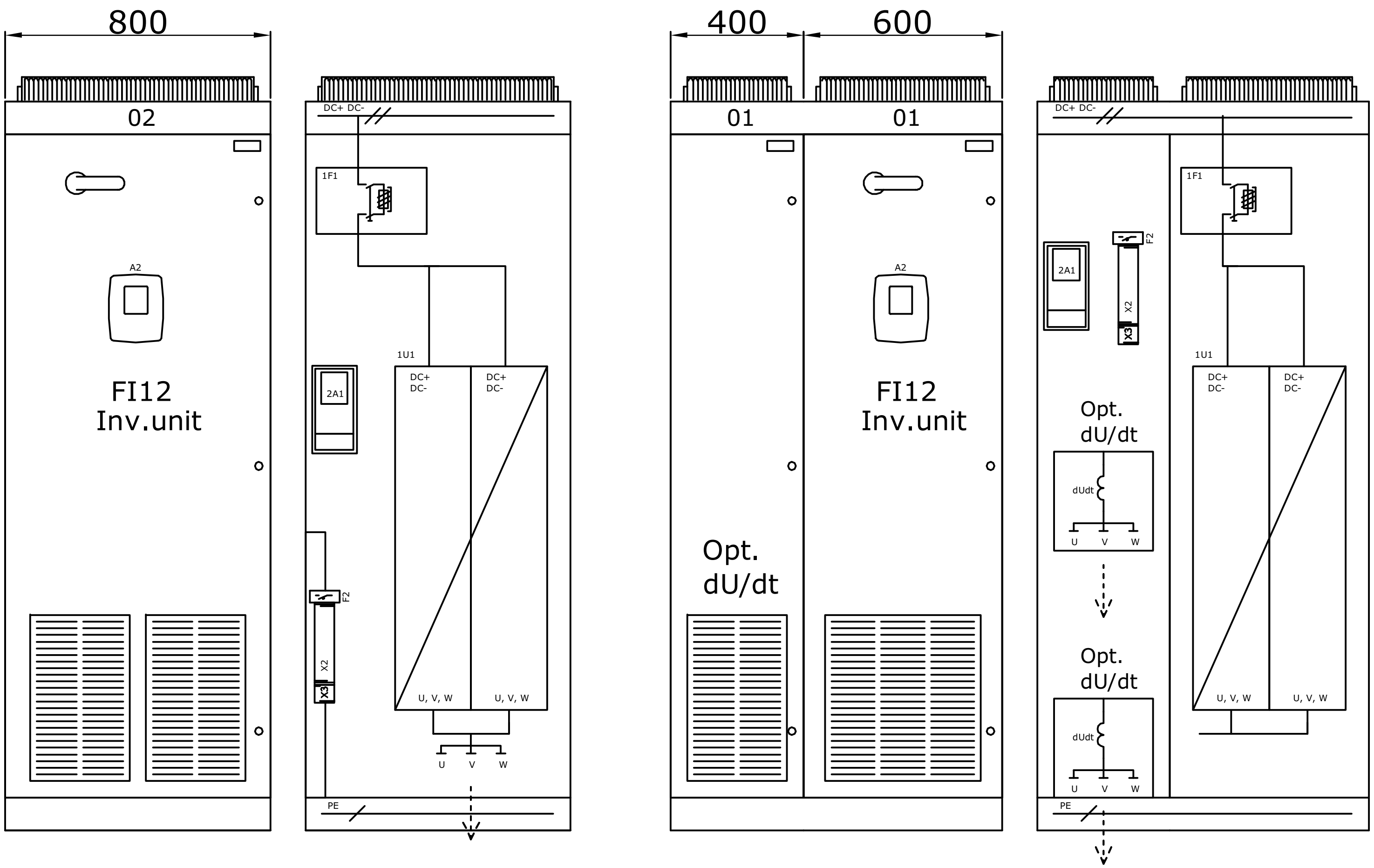



FR8, FI9 and FI10 all require one full height cabinet. With FI9 and FI10 the dU/dt filter requires an additional cabinet.

For cooling, switch fuse and cabling, see chapter “Dimensions and layout of FR4, FR5, FR6 and FR7 inverter units” on page 128.

FI9 and FI10 require an external pre-charging circuit. Pre-charging can be either inverter-specific or via common DC bus. With common pre-charging the individual inverters must have only DC fuses on the supply side. If common DC bus pre-charging is used, you must not connect inverters to a live bus.

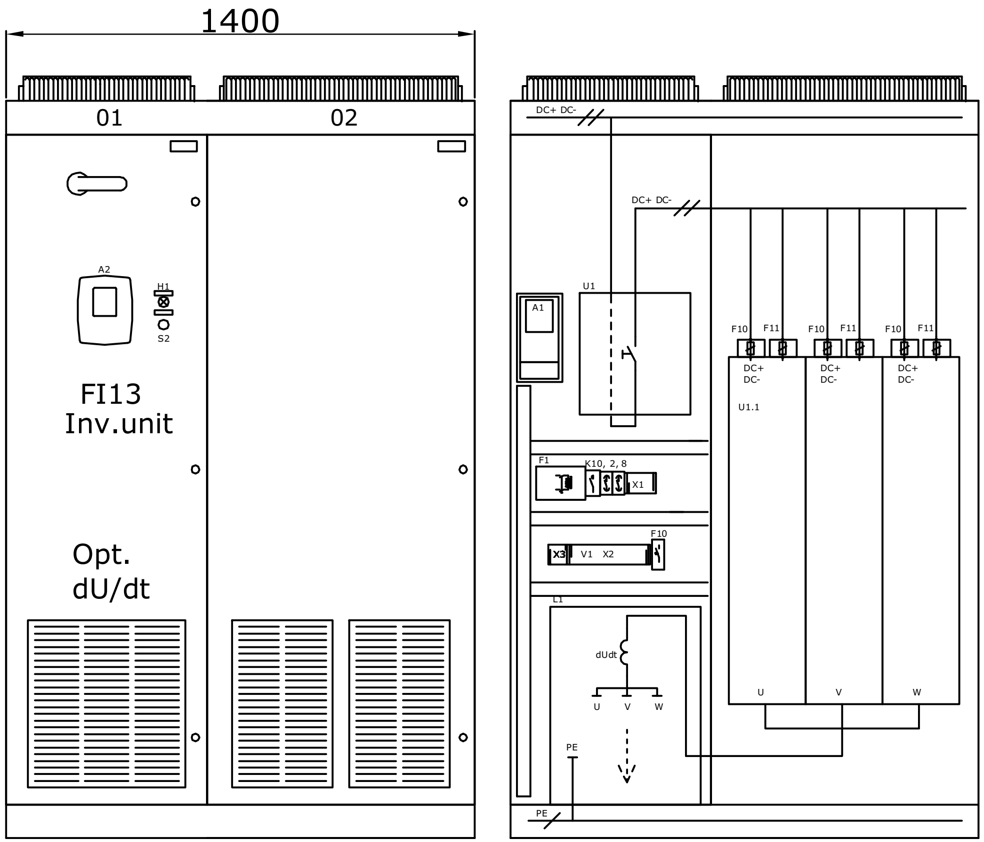
## 10.9.9 Dimensions and layout of FI12 and FI13 inverter units




With the FI12 inverter unit, a dU/dt filter requires an additional cabinet. For cooling, switch fuse and cabling, see chapter “Dimensions and layout of FR4, FR5, FR6 and FR7 inverter units” on page 128.

The FI12 inverter unit requires an external pre-charging circuit. Pre-charging can be either inverter-specific or via common DC bus. With common pre-charging the individual inverters must have only DC fuses on the supply side. If common DC bus pre-charging is used, you must not connect inverters to a live bus.

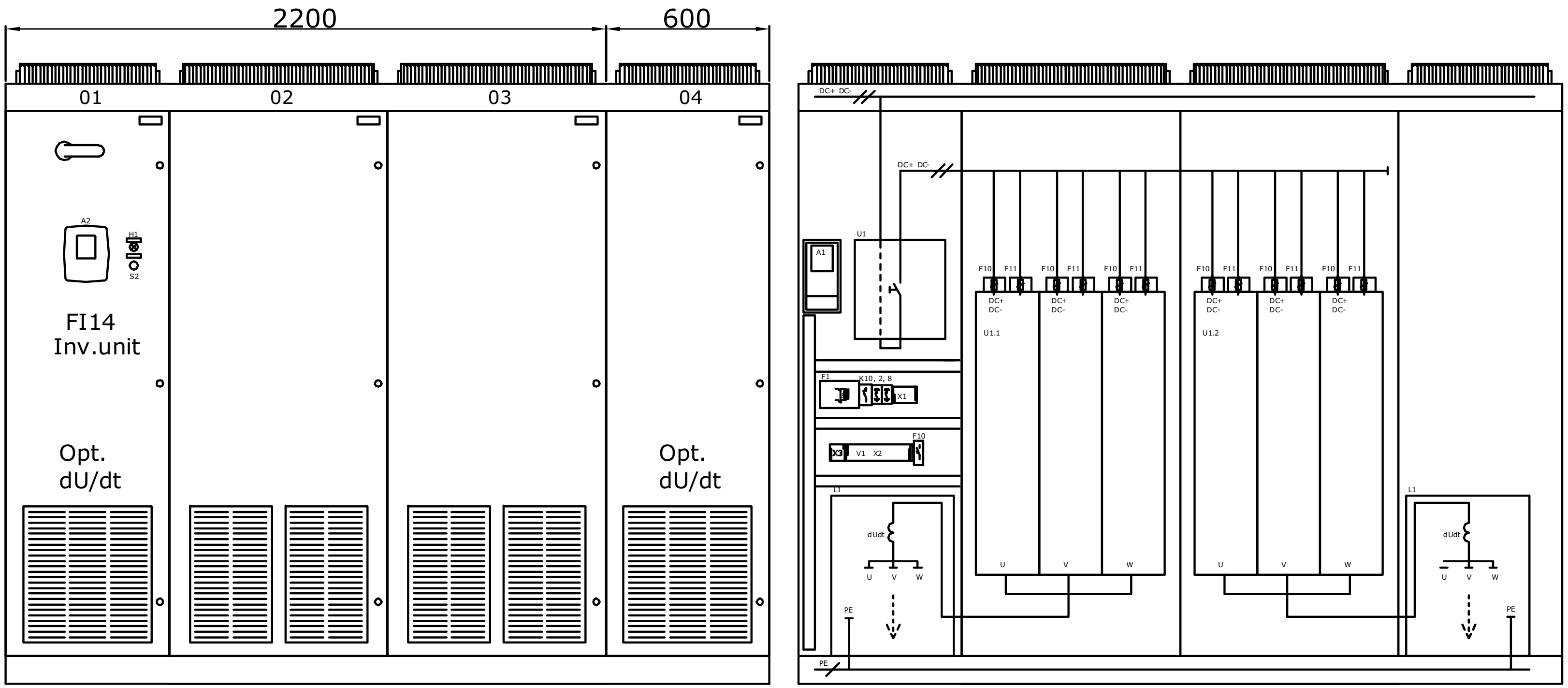
### 10.9.10 Dimensions and layout of FI13 inverter unit




With the FI13 inverter unit, a dU/dt filter requires an additional cabinet. For cooling, switch fuse and cabling, see chapter “Dimensions and layout of FR4, FR5, FR6 and FR7 inverter units” on page 128.

The FI13 inverter unit requires an external pre-charging circuit. Pre-charging can be either inverter-specific or via common DC bus. With common pre-charging the individual inverters must have only DC fuses on the supply side. If common DC bus pre-charging is used, you must not connect inverters to a live bus.

### 10.9.11 Dimensions and layout of the FI14 inverter unit




The FI14 inverter unit contains two FI13 inverter modules.

With the FI14 inverter unit, a dU/dt filter requires an additional cabinet. For cooling, switch fuse and cabling, see chapter "Dimensions and layout of FR4, FR5, FR6 and FR7 inverter units" on page 128.

The FI14 inverter unit requires an external pre-charging circuit. Pre-charging can be either inverter-specific or via common DC bus. With common pre-charging the individual inverters must have only DC fuses on the supply side. If common DC bus pre-charging is used, you must not connect inverters to a live bus.

# 11. Cooling system of liquid-cooled Vacon AC drives

Vacon NX Liquid-Cooled AC drives are cooled with liquid circulating in the cooling elements of the drive. Cooling element is made of aluminium or nickel coated aluminium. As cooling liquid you can use drinking water with inhibitor, demineralised water with inhibitor, or a mixture of water and glycol. There are two different circulation system types:

- closed system
- open system

In a closed system, the piping is completely air-tight and there is pressure inside the pipes. The pipes must be made out of metal, or specific plastic or rubber that includes oxygen barrier. Preventing of oxygen diffusion in the coolant diminishes the risk of electrochemical corrosion of metal parts, and generation of rust deposits.

An open system has no pressure, and it allows free contact between the liquid and air.

Always use a closed system with Vacon NX Liquid Cooled AC drives. In case there is no other option than using a semi-open system, you must take several precautions. Use glycol or inhibitor in the coolant, examine the water quality regularly, and add inhibitor accordingly. You must check once a year that the properties of the cooling liquid are in accordance with the specification in the device manual.

## 11.1 Choosing the cooling system type

The drive's liquid circulation is connected to a heat-exchanger which cools down the liquid. There are three main heat exchanger types for cooling down the heat from the circulating liquid:

- liquid to liquid - using a heat exchanger
- liquid to air, using a radiator
- "chiller", using compressor technology

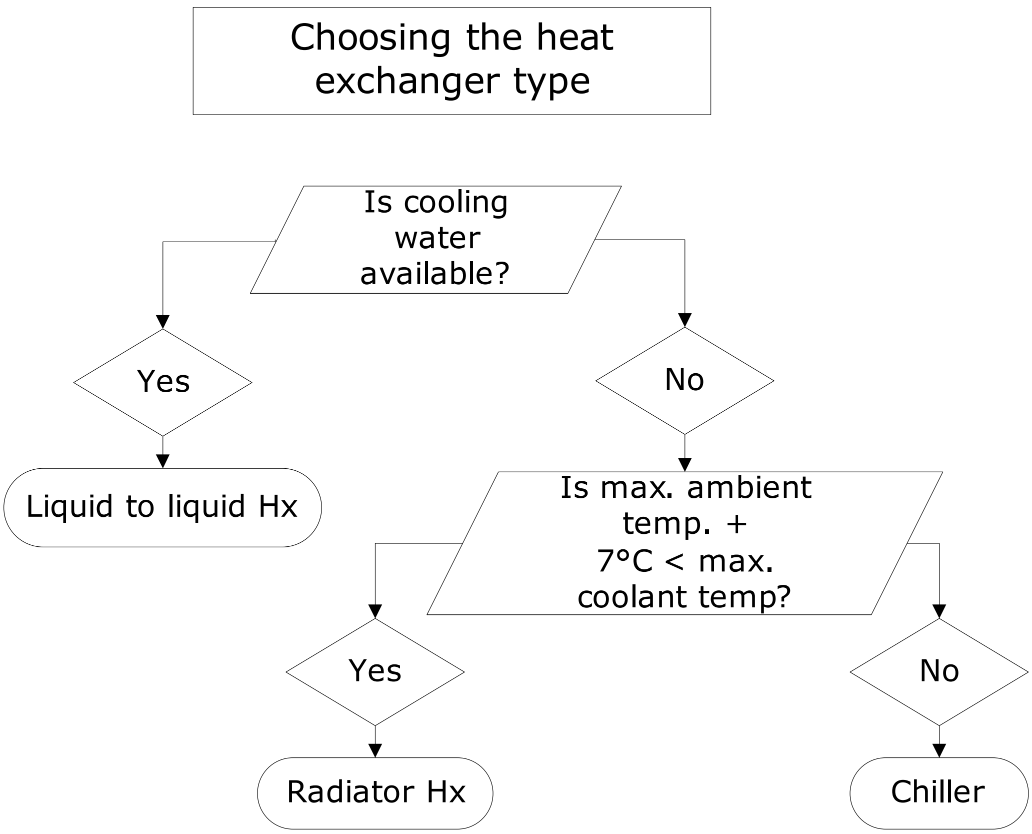



*Figure 94. Choosing the heat exchanger type*

### 11.1.1 Liquid to liquid heat exchanger

Vacon's product range includes several liquid to liquid heat exchanger types. The HX-unit's principle of operation is based on liquid-to-liquid transfer of heat. The primary circuit transports the heat load from the frequency converter to the plate heat exchanger. The secondary circuit, liquid flowing through the plate heat exchanger, then collects the heat load and transports it to an external condenser. This external condenser is part of the customer and/or end-user's existing cooling system.

Another way to dispose of the heat load is to use existing natural resources e.g. a lake or river. The use and choice of a system for disposing of the heat load is the customer's and/or end-user's responsibility.

- Primary circuit, green colour in the figure right (lighter colour in black and white)
- Secondary circuit, red colour in the figure right (darker colour in black and white)

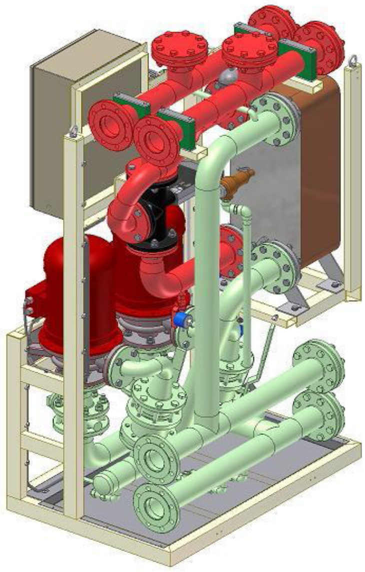


*Figure 95. Primary and secondary circuit of the HX heat exchanger*

The flow switch, which monitors the flow in the primary circuit, also includes a temperature sensor. This sensor controls the primary circuit's temperature. It sends out an analogue signal to the HX control unit. The control unit application adjusts the secondary circuit's flow through the plate heat exchanger by adjusting the 3-way valve to match the primary circuit's temperature setup value. This value is project-specific and it depends on the ambient temperature in the drive cabinet, and the maximum temperature of the secondary circuit's inlet liquid.

The HX heat exchanger unit has flow, temperature, pressure and leak supervision in the primary circuit. The HX control unit application monitors these quantities and generates alarms or shut-offs depending on the parameter settings.

Monitoring the temperature and flow of the secondary circuit is the responsibility of the user.

See Vacon's heat exchanger manuals for further details.

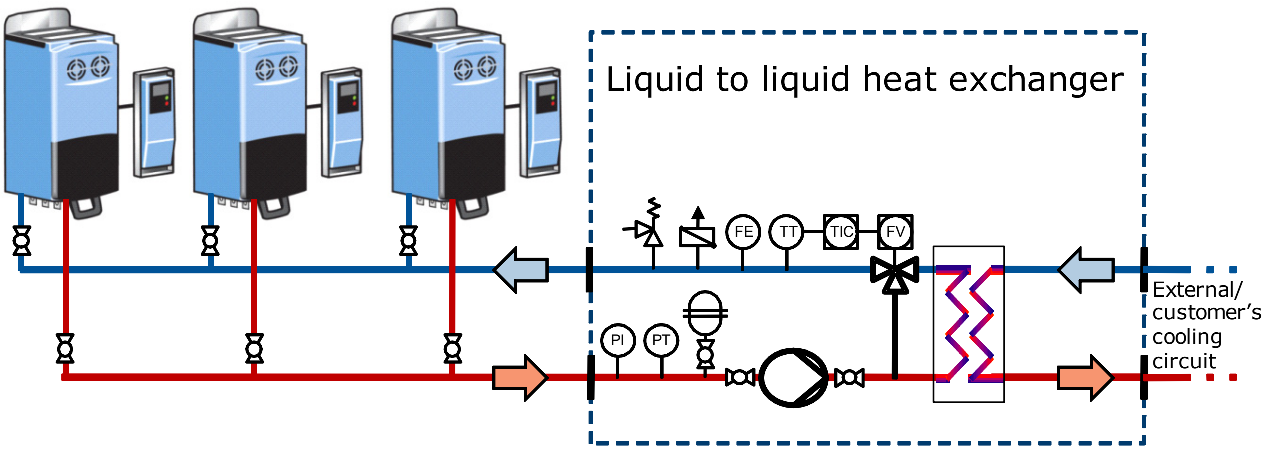



*Figure 96. Liquid to liquid heat exchanger*

### 11.1.2 Radiator

Vacon's product range does not include radiator-type heat exchangers. They are a process-specific project. Design and dimensioning of radiator heat exchanger must be done with the equipment manufacturer.

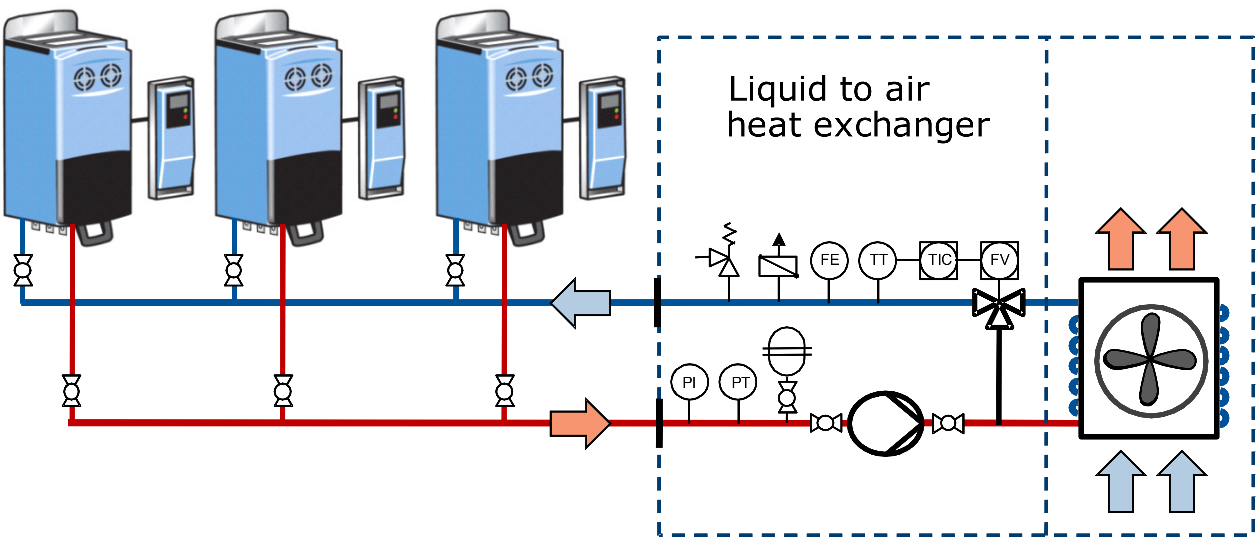
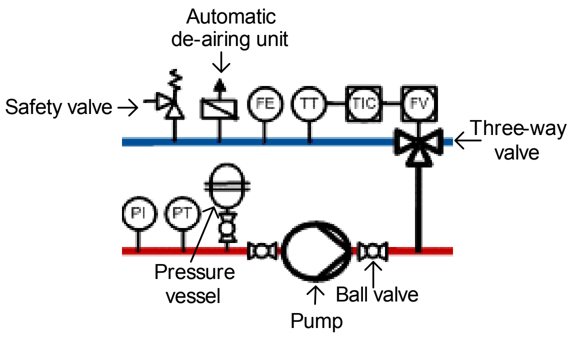



*Figure 97. Liquid to air heat exchanger*

#### *11.1.2.1 Legend to the flow circuit*




FE = Flow Supervision

TT= Temperature Transmitter

TIC = Temperature Indicating Controller

FV = Flow Valve

PI = Pressure Indicator

PT = Pressure Transmitter

### 11.1.3 Chiller

Chiller-type heat exchangers are available from Vacon.

The process water to be chilled passes through the heat exchanger, which is cooled by a separate refrigerant unit. The refrigerant circuit ensures that the pre-adjusted temperature is reached.

See the manufacturer's documentation for further details.

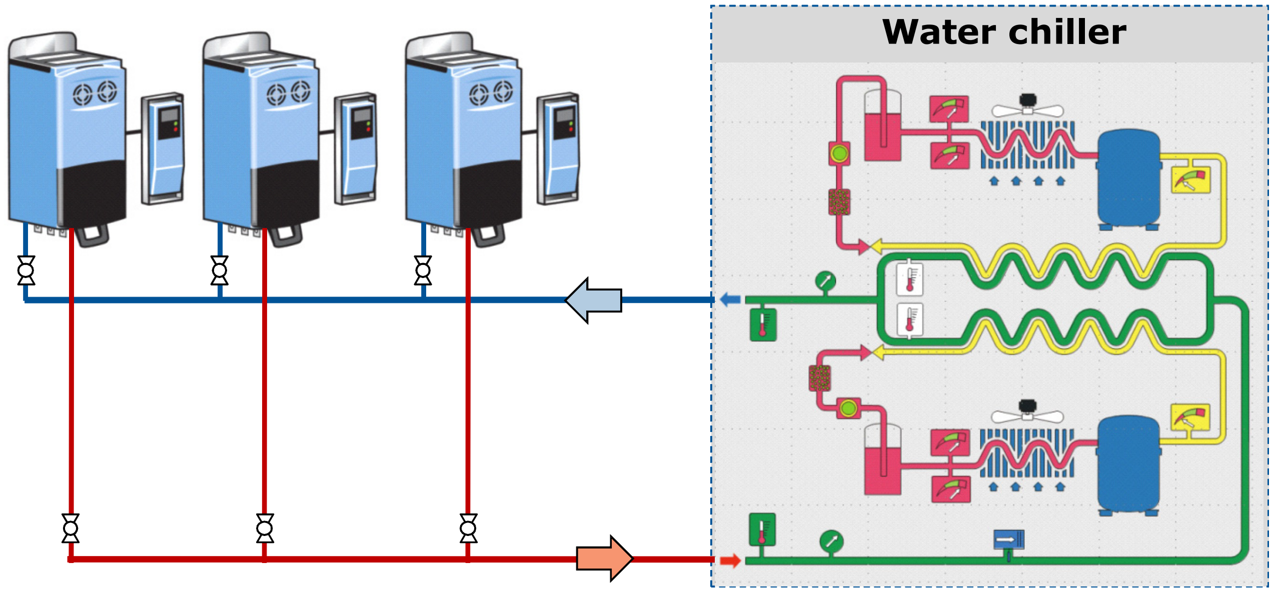



*Figure 98. Chiller*

### 11.1.4 Materials and components of the cooling system

The default temperature of the cooling agent entering the drive module(s) is 35°C. While circulating inside the cooling element, the liquid transfers the heat produced by the power semiconductors (and the capacitors). The default temperature rise of the cooling agent during the circulation is less than 5°C. Typically, 95% of the power losses is dissipated in the liquid. We advise you to equip the cooling agent circulation with temperature supervision.

The heat exchanging equipment can be located outside the electrical room in which the frequency converters are. The connections between these two are made on site. In order to minimize the pressure drops, the pipings must be as straight as possible. We further recommend that a regulating valve equipped with a measurement point is mounted. This makes the measurement and regulation of liquid circulation possible in the commissioning phase.

In order to prevent dirt particles from accumulating in the connections and thus gradually weakening the cooling effect, installation of filters is also recommended.

The highest point of the piping must be equipped with either an automatic or a manual venting device. The material of the piping must comply with at least AISI 304 (AISI 316 is recommended).

Prior to the actual connection of the pipes, the bores must be cleaned thoroughly. Cleaning with water is recommended, but if water is not available, pressured air must be used to remove all loose particles and dust.

To facilitate the cleaning and venting of the coolant circulation, we recommend you to install a bypass valve in the main line and valves at each frequency converter inlet. Open the bypass valve and shut the valves to the frequency converter when cleaning and airing the system. On commissioning the system, the bypass valve must be closed and the valves to the converters opened.

Vacon recommends to equip the cooling system with pressure and flow supervision (FE). The flow supervision can be connected to digital input function External fault. If the coolant flow is too low, the frequency converter stops.

Choose the materials used in cooling system so that the risk of electrochemical processes is minimised. In case you use liquid cooled drives with aluminium heatsink, do not use for example copper and brass or iron within the same installation. To avoid electrochemical corrosion, add an inhibitor in the cooling liquid.

*Table 42. Materials and components of a cooling circuit*

| Material | Used in | Vacon Liquid Cooled Drives |
|---|---|---|
| Brass & copper | Pipes, valves and fittings | Can be used only in closed circuits, if the heatsink and the copper component are separated using non-conductive material, such as plastic or rubber.<br>With nickel coated heatsink the re is no need for separation of the copper or brass components.<br>Inhibitor must be used. |
| Common steel | Pipes | Permissible in closed circuits with inhibitors, check for oxide information, regular inspection of water quality recommended |
| Cast steel, cast iron | Pipes, motors | Permissible in closed circuits with inhibitors, check for oxide information, regular inspection of water quality recommended. |
| PVC/PVC-C | Pipes, valves and fittings | Suitable for drinking water or tap water with inhibitor and glycol. |
| Installation made of different metals (mixed installation) | Pipes, valves and fittings | Do not use mixed installation |
| Rubber/ plastic with oxygen barrier | Hoses | Can be used. With non-Vacon hoses, check suitability regarding inhibitor and glycol. |
| EPDM/NBR rubber | Seals | Can be used. |

## 11.2 Designing and dimensioning the cooling system for liquid cooled drives

### 11.2.1 How to select Vacon's HX heat exchanger type

When choosing between Vacon's HXL-040, HX-120 or HX300 Heat exchangers, consider the following factors:

Calculate the total heat load of the AC drive system, including LC chokes, LC output filters and air to liquid heat exchangers.

Calculate the total flow requirement that consists of nominal flow + a margin of 10...20%

Check the following things regarding the needed cooling power.

- Evaporator power & efficiency
- Maximum coolant ΔT rise in customer/process circuit
- Derating/oversizing

Check the ratio of water and glycol in the coolant. The ratio affects the nominal flow requirement of the AC drive. Select the heat exchanger unit based on the maximum flow and maximum cooling power.

Check how long the distribution piping is. It must be within the following values:

- HXL-040: Δp = 0.3 bar/10 m+10m straight pipe (DN25)
- HXL-120: Δp = 1.0 bar/40 m+40 m straight pipe (DN50)
- HXM-120: Δp = 0.7 bar/25 m+25 m straight pipe (DN50)
- HXS-070: Δp = 1.0 bar/40 m+40 m straight pipe (DN50)
- HXT-070: Δp = 0.7 bar/25 m+25 m straight pipe (DN50)
- HXL-300: Δp = 1.0 bar/40 m+40 m straight pipe (DN 80)
- HXM-300: Δp = 0.7 bar/25 m+25 m straight pipe (DN80)

*Table 43. Vacon Heat Exchanger types*

| | HXL-M/V/R-040-N-P | HXL/M-M/V/R-120-N-P | HXS/T-M/V/R-070-N-P | HXL/M-M/R-300-N-P |
|---|---|---|---|---|
| Cooling power | 0...40 kW | 0...120 kW | 0...69 kW | 0...300 kW |
| Mains supply | 380...440 VAC | 380...440 VAC | 380...440 VAC | 380...440 VAC |
| Flow | 40...120 l/min | 120...360 l/min | 120...200 l/min | 360...900 l/min |

The main pipeline must be dimensioned so that when the liquid is distributed to the individual drives, the liquid pressure in each drive is identical.

When designing and dimensioning the cooling system, see the following tables in the Vacon NX Liquid Cooled Drives User's Manual:

- Table 5-6. Information about cooling agent and its circulation
- Tables 5-9. and 5-10. Pressure losses
- Tables 5-3, 5-4, and 5-5. Water specifications

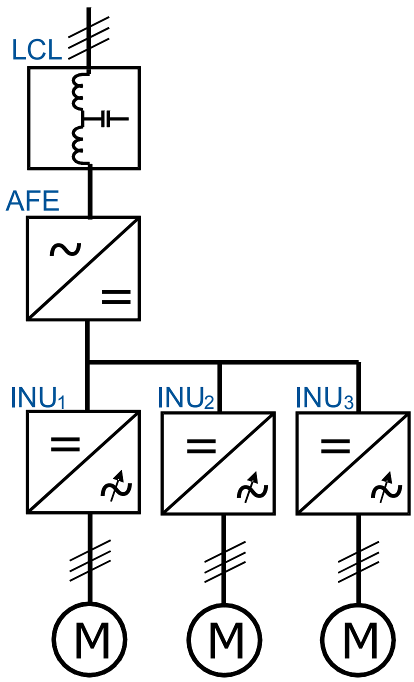
### 11.2.2 Example of heat exchanger selection

The following example shows how to calculate the power loss and nominal flow values for a drive system containing one front end unit with an LCL filter and three inverter units, and select the HX heat exchanger type based on the calculated values.

*Table 44. Example of a liquid cooled common DC bus drive system*

| Unit ID | Chassis | Voltage (U) | Current (A) | Power losses to liquid (kW) | Required nominal flow (l/min) |
|---|---|---|---|---|---|
| LCL-filter | RLC-920 | 400 | 920 | 5,5 | 40 |
| AFE | Ch63 | 400 | 920 | 14,4 | 50 |
| $INU_1$ | Ch61 | 400 | 385 | 5,5 | 25 |
| $INU_2$ | Ch61 | 400 | 300 | 4,5 | 25 |
| $INU_3$ | Ch61 | 400 | 300 | 4,5 | 25 |
| Total: | | | | **34,4** | **165** |

In this example, the drive system's total power losses to liquid amount to 34,4 kW, which would indicate that a HXL-M-040-N-P unit could be sufficient. However, the 165 l/min flow requirement means that the HXL-M-120-N-P unit is actually needed.



## 11.3 CONDENSATION

When planning a liquid cooled drive system, you must take into account that there must be no condensation inside the drive cabinet, and especially on the cooling plate of the NX liquid cooled drive. As the coolant piping is located inside the drive cabinet, it is vital that the coolant's temperature stays above the dew-point. The most secure way of preventing condensation inside the drive cabinet is to keep the coolant temperature higher than the ambient temperature inside the drive cabinet.

Use the graph below to determine if the drive operating conditions (combination of room temperature, humidity and cooling liquid temperature) are safe, or, to choose the allowed temperature for the cooling liquid.

The conditions are safe when the point is below the respective curve. If not, take adequate precautions by decreasing the room temperature and/or the relative humidity or increase the cooling liquid temperature. Note that increasing the temperature of the cooling liquid above figures in loadability charts decreases the nominal output current of the drive. The below curves are valid at sea level altitude (1013 mbar).

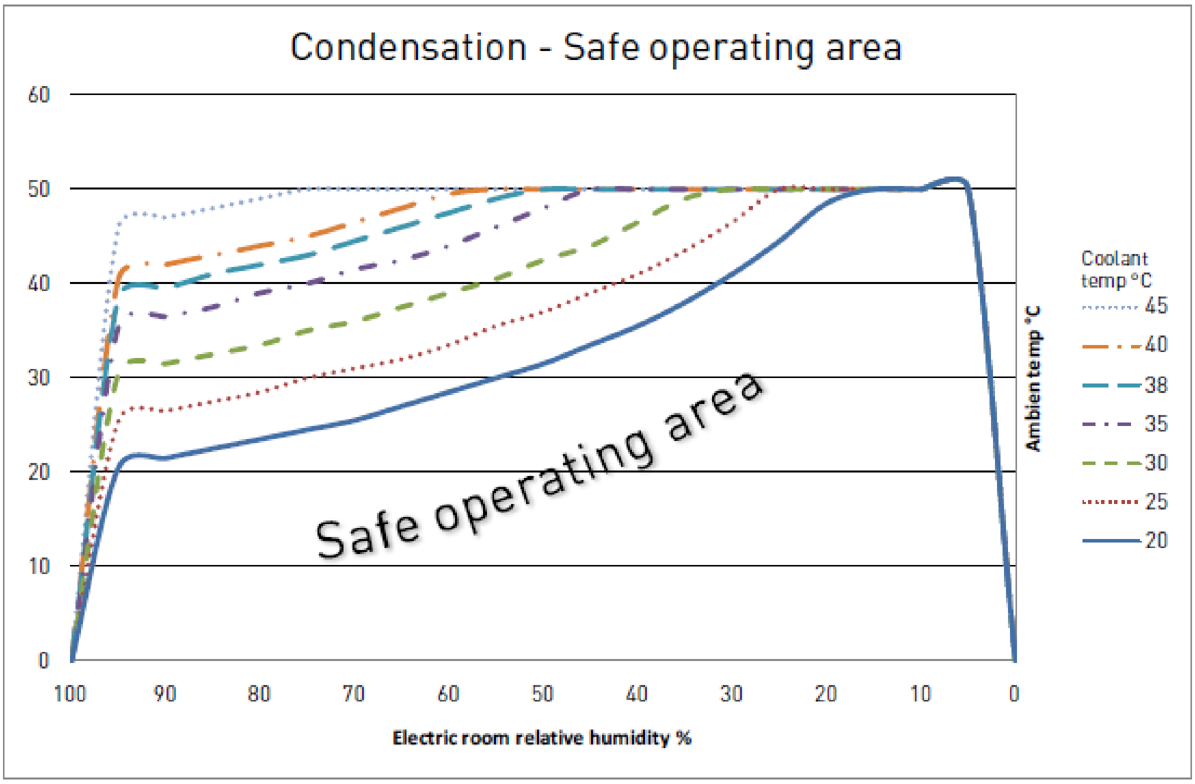



*Figure 99. Safe operating area*

Example:

If the temperature of the electric room is 30°C, the relative humidity is 40% and the temperature of the cooling liquid is 20°C (the lowest curve in the figure Safe operating area), then the drive operating conditions are safe.

However, if the room temperature were to rise to 35°C and the relative humidity to 60%, then the operating conditions of the drive would no longer be safe. In this case, to reach safe operating conditions, the air temperature should be cooled to 28°C or lower. If it is not possible to lower the room temperature, then the temperature of the cooling liquid should be raised to at least 25°C.

# 12. Motor cables and output filters

Motors and cables are subject to certain phenomena that include voltage reflections, current spikes, resonances, high rate of change of output voltage (i.e., dU/dt) and bearing currents. There are three different types of filters that can be connected to the output of a frequency converter to reduce these potentially harmful effects.

- the dU/dt filter
- the sine filter
- the common-mode filter

## 12.1 Output filters

### 12.1.1 DU/dt filter

A du/dt filter is essentially an LC low-pass filter, whose cut-off frequency exceeds the switching frequency of the converter.

The filter increases the rise time of the voltage pulse, i.e. reduces the change rate and high frequency content of the frequency converter's output voltage. A du/dt-filter reduces the du/dt value below 1kV/μs. This reduces the risk of partial discharges in the winding. Partial discharges are caused by exceeding the dielectric strength of the insulation, and the discharges slowly degrade the insulation, causing turn-to-turn faults in the winding.

A du/dt filter also helps to diminish voltage reflections, which cause voltage stress to the motor. This is also achieved due to an increase in the cable surge impedance, which decreases the difference between the cable and motor impedances, and thus the reflection coefficient. Consequently, the critical cable length is longer.

Reducing the du/dt value results in smaller capacitive leakage current. A du/dt-filter reduces also ground currents and lessens the impact of the various sources of bearing currents.

A du/dt filter causes a slight voltage drop in the circuit. Therefore the pull-out torque limit of the motor may be decreased by a few percent. This will not normally have any effect on the process.

Filter does not reduce radiated emissions. The motor cable must therefore be shielded.

The filter must be installed at the frequency converter's output. You must also take care of the filter's cooling requirements.

Motor's insulation requirements are a main issue in determining whether you need a du/dt filter. Vacon gives the following recommendation on the use of du/dt filters:

*Table 45. Use of du/dt filters*

| Supply voltage | Need of filter |
|---|---|
| 200-400V | No need |
| 440-525V | If the motor is double insulated and can withstand high voltage spikes, no need. Otherwise use a du/dt filter. From frame size 200kW upwards, no need |
| 525-690V | Use du/dt or sine filters. If the motors are double insulated and specially designed for the purpose, no need. |

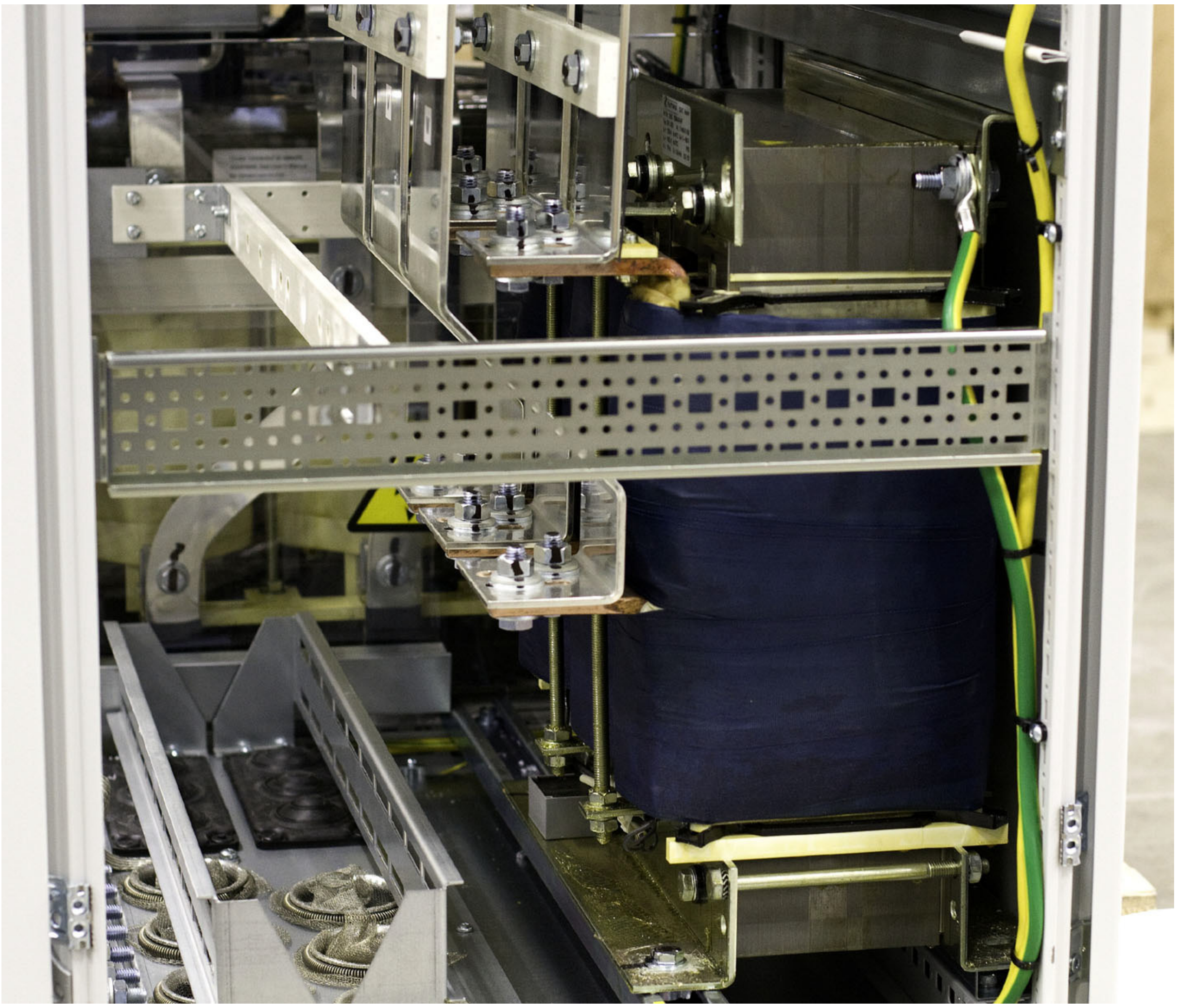


*Figure 100. Du/dt filters*

### 12.1.2 Sine filter

A sine filter is a LC low-pass filter, whose cut-off frequency, unlike that of a du/dt filter, is set to eliminate all the high frequency components of the frequency converter's output voltage. It produces a near perfect sinusoidal voltage waveform.

With a sine filter, the voltage stresses on the motor correspond to those existing in normal DOL (direct-on-line) use with a power source of the same voltage. A sine filter is suitable especially for old motors not designed to be used with AC drives.

Sine filter eliminates bearing currents and voltage reflections, and it also reduces motor's noise levels. If you use an output transformer, the sine filter eliminates high-frequency components that could stress the transformer.

You can always use a sine filter instead of a du/dt-filter but it is much more expensive, than a du/dt-filter. This is because the desired frequency characteristics require the use of larger inductance and capacitance.

The sine filter typically causes a 7-10% voltage drop. This may require boosting the output voltage of the frequency converter. When used in the field weakening range, the pull-out torque drops faster (than without a sine filter).

The sine filter allows the use of considerably longer motor cables. However, not all common-mode voltage and EMC interference is eliminated, which means that the motor cable must be shielded.

Both du/dt filters and sine filters are a possible source of noise, sine filters more than du/dt filters.

If you use third party du/dt or sine filters, verify for which switching frequency the filter has been designed and make sure that the drive's settings are correct. Also check the loadability of 690V drives if the switching frequency is higher than the default setting.

### 12.1.3 Common-mode filters

Common-mode filters are used to reduce bearing and ground currents.

High frequency common-mode filtering can be achieved using toroidal cores of ferromagnetic material, in other words, by slipping a ferrite ring on to a cable. A cable carrying a current has a magnetic field around it. The effect of the ferrite is to concentrate this field and, hence, to increase the cable's inductance by several hundred times.

If a ferrite is put on to a cable which includes all three phases, it will have no effect on the differential-mode current, but it will increase the impedance of common-mode currents. This is because the differential currents, by definition, sum to zero and therefore there is no net magnetic field. The common-mode currents produce a net magnetic flux and this flux is concentrated in the bulk of the ferrite, resulting in an increased impedance for common-mode currents only.

This is also why only phase conductors are slipped through the rings. The PE (Protective Earth) conductor must be separated. All ferrites are conductive, so it is important that cables passing through them are sufficiently well insulated.

A common-mode filter does not provide any significant dU/dt filtering.

A commo- mode filter should be installed directly after the drive output, before any other output filters.

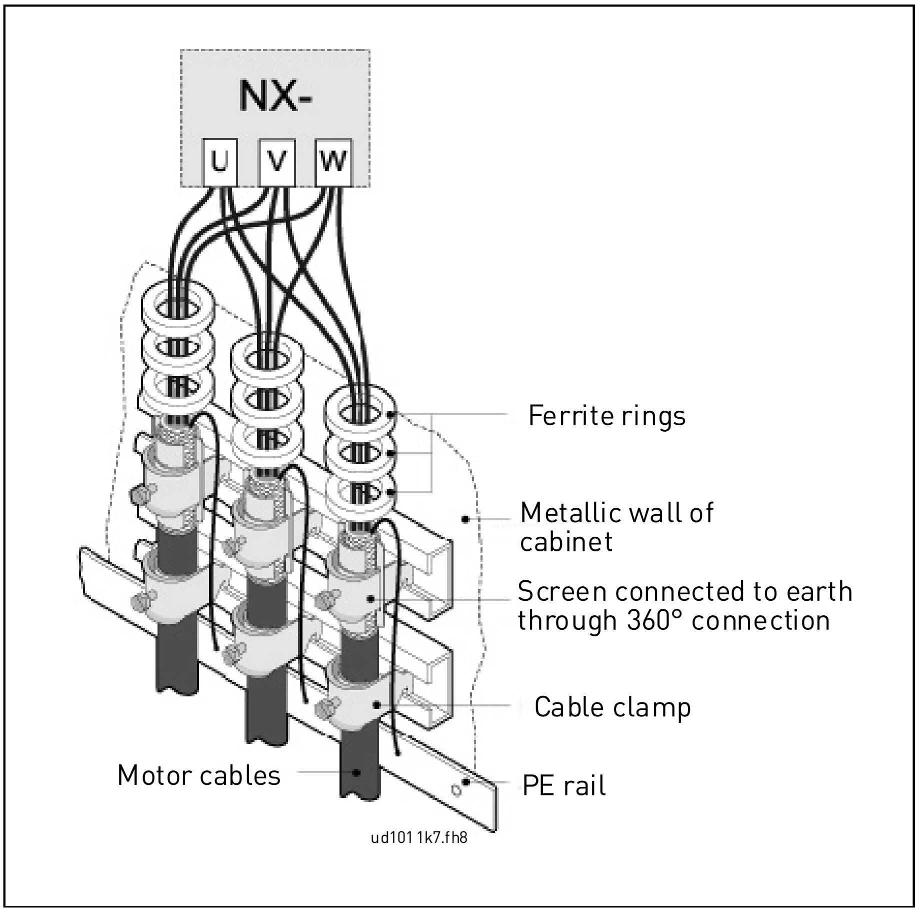



*Figure 101. Ferrite rings*

## 12.2 Bearing currents

The output voltage of a frequency converter has a high frequency common mode voltage component. In some cases this common mode voltage may cause bearing currents, that can produce harmful effects on the motor bearings. The resulting erosion of the bearing races and bearing balls causes rapid deterioration of bearings due to material removal. The bearing and race wear also results in motor noise and vibration.

When the bearing is operating at normal speeds, the lubrication insulates the balls from the bearing races. If a voltage develops across the bearing, the electrical field through the film increases, as the capacitor is charged, until the breakthrough voltage is reached. When the film breaks, a spark jumps the gap. Each spark removes a trace of material from the ball and the race, eventually creating a washboard pattern on the bearing race. This current is known as the EDM (electrical discharge machining) current.

The bearing lubricant film is typically 0.2 to 2.0 μm thick. With low frequencies (50 Hz DOL motors), the breakthrough voltage is on the order of a few volts, but with fast rise times, the instantaneous withstandability of the film can reach values in the 20 to 30 V range at 10 μs pulses. These values are quite conservative, as the actual value is a complicated function of temperature, metallic pollution, viscosity and a number of other factors. The frequency and magnitude of these currents determine how quickly the bearing is destroyed. The frequency is determined by the switching frequency of the drive, and the magnitude of the physical characteristics of the drive, the motor, and also the earthing. In all bearing currents are difficult to control or measure very exactly.

### 12.2.1 What actually happens in the bearings

Typical discharge of rotor capacitance is 12V, with the duration of 50ns. High peak current if from 10 to 100A. This heats the steel locally, so that a small amount gets vaporized, and a small crated is formed. The diameter of the crater is below 1 μm. After the formation of several millions of such craters, the balls start to bounce. This bouncing creates the wash-board pattern. The pattern has no connection with the AC drive's frequencies.

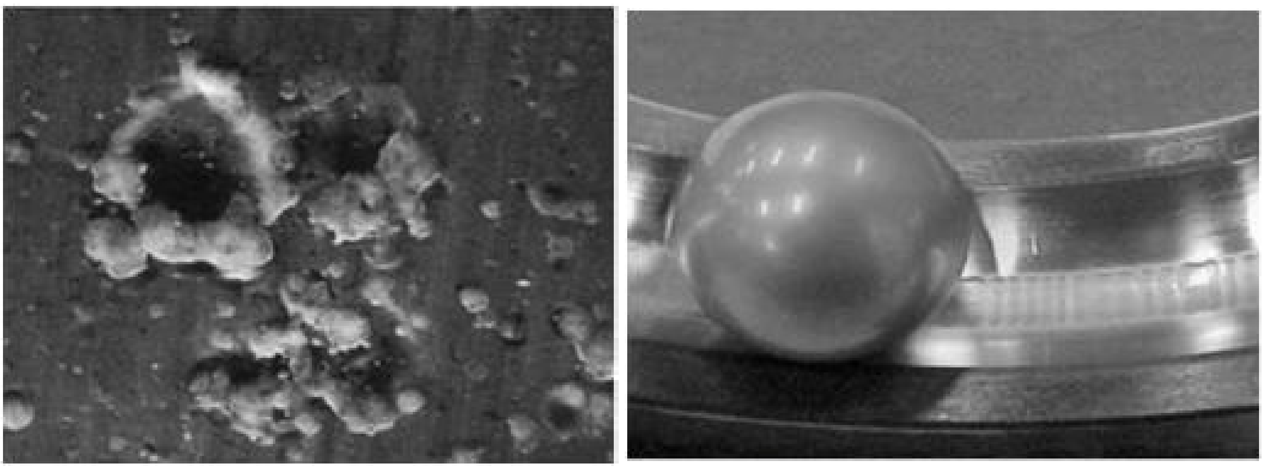


*Figure 102. Left: miniature craters (microscope image), right: washboard pattern*

### 12.2.2 Three main categories of bearing currents

The bearing current phenomenon can be divided into three main categories: capacitive voltages, circulating currents and shaft-earth current.

### 12.2.2.1 Capacitive voltages

In frequency converter's output, semiconductors produce a modulation pattern. The potential between the motor's phases and the motor's stator windings varies between the + and - voltages of the intermediate circuit, depending on which semiconductor is conducting at the time. Thus for example the stator windings in a 400 V network can be at +280V compared to the motor's frame at one moment, and with other switch positions at -280V compared to the motor's frame. This voltage variation can be seen also as voltage division in motor constructions in relation with the motor's stray capacitances. In the figure below, (Capacitive voltage sharing) C1 is the stray capacitance from the motor's windings to the rotor circuit (motor shaft) and C2 is from rotor circuit to the motor's frame. Voltage over the motor's bearings is the same as over the capacitor C2. If this voltage (U bearing in the figure) exceeds the breakdown voltage of the bearing's lubricant film, a small EDM current takes place inside the bearing.

Usually the values of C1 and C2 are very small, and thus the resulting energy of the EDM current is also very small. For this reason this type of bearing current usually does not cause premature damage to the bearings.

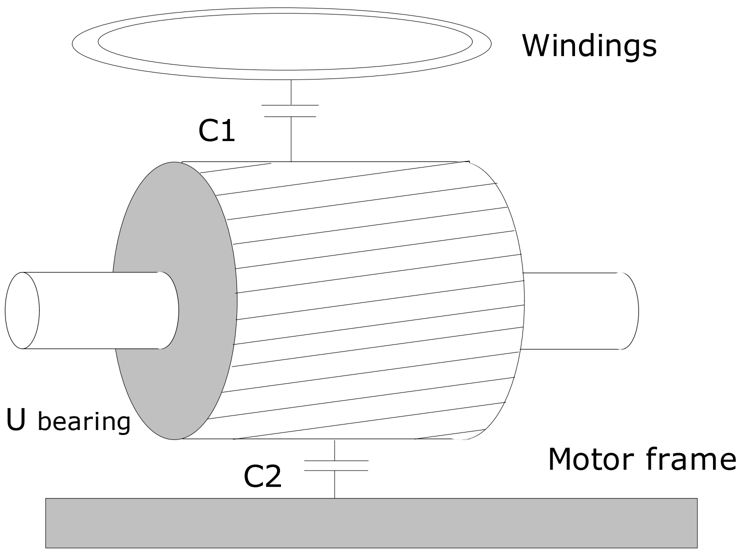



*Figure 103. Capacitive voltage sharing*

### 12.2.2.2 Circulating currents

Asymmetrical leakage current in the motor's frame induces voltage on the motor's shaft. If the voltage is high enough, a current loop is formed through bearings. This is a problem with big motors, typically >110kW.

When the frequency converter is modulating motor's supply voltage, at the moment when the semiconductors are switching on or of generating rising or falling edge of voltage, the stator windings' potential changes causing asymmetrical capacitive currents inside the motor. These leakage currents induce a voltage (U) in the rotor circuit between the ends of the motor's shaft. If this voltage exceeds the breakdown voltage of the bearings, EDM takes place.

The amplitude of the induced voltage between the bearings on the ends of the motor's shaft depends on their distance. Typically voltage rises as a function of distance. Thus the risk of this type of bearing current phenomenon is highest with motors of large frame, in other words, with big, high power motors. For this reason the motor manufacturers usually have specific recommendations for the situations when their motors are controlled using a frequency converter. These recommendations may include for example the use of isolated bearings and output filters. For example, 100kW is often used as the power limit after which it is recommended to provide the motor with insulated bearings.

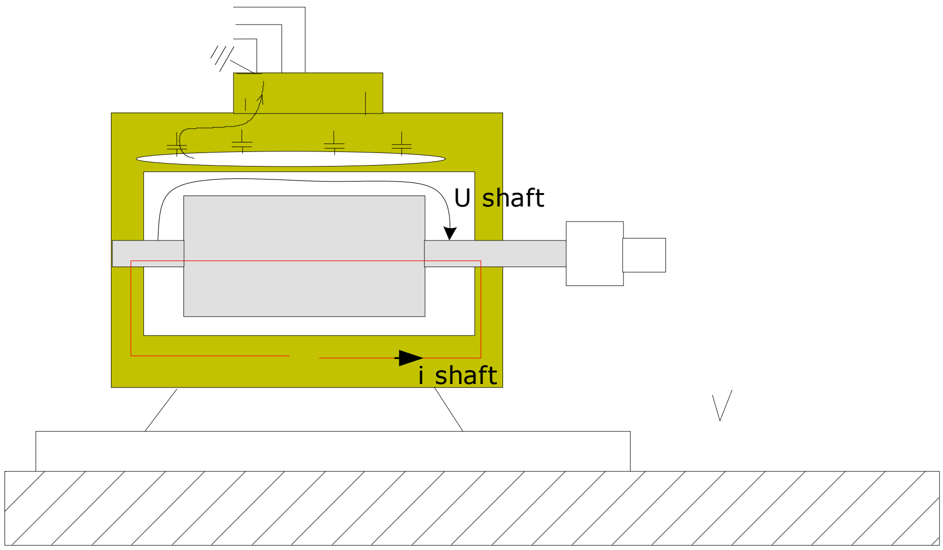



*Figure 104. Circulating current*

### *12.2.2.3 Shaft earth current*

Shaft earth current can occur if voltage potential difference between the motor frame and the machine is larger than the break-through voltage limit on the bearings.

During the switching edges of semiconductors, the potential of motor's frame tends to make high frequency swings up and down depending on the potential of the windings and earthing impedance. In proper installation, the voltage swings in the motor frame are prevented by proper earthing of the motor, where any capacitive leakage currents are directed to equipotential bonding.

The route of the leakage currents is divided in accordance with earthing impedances. If the device controlled by the motor (for example a fan), has a conductive connection to the motor's shaft and the earthing impedance is smaller than the earthing impedance of the motor's frame, there is a danger that the voltage over the bearing exceeds the breakdown voltage value, and the leakage currents go through the bearing to the shaft, and that way through the device to the earthing circuit. In this case there is a risk of premature bearing damage. There is also a risk that the leakage currents go through the device's bearing or bearings, and they may get damaged as well.

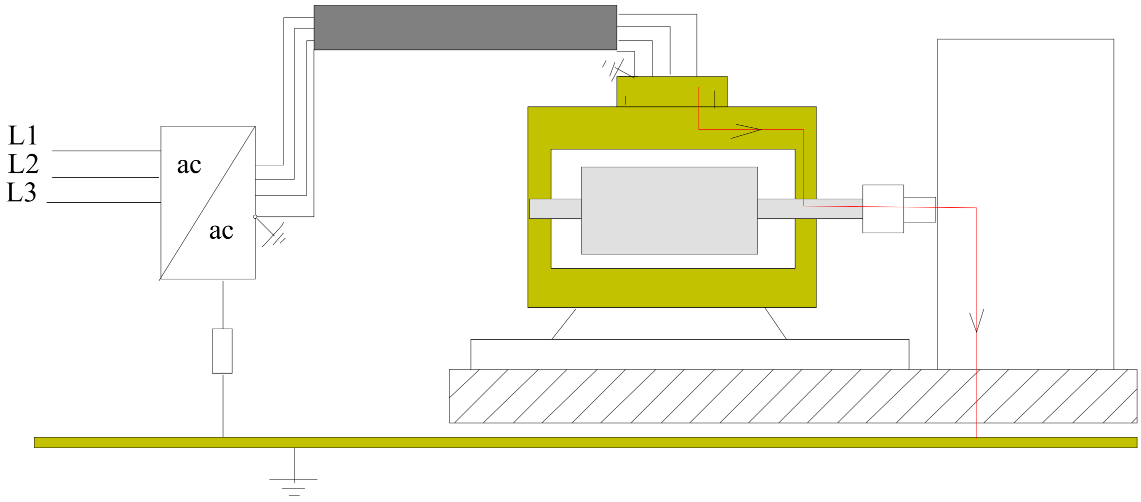



*Figure 105. Shaft earth current*

### 12.2.3 Preventive measures

#### *12.2.3.1 Cables and cabling*

In order to minimise the common mode voltage, it is recommended to use a symmetrical cable with three 3-phase conductors, and a separate shield as show in the figure below (Symmetrical cable). To minimise the high frequency impedance of the earthing chain, the concentric shield must be connected to earth, or to the frequency converter's frame, or the motor's frame, using so called 360°C earthing. This 360°C earthing must be done all through the motor cable, in other words at the motor end, frequency converter end, and at any possible safety switches, connection boxes, or any other items connected between the frequency converter and the motor.

In case a 360° earthing is not possible, the distance between the peeling point of the cable shield and the earthing point must be as short as possible, for example shorter than 3 - 4 cm, in order to minimise the inductance in the earthing circuit. So called pigtail earthing is not recommended due to high impedance.

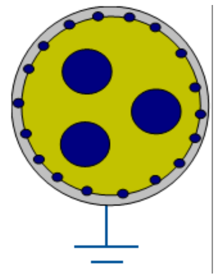


*Figure 106. Symmetrical cable*

- Use a symmetrical cable. Most common cable type is 3core + separate concentric earth (low PE wire potential)
- Connect the motor and machine frame together using low hf impedance, to prevent high voltage potential difference.

#### *12.2.3.2 Isolated bearings*

Bearing currents can also be prevented by lifting the breakdown voltage value of the bearings to a safe level, to eliminate any EDM bursts from happening. Usually this is carried out by using either isolated bearings, end shield, or possibly a bearing with ceramic balls. Motor manufacturers offer various options for their products.

#### *12.2.3.3 Use of output filters*

As low cost filter especially for bearing currents you can use a so called common mode filter, which is formed by ferrite rings installed around the phase conductors.

Other filters, such as dU/dt filter, sine filter and AC choke that are used mainly to protect the motor's insulation also attenuate or diminish to some extent the risk of bearing currents. However, as they are usually constructed on three-pole iron core, their common mode inductance is relatively low. In order to the above filters to be effective against bearing currents, they should be manufactured using single phase elements.

#### *12.2.3.4 Equipotential bonding between the device and the motor's frame*

In case there is a conductive connection between the device and the motor's shaft, you must make sure that their potential is also identical concerning high frequency. Usually there is no risk if both have been installed on the same metallic frame or metal plate, and the connection points have a conductive connection to the metallic frame. If the risk exists, an equipotential bonding must be formed in between them. This can be carried out using a plate with low inductance, for example 10 cm in width. A 16 mm$^2$ earthing conductor used in normal installation is not applicable for this purpose, as high frequency impedance is formed in it.

## 12.3 Encoders

Encoders deliver data regarding the position of the motor. The data can be incremental or absolute.

### 12.3.1 Encoders that deliver incremental data

Incremental data can be used for adjusting the motor. In some cases you can use incremental data also for positioning, but that requires calibration at start-up, using for example limit switch

- Encoder RS422 (TTL)
- Encoder 10---24V (HTL)
- Double encoder (Wide Range)
- SIN/COS encoder interface

**HTL** = High voltage Transistor Logic, voltage level is 10V-30V

**TTL** = Transistor to Transistor Logic, voltage level is 5V

**RS422** = Differential receiver for -6V to +6V signal. (Compatible with TTL encoders with inverted outputs)

### 12.3.2 Encoders that deliver both incremental and absolute data

Encoders that deliver both incremental and absolute data can be used for adjusting the motor and for more speedy and precise positioning.

- SSI and ENDAT Encoders (with SIN+COS)
- RESOLVER

**RESOLVER** is a rotary transformer where the magnitude of the energy through the resolver windings varies sinusoidally as the shaft rotates. A resolver contains one primary winding and two secondary windings, the SIN and the COS windings.

**ENDAT** is a bidirectional synchronous serial interface for absolute encoders. For example, the encoder position data can be read and encoder parameters can be set via ENDAT connection. It also forwards the messages related to the encoder functions.

**SSI** (Synchronous Serial Interface) is a single directional interface for transmitting absolute position value.

Note: Sensors that deliver SIN+COS data can be used also for slow running of the motor with interpolation (< 6Hz).

### 12.3.3 Encoders that deliver only absolute data

Encoders that deliver only absolute data can be used for precise positioning, when speed requirement is relatively slow.

- SSI and ENDAT Encoders (digital only)

### 12.3.4 Installation

Vacon recommends to use always shielded twisted pair cables with encoders. Use cables that are recommended for encoder feedback. Do not mix signals in twisted pairs.

Always make earthing contact throughout the full circumference of the cable (360°) and grounding at the device end only.

The feedback signals may also suffer from the noise coming from motor and supply cables. Use shielded symmetrical motor cables. It is recommended to connect the motor cable shield with 360° EMC bushing. The motor and supply cables should not be in parallel with the encoder's signal cable.

# 13. COMMISSIONING

Installation phase is followed by commissioning of the drive, after which the drive system is handed over to the operative personnel.

It is important to understand the drive's position and role in the customer's process. In a complex industrial process there is usually an upper level control architechture which takes care of certain control functions. A system specification defines which operations or controls must be handled by this upper level control architecture, and which ones belong to the drive. This definition must be obeyed.

In addition, there are usually various additional drive functions or properties that can be used to further improve the customer 's process. Thorough knowledge of the customer's process requirements and the drive's properties allow the commissioning team to figure out how these additional functions may be utilised. As a result, the commissioning team can achieve results that meet and even exceed the customer's expectations.

Commissioning is one of the last phases of an entire project. Project schedule is usually tight and getting tighter towards the end. Often it is possible to do some preparations for the commissioning process beforehand, such as acquiring materials, or even running some tests in a laboratory. Commissioning is teamwork, involving specialists from various fields of expertise. The project manager can provide the members of the commissioning team with an opportunity to do an interface cross-check with other participants. The customer can again check up their needs and compare them to the planned outcome of the project. A preliminary definition of the commissioning helps to see if the schedule and phasing of the commissioning project are sensible. This way the work proceeds smoothly as it is possible to have the right people available at the right time.

## 13.1 TYPICAL COMMISSIONING PROCESS

Each commissioning process is unique. This chapter contains some examples and general descriptions that are meant to give an overall idea of the scope of commissioning. Chapter "Checking the installation and connections" on page 149 contains some connection diagram examples.

### 13.1.1 SAFE WORK PRACTICES

For reasons of personal safety, the personnel who carry out the commissioning must have adequate competence in safety issues. Electrical safety is essential also during the commissioning phase. Working with any level of voltages requires caution.

*Figure 107. Warning sign*

Also, to avoid any injuries to the personnel or damage to the drive system's components, the tools and other equipment used in the commissioning must be appropriate, and the premises must be kept clean and tidy.

### 13.1.2 CHECKING THE INSTALLATION AND CONNECTIONS

Installation and connections refer to the main control systems, auxiliary controls, measurements and feedback from the process. These are mechanical and electronical connections directly to the drive.

Further basics that need to be studied before the actual commissioning procedure include transmission details and mechanics. The motor together with the drive give a certain performance. However, the mechanical properties of the system set their own limits, and the process where the drive is used has certain requirements. In an optimal commissioning procedure all these are taken into account.

Drives have a number of functions for monitoring the mechanical operations and feedback. These functions need to be commissioned in an appropriate way - those that have already been defined in the system specification, and those additional ones that can be used to enhance the system's operation.

It is necessary to check that all the drive system's components have been delivered in accordance with the delivery contract, and that there is no visible damage to the equipment.

The following list gives some examples of the items that need to be checked.

- Mechanical and electrical equipment are installed in accordance with the regulations or specifications.
- All connections are made in accordance with the regulations or specifications.
- Grounding (Protective Earth and possibly Technical Earth) is checked.
- All cable and busbar connections are tightened in accordance with the recommended torque, and have a correct insulating distance
- Settings for the components and cabling related to the emergency stop circuit are checked
- The equipment and the premises are clean. There is no scrap or dust inside the drive cabinet.
- All tools removed from inside the drive cabinet.
- There are no short circuits between the phases or the ground. This can be checked by carrying out insulation tests. If any high voltage insulation tests need to be done, they have to be carried out by authorised personnel.

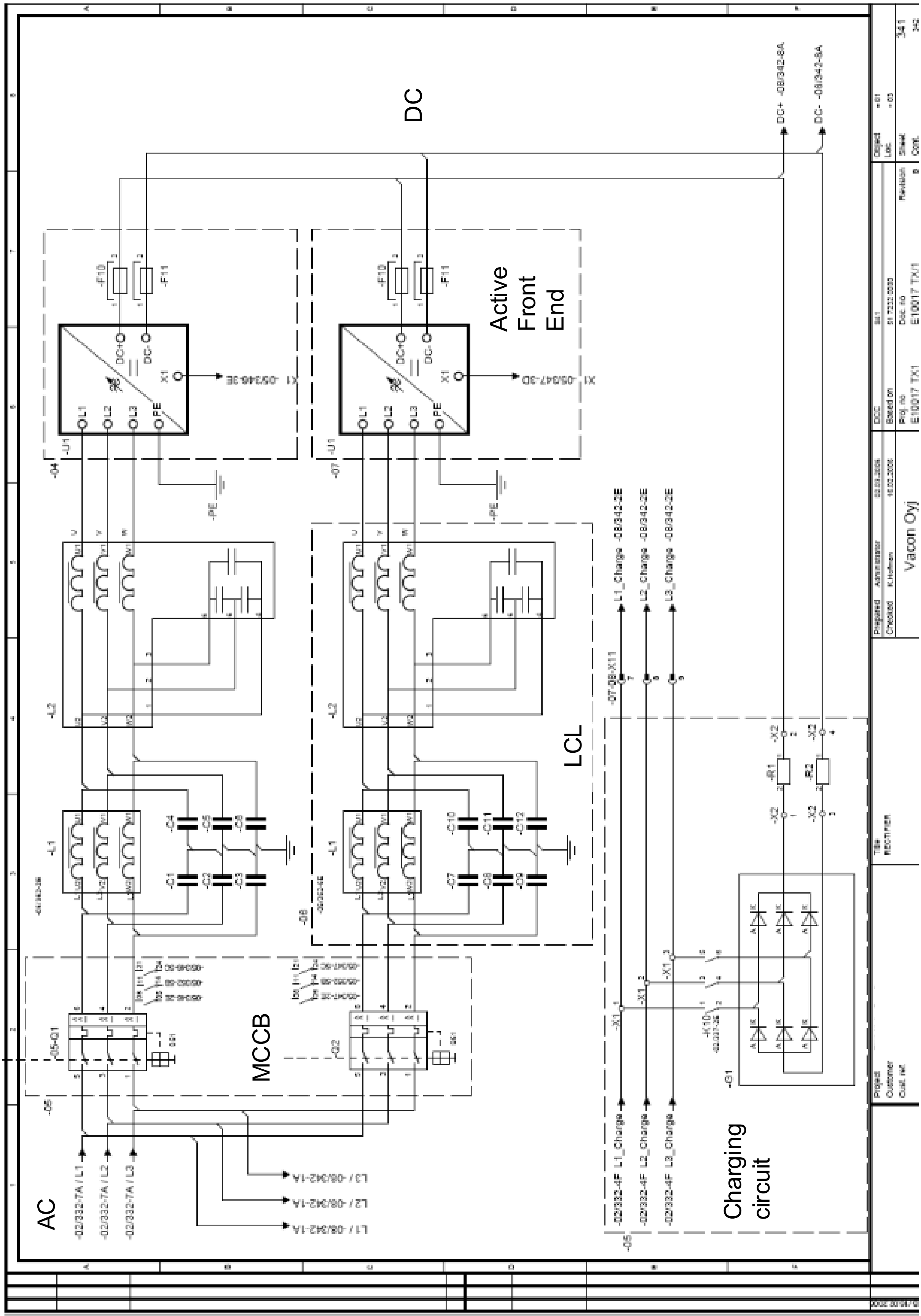



*Figure 108. The supply section*

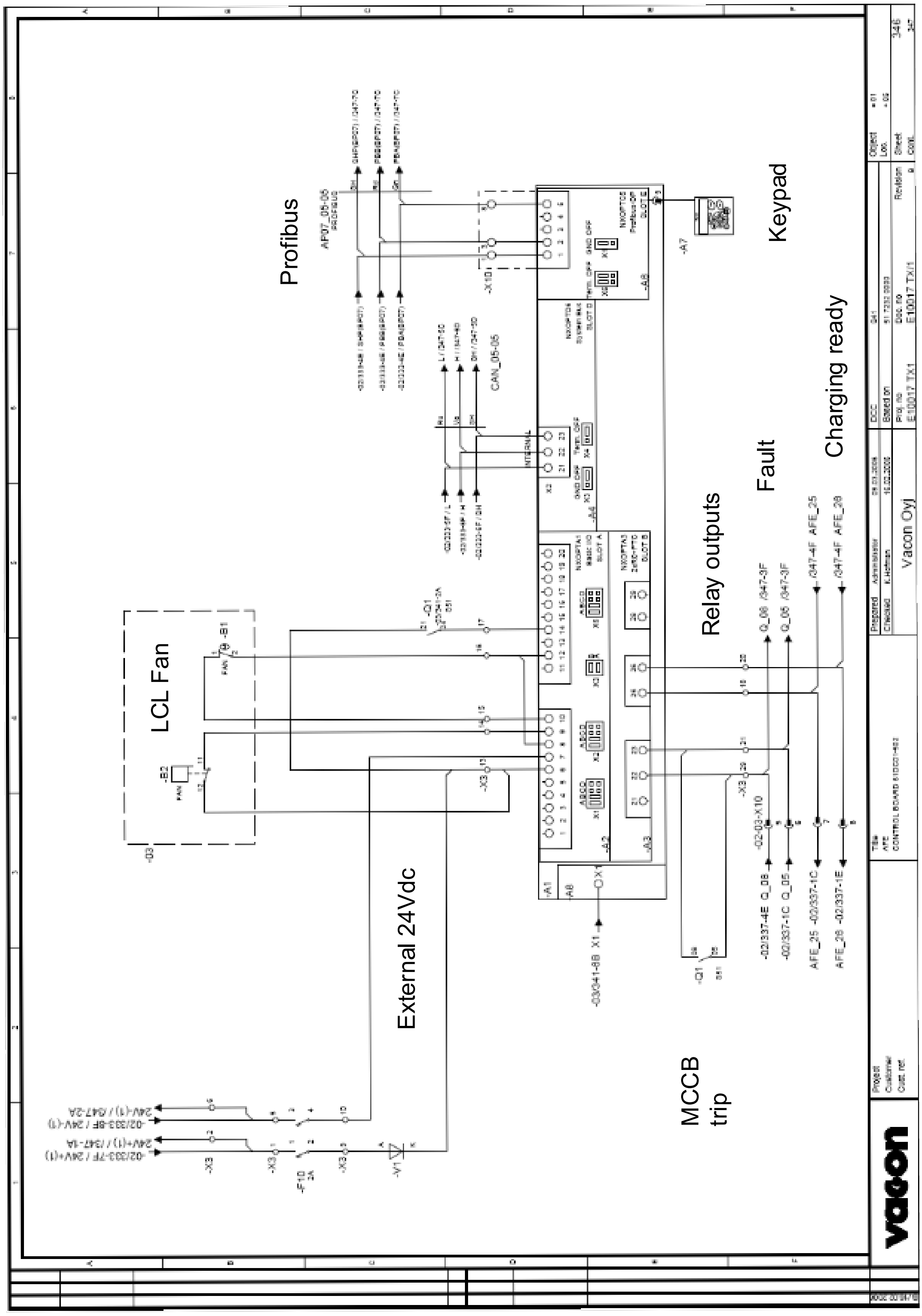



*Figure 109. Supply section - control wiring*

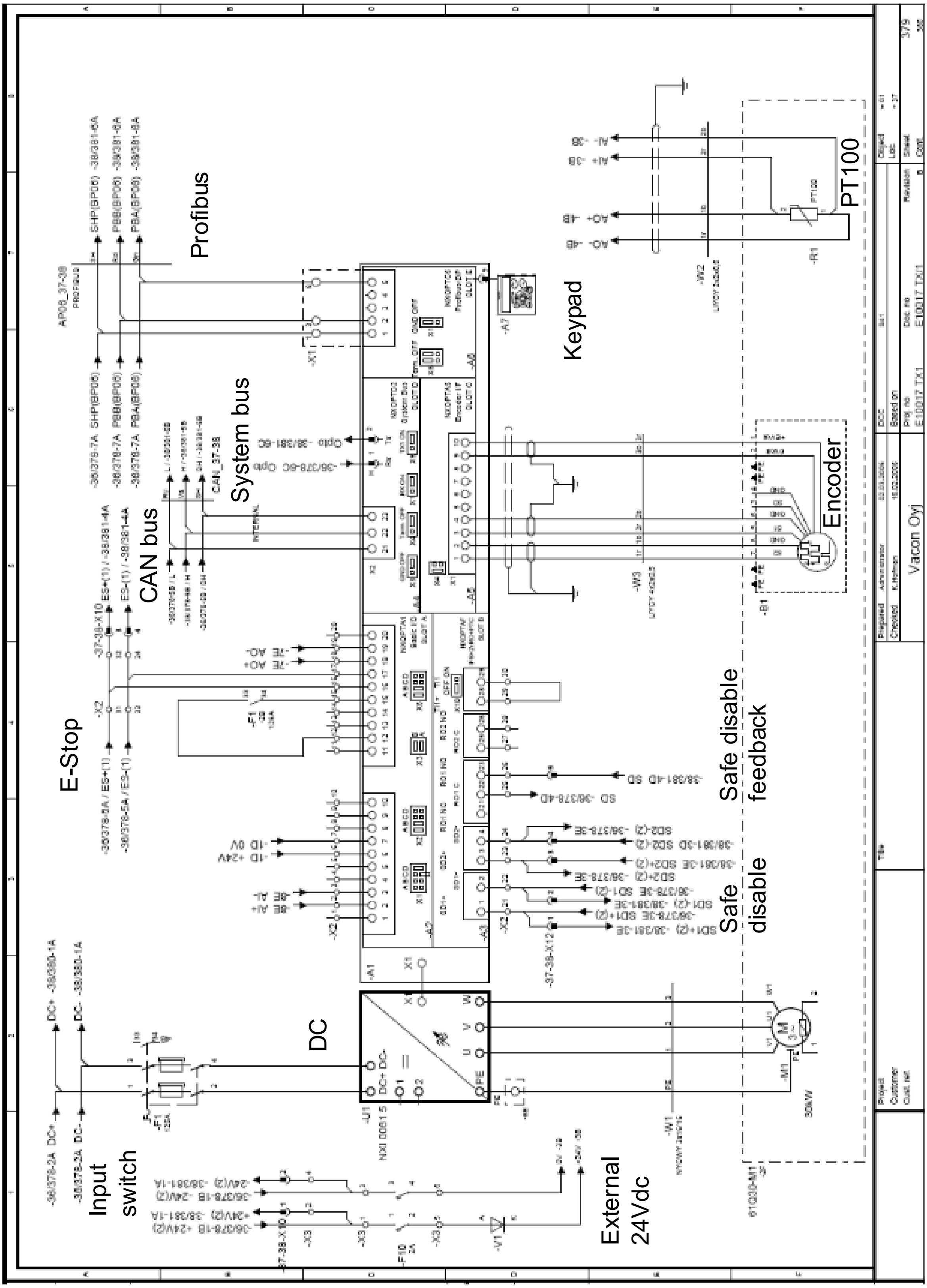



*Figure 110. Inverter section - control wiring*

### 13.1.3 Checking the settings

As a part of the preliminary phase, the various settings of the drive system must be checked. Such setting include for example the following:

- Relays of the emergency stop circuit
- Timer relay
- Overload relay, thermal overload relays, etc.
- Breaker settings
- Earth leakage current protection circuit

### 13.1.4 Gathering drive system and process-specific data

In order to proceed in the commissioning, you need to cross-check the data regarding the motor, the drive system and the customer process. The data, such as process speeds, directions, etc. must be in line with the actual process description. Based on this data, you need to check that the system has been built in accordance with the requirements of the customer's process.

The details include for example the following:

- Motor's rating
- Encoder
- Cooling fan details
- Motor's temperature measurement device, eg. Pt100, thermistor, over-temperature switch, etc.
- Mechanical brake
- Direction of the rotation of the motor and the corresponding process requirement
- Maximum motor speed, process speed and any other speed requirements
- Speed factors, such as transmission ratio and diameter
- Speed ramps
- Start/Stop method

### 13.1.5 Connecting power

Make sure that the motor does not start unintentionally when power is connected to the drive.

- Test the motor's temperature sensor and safety switch circuit. Verify these connections from the motor end.

- Running with no load with motor disconnected from the load
- Set the motor's name plate data, encoder related parameters, start, stop method, acceleration and deceleration ramp times and related IO settings.
- Set the current limit. Typically same as the motor's nominal current limit.
- Start running the motor at no load gradually up to the full speed. Check the encoder feedback and also smooth running of motor through the speed to confirm its correct installation.

- Perform an ID (Identification) run.
- It is recommended to perform a complete Identification run. During the ID run the motor is typically run to 60-70% of its nominal speed. In some applications, load cannot be disconnected from the motor. In these cases the identification run can be done with the motor at standstill.
- Set the motor control mode to be Open Loop or Closed Loop with speed or torque control.
- Set the limits based on the process requirement: speed, torque and current.
- Process-specific settings/tuning of speed controller, load drooping, acceleration or load compensation.

- Running with load
- Run the motor with load throughout the speed range of the process in both directions. This way you can check the stability of the control and smooth running of the process and mechanics within limits.

### 13.1.6 DOCUMENTATION

Documentation is needed for maintenance and servicing purposes. It must be stored during the drive system's entire lifetime and maintained in a usable format.

- If any connections were changed during the commissioning, the changes must be marked into the circuit diagram
- All documents and drawings must be updated for the customer and the engineering team.
- The drive's parameter files must be saved

As a result of  a successfull commissioning the drive system can be handed over to the customer. The customer can start using the system, aiming at optimum performance. Any feedback from the customer as well as the experiences of the commissioning team should be collected. Further process improvement and maintenance rely on the information learned during the commissioning. This information is needed also for training of the operating personnel. User and installation manuals only define the starting point, but every commissioned system is customer/project specific.

A well commisioned drive system is likely to be more reliable, and meet the customer's expectations - even exceed them, and thus add to customer satisfaction. Commissioning gives one more chance to interpret the customer's real needs and to customise the drive system accordingly.

# 14. ABBREVIATIONS

*Table 46. Abbreviations of terms used in the Engineered Drives Manual*

| Abbreviation | | Term |
|---|---|---|
| AC | = | Alternating Current |
| ACB | = | Air Circuit Breaker |
| AFE | = | Active Front End |
| BCU | = | Brake Chopper Unit |
| CAN | = | Controller Area Network |
| CISPR | = | Comité International Spécial des Perturbations Radioélectriques |
| DC | = | Direct Current |
| DOL | = | Direct On Line |
| EDM | = | Electric Discharge Machining |
| EMC | = | Electromagnetic Compatibility |
| EN | = | European Norm |
| EPDM | = | Ethylene Propylene Diene Monomer (type of rubber) |
| FC | = | Frequency Converter |
| HTL | = | High voltage Transistor Logic |
| HVAC | = | Heating Ventilation and Air Conditioning |
| Hx | = | Vacon's liquid to liquid Heat exchanger unit |
| IEC | = | International Electrotechnical Commission |
| IEEE | = | Institute of Electrical and Electronics Engineers |
| IFA | = | Institut für Arbeitsschutz der Deutsche Gesetzlichen Unfallversicherung |
| IGBT | = | Insulated Gate Bipolar Transistor |
| INU | = | Inverter Unit |
| IP | = | Protection class |
| ISO | = | International Organisation for Standardization |
| LV | = | Low Voltage |
| MCB | = | Miniature Circuit Breaker |
| MCCB | = | Moulded Case Circuit Breaker |
| MEN | = | Multiple Earthed Neutral |
| MV | = | Medium Voltage |
| NBR | = | Nitrile rubber |
| NFE | = | Non-regenerative Front End |
| NXI | = | NX is a Vacon AC drive product family, I comes from "Inverter" |
| OPT | = | Option board |
| PC | = | Personal Computer |
| PCC | = | Point of Common Coupling |
| PDS | = | Power Drive System |
| PE | = | Protective Earth |
| PID | = | Proportional-Integral-Derivative |
| PL | = | Performance Level |

*Table 46. Abbreviations of terms used in the Engineered Drives Manual*

| Abbreviation | | Term |
|---|---|---|
| PME | = | Protective Multiple Earthing |
| PPR | = | Pulses Per Revolution |
| PVC | = | Polyvinyl Chloride |
| PWM | = | Pulse Width Modulation |
| RMS | = | Root Mean Square |
| RPM | = | Revolutions Per Minute |
| SCR | = | Short Circuit Ratio |
| SIL | = | Safety Integrity Level |
| SS1 | = | Safe Stop 1 |
| SSI | = | Synchronous Serial Interface |
| STO | = | Safe Torque Off |
| THD | = | Total Harmonic Distortion |
| TTL | = | Transistor to Transistor Logic |
| Vacon NXP | = | NX is a Vacon AC drive product family, P comes from “High Performance” |
| VCB | = | Vacuum Circuit Breaker |
| VTT | = | Technical Research Centre of Finland |
| XLPE/PEX | = | Cross linked Polyethylene |

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