Nidec
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Guide to best practices

Motor-drive systems

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LEROY-SOMER™

CONTENTS

1 - PREAMBLE

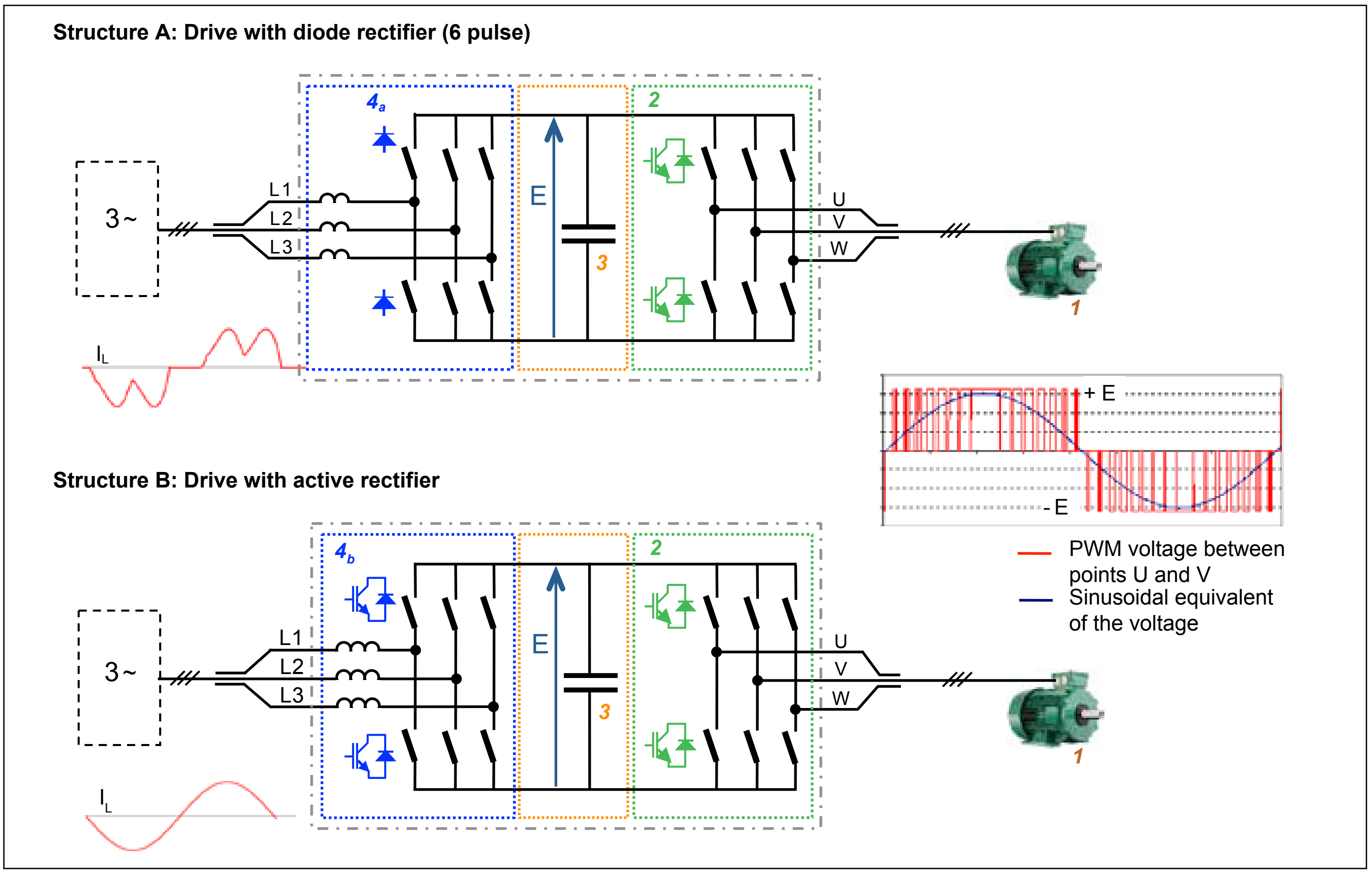
The continual industrial evolution requires even more efficient, more reliable and robust drive systems. Thanks to a long experience in the industrial world, Leroy-Somer is today recognised as a leader in the field of motor and drive systems. Leroy-Somer has developed this guide to best practice, which is primarily intended for those who design installations and wiring of motor and drive systems for low-voltage industrial power supplies. This document provides information on the rules to be respected for correct operation of the installation and optimal service life of equipment.

2 - INTRODUCTION

2.1 - Recapitulation of the principle of operation of electronic drives

An electronic drive, otherwise known as a frequency inverter, provides power supply to an electric motor at variable voltage and frequency by taking power from electrical power supply of fixed voltage and frequency. Figure 1 symbolically represents the 2 (two-stage) frequency inverter structures commonly used in industry.

Illustration 1 - Frequency inverter structures



1 **Motor** which can be based on asynchronous, synchronous, reluctance or hybrid technology.

2 **Inverter**: AC/DC inverter for which the components of the output stage (IGBT) behave as electronic switches that pass a continuous voltage E at a frequency of several kHz, in order to generate an alternating voltage between phases equivalent to a sine wave of variable amplitude and frequency. This mode of operation by voltage switching, commonly called PWM (Pulse Width Modulation), provides a huge advantage of limiting inverter losses to about 2% of the transmitted power. This leads to several side-effects on the motor-inverter installation.

3 **DC bus**: Filtering stage made up of several capacitors connected in a series-parallel assembly. The DC bus voltage value (E) is linked to the value of the mains voltage and the rectifier technology.

4 **Rectifier**: AC/DC power supply inverter. It consists of a simple passive diode rectifier for the most recent drives (4a). The power can then pass only from the power supply to the motor. The line current of the power supply is not sinusoidal and its harmonic distortion level is high. For applications that require a low level of harmonic distortion in the power supply or for applications where the power must be returned to the power supply, the AC/DC converter is designed with IGBT (4b).

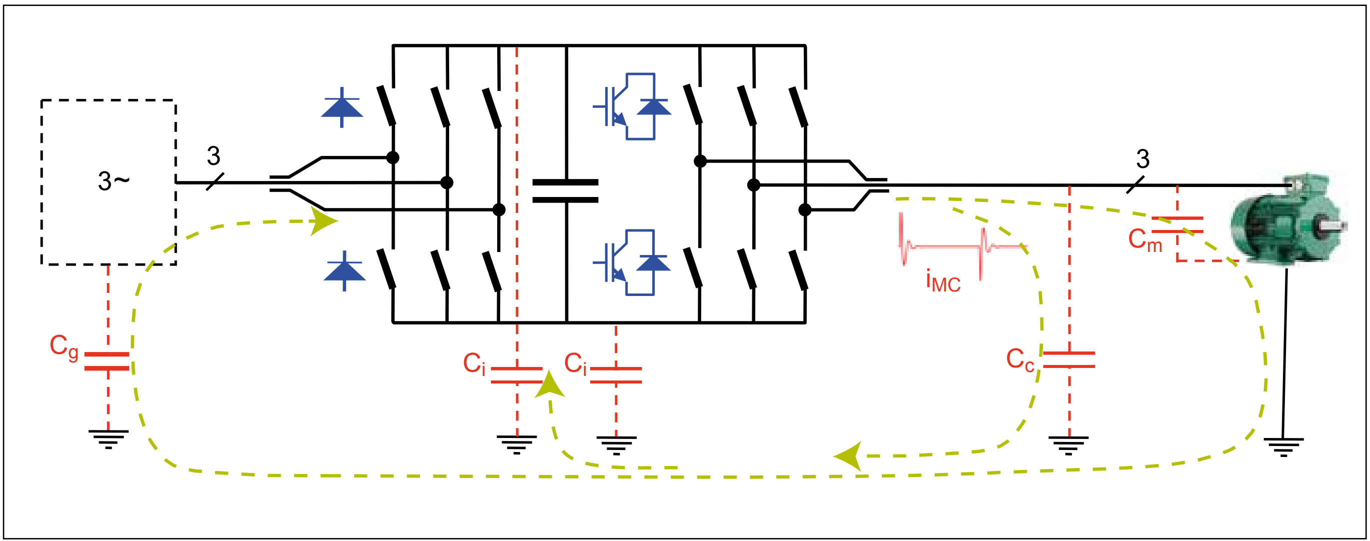
2.2 - Effects of PWM operation

2.2.1 - Common mode currents

Each switching of the inverter bridge quickly alters the potential difference between the output phases U, V, W and the earth. During each of these voltage variations, a **common mode current**, commonly called **HF leakage current**, circulates in the 3 conductors of the motor cable and charges/discharges the **structural capacitance** of components: capacitance between windings and the motor housing, capacitance between conductors and the cable shield, etc.

The high frequency (a few MHz) current will return to the variable speed drive by circulating in the shield of the motor cable, the equipotential bindings, the earthing points of the installation and the power supply line.

Illustration 2 - Common mode currents



C_m : Common mode structural capacitance of the motor
C_c : Common mode capacitance between the cable and its shield or the environment
- - - - : HF leakage current paths
C_i : The structural capacitances between active parts of the inverter and earth
C_g : Structural capacitance between the power supply and the earth.

The common mode currents are the main source of electromagnetic emissions (see "2.3.1 - Electromagnetic emissions", page 6) and may, under certain circumstances, shorten the life of the bearings ("2.3.3 - Bearing current flow", page 7).

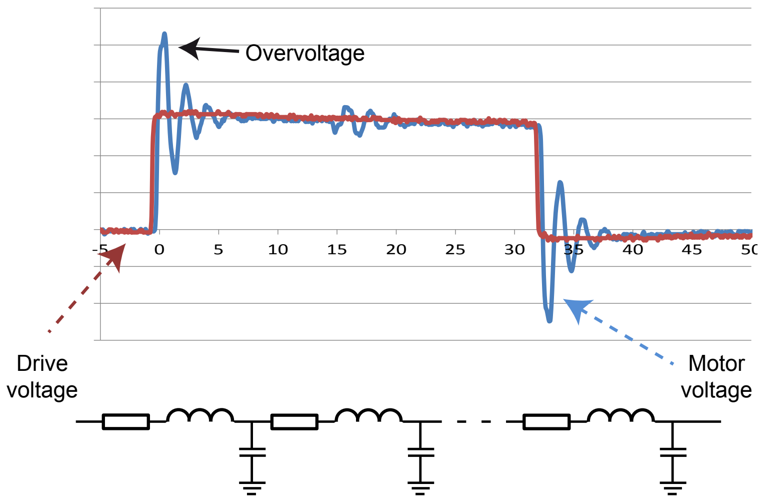
2.2.2 - Reflection of the voltage wavefronts

At low frequencies of 50/60 Hz, the motor cable behaves like a simple resistor. However, beyond a few kHz, the cable must be represented by a more complex equivalent circuit, made up of a combination of inductances, capacitors and resistors.

The high rate of change of the voltage due to PWM inverter operation (> 3000 V/µs) leads to reflected waves and voltage overshoots at the motor phase terminals (Figure 3). The choice of the motor cable will affect the value of the peak voltage. The peak voltage increases linearly with the length of the cable up to a **critical length L_C**. Beyond this length, the peak remains stable or increases slightly to attain a maximum of 2 times the DC bus voltage. For example, for a 6-pulse drive supplied with 400 V, the DC bus voltage is 560 V (√2 x 400 V).

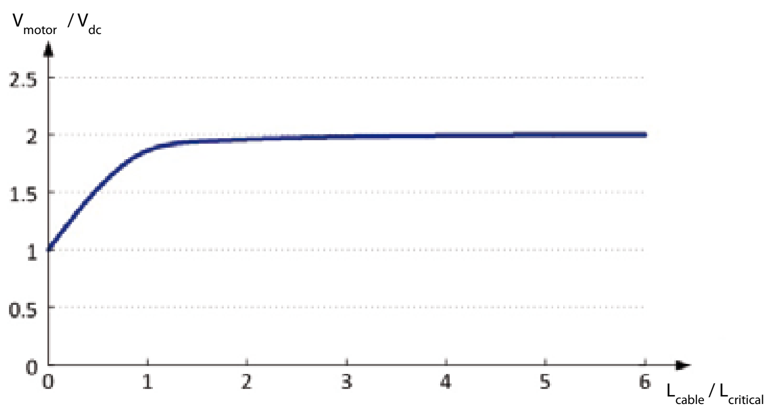
The critical length depends on the value of the rate of change of the voltage imposed by the variable speed drive. The higher the rate of change of voltage, the lower will be the critical length.

Illustration 3 - Voltage wave reflection effects



Simplified model of one of the conductors of the motor cable

Illustration 4 - Peak voltage as a function of the cable length



Order of magnitude of the critical length L_C: about 15m for shielded cables and about 30m for unshielded cables.

2.3 - Consequences for the motor of using PWM

2.3.1 - Electromagnetic emissions

Electromagnetic compatibility is a set of measures and regulations that allows electronic devices to work together, without interfering with each other through electromagnetic interferences. This requires that the emissions of each device are less than the susceptibility level of all others.
Electromagnetic emissions mainly arise from common mode currents. They interfere with the environment in two ways:

- the emission of electromagnetic radiation
- the signal transmission by conduction

Regardless of the mode of transmission, electromagnetic emissions may adversely affect the operation of sensitive components located close to the variable speed drive (sensor or sensitive device, power supply of radio communication network, etc.).
The maximum limits of electromagnetic emissions are governed by standards. If there is no specific standard related to the product in which the drive is installed, then the standard IEC 61800-3 will apply to drives.

The limits of the different standards depend on the environment in which the product is installed (industrial or residential environment), the complexity of the installation and criteria related to the value of current or rated power.

Generally, variable speed drives comply with more or less restrictive emission standards when the installation is conducted according to accepted best practices (see "4 - Wiring rules", page 14).

Filters, which are required to meet lower than general emissions standards are described in the drive documentation.

2.3.2 - Stresses on the winding

In classical use with 50 Hz/60 Hz LV (low-voltage) power supply, there is a very significant safety margin between the electrical stress applied to the motor winding copper wire enamel and the levels which would lead to winding insulation damage.

An inverter supply leads to the transmission of a PWM voltage waveform which gives rise to a non-uniform distribution of electrical voltage along the length of the winding. Depending on the conditions of use, the electric stress in the initial winding turns can be much higher than that in the other turns. If local electric stress between 2 contiguous coils is too large and exceeds the acceptable threshold of the insulation system, electrical micro-discharges will occur inside the insulation of the conductors. These electrical discharges, known as **partial discharges**, do not immediately short-circuit the insulation, but lead to an accelerated reduction in the service life of the winding.

Conditions that influence the occurrence of partial discharges are:

- the nominal voltage value of the electrical mains (400 V, 480 V, 690 V),
- high DC bus voltage of the drive, for example, due to the presence of regenerative braking or the use of drives with an active rectifier,
- the length and the type of motor cable.

The standard IEC 60034-18-41, "Rotating Electrical Machines: Electrical insulation systems without partial discharge (Type I) used in rotating electrical machines powered by voltage converters - Qualification and quality control tests" published in 2014, defines 4 levels (IVIC classes) of resistance to partial discharge: A (Low), B (Moderate), C (Severe), D (Extreme).

The classification into one of the given levels ensures that the motor winding will not be subjected to premature ageing, provide that it is subjected to a voltage level which does not exceed the maximum recommended peak-to-peak voltage ($V_{pk/pk}$).

The standard NEMA MG1 part 31, as such, does not define any specific levels and lets the manufacturer define the insulation system depending on the mains voltage.

For an optimum protection of the motor, several levels of protection of the winding are available: refer to "3.1 - Winding protection", page 9.

2.3.3 - Bearing current flow

Currents in bearings of electrical machines cause a potential difference (voltage) between the housing and the rotor. An inverter supply is one possible cause of this potential difference.

As seen at the "2.2.1 - Common mode currents", page 4, the high-frequency common mode current which flows to the machine through the motor cables must return to the inverter by earth connections or through other paths.

In addition, inside the motor, this current flows in different structural capacitances.

When the motor is earthed according to best practice, the majority of the current passes through the structural capacitance between the winding and the casing and flows back to the inverter through the earth link or the cable shielding (**blue circuit**).

However two mechanisms can lead to HF currents flow through the bearings:

- Some of the common mode current that enters the motor circulates through the capacitive divider consisting of the air gap and bearings (**red circuit**).
- By transformer effect, the main HF common mode current induces a current which flows through the shaft, the bearings and the housing (**purple circuit**). This mechanism is more pronounced on machines having a large frame size.

The currents flowing through the bearings generate a voltage between their outer and inner rings. If this voltage exceeds the breakdown voltage of the oil film, electrical discharges will occur at the ball-oil film-ring interface, leading to premature wear or even destruction of the bearing.

Bearings of the loads coupled to the machine as well as those of encoders mounted on the shaft may also be affected by this current flow (**green circuit**).

The bearing current level is related to the physical size of the machine, ranging from low for powers lower than 10 kW to very high for powers more than 200 kW. It is also related to the low limit of the operating speed range.

Illustration 5 - HF current flow in the motor and load bearings

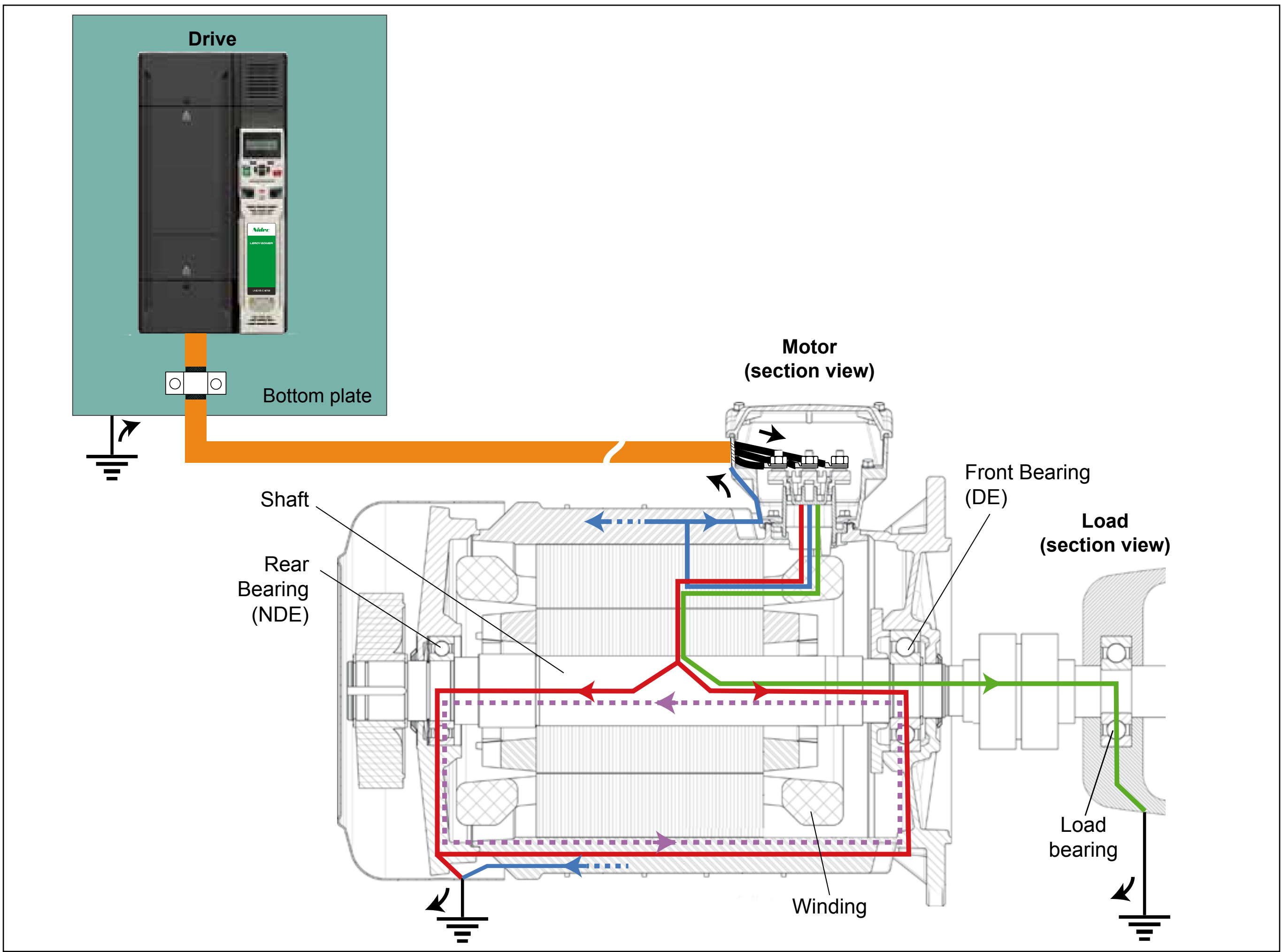


Illustration 6 - Common-mode current bearing damage

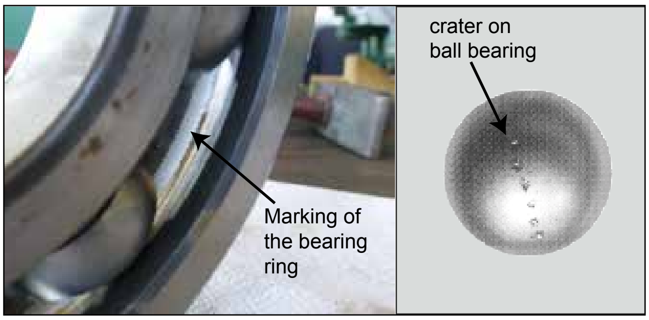


Illustration 7 - Bearing grease blackened following overheating due to multiple discharges

The first factor to limit the risk of capacitive discharge current flow in the bearings is following the wiring rules as described in "4 - Wiring rules", page 14 and, in particular, the quality of earth connections between drive, motor and gearbox. As a result, the current may more easily flow through the blue circuit as described in figure 5.

In some situations, additional measures must be taken: Use of insulated ball bearings (see "3.3.2.1 - Insulated bearings", page 11), earthing of the machine shaft through a shaft grounding ring (see "3.3.2.2 - Grounding ring", page 11).

For more information about different levels of protection of the bearings, proposed by Leroy-Somer, refer to the "3.2 - Bearing protection", page 10.

2.3.4 - Motor heating

An inverter supply leads to increased heating in the motor compared with a mains supply:

- at speeds close or equal to the rated speed, additional heating causes increased resistive heating and iron losses, due to the shape of the PWM voltage waveform. The lower the PWM frequency of the variable speed drive, the higher will be the losses of the motor.
- for self-cooled motors, cooling air flow depends on the rotational speed. Consequently, heating of the motor may increase when the speed decreases.

Although Leroy-Somer pays special attention to its motor design to minimise this effect, it is sometimes necessary to use an optional forced ventilation, providing optimal cooling at very low speeds. Leroy-Somer provides torque derating curves, depending on the rotational speed as well as the minimum PWM frequencies to be used when the motor is fed from an inverter.

Refer to the catalogues and the motor nameplate.

2.3.5 - Acoustic noise

The harmonics generated by the PWM lead to magnetic pressure waves that slightly deform the stator and its housing. These micro-deformations lead to an increased level of acoustirc noise, which can be more or less significant, depending on the type of motor and its design.

When low noise levels are required, the most important measure to reduce the overall level is to increase the PWM frequency of the drive or to add a filter between the drive and the motor.

3 - WINDING AND BEARING PROTECTION FOR LEROY-SOMER MOTORS FED BY VARIABLE SPEED DRIVE

3.1 - Winding protection

In order to meet a wide range of variable speed industrial applications, Leroy-Somer offers several protection strategies, including 2 types of motor insulation:

- **Standard insulation system of the motor winding** with $\hat{U}_{LL}$ < 1500 V_{pk} and $\hat{U}_{LE}$ < 1100 V_{pk}.
- **Reinforced insulation system of the motor winding (RIS)** with $\hat{U}_{LL}$ < 1800 V_{pk} and $\hat{U}_{LE}$ < 1300 V_{pk}.
- **Optional filters: dv/dt filter or differential mode sine filter** to be connected at the output of drive.

NOTE

- $\hat{U}_{LL}$: Peak voltage between phases (V_{pk})
- $\hat{U}_{LE}$: Peak voltage between phase and earth (V_{pk})
- For values of $\hat{U}_{LL}$ or $\hat{U}_{LE}$ higher than those mentioned above, please consult Leroy-Somer.
- The term "standard insulation" includes the standard built-in protections for certain motor ranges, for which no optional protection is necessary.

The choice of protection is based on the specific nature of the installation. For more information on the benefits and disadvantages of the different protections, please refer to the "3.3 - Presentation of various motor protections", page 11.

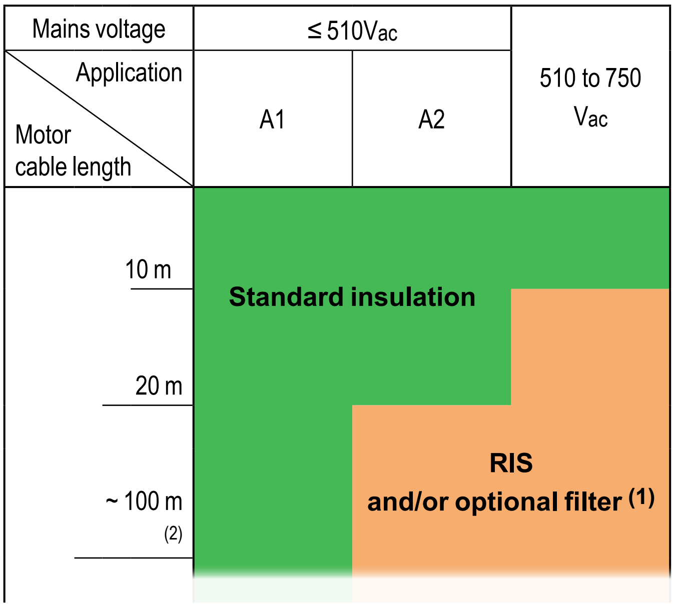
The table below allows to define the level of protection, depending on the application and installation conditions. There are two levels of applications:

• **Application A1**: All applications that do not meet the criteria listed in "Application A2".
For example, centrifugal pumps, fans, extruders and compressors, etc.

• **Application A2**: All applications that meet one of the following criteria:
- the drive has an active rectifier ("Low harmonic", "Regen"),
- the drive has a braking transistor whose cumulative braking time is greater than 5% of the total operating time.

For example, materials handling, cranes, power generation, etc.

• Induction motor ranges (LSES, FLSES, PLSES, LC, CPLS, etc.), permanent magnet motors (LSRPM, PLSRPM, LSHRM, FLSHRM, PLSHRM) including ATEX and high temperature motors



(1) Reinforced insulation system (RIS), dv/dt filter option or optional differential mode sine filter.

(2) Beyond 100 m, limitations not related to protection of the winding must be taken into account. These limitations depend mainly on the power of the motor-drive. Please refer to paragraph "3.3.3 - External protections", page 11 for more details.

Conditions of validity of the table:

- maximum dV/dt < 4000 V/µs at the terminals of the drive
- Minimum time between 2 PWM pulses of the drive: 5 µs

The variable speed drives of the range POWERDRIVE or UNIDRIVE meet the above limitations. The selection of a Leroy-Somer motor-drive system in conformity of the recommendations of insulation and the rules of good installation practices (cf. "4 - Wiring rules", page 14) ensure having a reliable solution that guarantees the duration of service life of the winding.

NOTE

• The combination of dV/dt filters and differential mode sine filters with permanent magnet motors is not always possible. Please refer to the "3.3.3.2 - dV/dt Filter", page 12 and "3.3.3.3 - Differential mode sine filter", page 12.

• Please consult "3.3.3.3 - Differential mode sine filter", page 12 for large motor cable lengths (> 150 m) and "4.3.3 - Special precautions for low power variable speed drive", page 17 for precautions concerning low-power drives (< 5.5 kW).

3.2 - Bearing protection

Leroy-Somer provides several levels of protection of its motor bearings:

- **Standard mechanism of rotation**
- **Reinforced protection systems of the mechanism of rotation** to prevent common mode currents: **insulated bearings** and/or **current diverter ring**
- Optional **common mode sine filter** to connect at drive output.

NOTE
The term "standard mechanism of rotation" includes the standard built-in protections for certain motor ranges, for which no optional protection is necessary.

For more information on the benefits and disadvantages of different protections, please refer to the "3.3 - Presentation of various motor protections", page 11.

The table below allows to define the level of protection, depending on the application and installation conditions. There are two levels of applications:

• **Application B1**: All applications that do not meet the criteria listed in "Application B2".
For example, the centrifugal pumps, the fans, the compressors, etc.

• **Application B2**: All applications that meet one or more of the following criteria:
- the drive has an active rectifier ("Low harmonic", "Regen"),
- the drive has a braking transistor whose cumulative braking time is greater than 5% of the total operating time,
- the low rotational speed stop is less than 500 min^{-1} (example: extruders).

For example, materials handling, cranes, extrusion, power generation, etc.

• Induction motor ranges (LSES, FLSES, PLSES, LC, CPLS, etc.), permanent magnet motors (LSRPM, PLSRPM, LSHRM, FLSHRM, PLSHRM) including ATEX and high temperature motors

Application	B1		B2
Frame size \ Mains voltage	≤ 510 Vac	510 to 750 Vac	
≤ 160	Standard mechanism of rotation	Standard mechanism of rotation	Standard mechanism of rotation
180 ≤ SL ≤ 250	Standard mechanism of rotation	Reinforced protection of the mechanism of rotation or optional filter (1)	Reinforced protection of the mechanism of rotation or optional filter (1)
≥ 280	Reinforced protection of the mechanism of rotation or optional filter (1)	Reinforced protection of the mechanism of rotation or optional filter (1)	Reinforced protection of the mechanism of rotation or optional filter (1)

(1) Reinforced protection by use of insulated bearings, current grounding rings or optional common mode sine filter.

NOTE
• For an operation of the motor beyond 3600 RPM, consult Leroy-Somer.
• The reinforced protection solution includes the use of an insulated speed or position sensor (incremental or absolute encoders, resolvers, etc.) when it is equipped with bearings in contact with the motor shaft. For more information, refer to the speed sensor technical guide and position ref. 5664.
• For large motor cable lengths, use of a common mode sine filter is a significant economical alternative to the reinforced protection of the mechanism of rotation, please see "3.3.3.4 - Common mode sine filter", page 13.

3.3 - Presentation of various motor protections

3.3.1 - Winding protection: Reinforced insulation system

A reinforced over-insulation system of the motor is an insulation system that allows to increase the inception threshold of partial discharges.

3.3.2 - Bearing protections

3.3.2.1 - Insulated bearings

An insulated bearing is developed with an insulating coating or non-conducting ceramic balls.
It limits or even eliminates the passage of current flow through the bearing.
In the case where a single insulated bearing is used, it must be installed at the non drive end of the motor and must be combined with a current grounding ring, in order to efficiently cut off the current circulation.

3.3.2.2 - Grounding ring

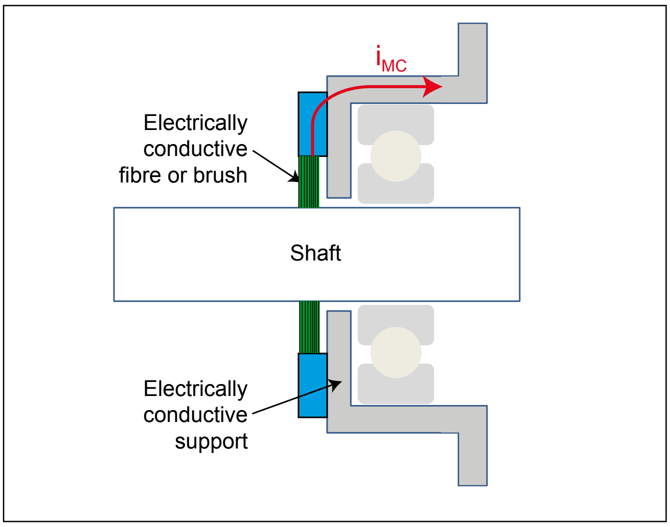
A grounding ring is composed of one (or two) brush and brush holder sets mounted on the front flange, and a collector ring fixed on the shaft. This system prevents shaft currents from flowing through the bearings (causing a premature wear).

The grounding ring must ensure a good high frequency connection with the rotating shaft. Therefore, it is important to regularly ensure that the contact surface of the brush is clean in order to maintain a low contact impedance.

A grounding ring does not replace a good high frequency earthing between the motor and the variable speed drive as well as between the motor and its load. Indeed, if the earthing is of poor quality, common mode currents can flow through the frame, the grounding brush, the transmission shaft, the coupling and the load. This situation could therefore be risky by shifting the problem from the motor bearings to those of the load.

Illustration 8 - Grounding rings

Illustration 9 - Current flow with diverter ring



The common mode currents are diverted from the bearing, and pass from the current grounding brush to the casing.

3.3.3 - External protections

3.3.3.1 - dV/dt chokes

The dV/dt chokes are generally coils with magnetic cores, low inductance values (a few tens or hundreds of µH) and connected to the output of the drive. They reduce the current peaks linked to the charge/ discharge of the cable capacitances (see "4.3.3 - Special precautions for low power variable speed drive", page 17). Under some conditions, they also limit the over-voltages at the motor terminals.

Main advantages:

- Decrease in potential "overcurrent" trips of low power drives (<4kW) by limiting the current peaks at the output of the drive.
- Slight decrease in the magnetic sound pressure noise level of the rotating machine. Generally, the gain is 1 to 3 dB(A), depending on the power and polarity of the motor.

Disadvantage:

- Additional voltage drop of 2% at the drive outlet to be taken into account when sizing.

Illustration 10 - dV/dt choke

3.3.3.2 - dV/dt Filter

The dV/dt filters consist of a dV/dt choke combined with an RC damping circuit (comprising resistors and capacitors) and connected to the outlet of the variable speed drive. This combination makes it possible to limit the voltage fronts of the MLI to values < 500 V/µs, and consequently the overvoltages at the motor terminals. They allow standard motors to be used without special winding protection with long cable lengths.

NOTE

In excess of 200 m, prefer a sine filter to the dV/dt filter. The use of dV/dt filters is limited by the length of the motor cable and the switching frequency of the drive. Refer to instructions of the relevant filters.

Main advantages:

- Increase in the service life of motor by protection of the winding.
- Reduction of electromagnetic interferences with the environment.
- Reduction of charge/discharge currents of the cable capacitances.
- Slight decrease in the magnetic sound pressure noise level of the rotating machine. Generally, the gain is 1 to 3 dB(A) depending on the power and polarity of the machine.

Disadvantages:

- Additional voltage drop of 2% at the drive outlet to be taken into account when sizing.
- Cannot use dV/dt filters at the output of a drive controlling a permanent magnet motor in "Sensorless" mode (or only under certain conditions, consult Leroy-Somer)
- Must not be used at a switching frequency higher than the one for which it was designed.

Illustration 11 - dV/dt filter

3.3.3.3 - Differential mode sine filter

The sine filter, connected at the output of the variable speed drive, is a low-pass filter that converts the drive PWM voltage into a quasi-sinusoidal voltage between phases. It completely eliminates the risk of voltage peaks at the winding terminals.

This solution is particularly recommended for installations with a long cable length between drive and motor and for installation retrofits where the motor is not suitable for variable speed.

The sine filter has little effect on voltage variations between conductors of the motor cable and the earth, and therefore has little impact on common-mode currents.

Main advantages:

- Elimination of overvoltage peaks at the motor terminals.
- Increase in the service life of motor by protection of the winding.
- Reduced risk of capacitive discharge in the bearings.
- Reduction of electromagnetic interferences with the environment.
- Significant reduction of acoustic noise level related to PWM.

Disadvantages:

- Additional voltage drop of less than 2% at the drive outlet to be taken into account when sizing.
- The sine filter is not compatible with the operation of the drives in current control mode (permanent magnet motor in current control).

NOTE

The use of sine filters is limited by the length of the motor cable and the switching frequency of the drive. Refer to instructions of the relevant filters.

Illustration 12 - Differential mode sine filter

3.3.3.4 - Common mode sine filter

The differential mode sine filter, connected at the output of the variable speed drive, is used to eliminate the PWM modulation residues and get a quasi-sinusoidal voltage between the phases of the motor. However the PWM voltage fronts are always present between phases and earth.

The common mode sine filters are complete filters that also filter voltage fronts between the phases of the motor and the earth and are used to offer a solution that does not require local protection of the motor or load bearings. They are particularly suitable when the length of the motor cable is significant (from about 100 m for motors <10 kW and 250 m for motors > 200 kW).

Main advantages:

- Filtering the voltages between phases and the phase/earth voltages of the motor allow the use of unshielded motor cables.
- Very high limitation of leakage currents of the motor with respect to earth and elimination of the risk of capacitive discharge in the bearings.
- Reduction of electromagnetic emissions.
- Complete reduction of noise related to PWM. The machine has the same one-third octave LwA noise spectrum as when it was powered by a sine wave.

Disadvantages:

- For some filters, it is necessary to have access to the drive's DC bus.
- The sine filter is not compatible with the operation of the drives in current control mode (permanent magnet motor PM in current control).
- Its cost must be taken into consideration. However, this solution does not result in additional costs related to the purchase of shielded cables.

NOTE

The use of sine filters is limited by the length of the motor cable and the switching frequency of the drive. Refer to instructions of the relevant filters.

3.3.3.5 - Common mode ferrite ring

The ferrite rings are high permeability rings that surround the 3 conductors of the motor cable. They are located at the output of the drive and the equipotential conductor (PE, Earth Protection) must not cross over them. The ferrite rings damp the high frequency currents related to PWM and reduce their amplitudes. It may be interesting to use them only if the motor cables are unshielded (installation retrofit or very short distance between drive and motor), if all the earthing rules have been correctly applied and there exists no risk of electromagnetic interference.

For low power systems (< a few kW), the common mode chokes can replace the ferrite rings.

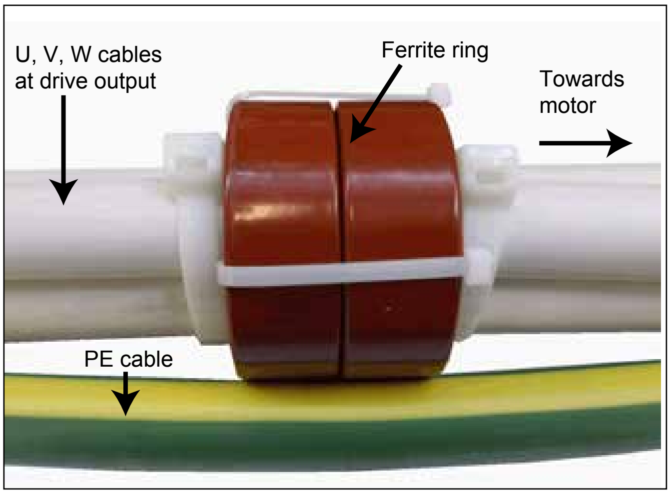
Main advantages:

- Limitation of the electromagnetic radiation of the motor cables.
- Limitation of the level of conducted emissions in some configurations.

Disadvantages:

- No or little effect on the voltage peaks at the motor terminals.
- The number of ferrite rings must be defined according to the installation.

Illustration 13 - Arrangement of the common mode ferrite ring



4 - WIRING RULES

4.1 - General

It is the responsibility of the user and/or the installer to connect the motor drive system in accordance with the current legislation and applicable standards in the country of use. This is particularly true for the cable size and the ground connection. Under no circumstances shall the following information be used as a substitute for the current standards, nor does it relieve the installation company of its responsibility.

4.2 - Equipotential earth bonding

4.2.1 - Grounding and earthing

The first objective of earthing of the components and equipment of an industrial installation is to ensure the protection of persons and to limit the risks of damage in the event of a major fault in the power supply or of a lightening strike. The second objective of earthing is to create voltage common voltage low impedance voltage equipotential reference:

- the risks of interference between equipment in installations incorporating sensitive and interconnected electronic and electrical systems,
- the risk of material failure in case of fault currents,
- the risk of current flow through bearings of electrical machines powered by a frequency inverter,
- the level of electromagnetic emissions whether conducted or radiated.

It is essential that the earth network is designed and implemented by the installation supervisor so that its impedance is as low as possible, in order to distribute the fault currents and high-frequency currents so that they do not pass through the electrical equipment. The basic philosophy of any earthing installation is to maximise the mesh of earthing connections between the metal parts (machine frame, building structure, pipes, etc.) and to connect this mesh to earth at multiple points. Metal grounds must especially be mechanically connected to each other with the largest possible electrical contact area or with grounding braids. The motor housing must be connected to the equipment frame by high frequency flat braids (their width/length ratio must at least be 1/10). Paint must be removed from any contact area with the flat braid.

Earth connections, designed to protect people by linking metal grounds to earth via a cable, should not under any circumstances be used as a substitute for ground connections (see IEC 61000-5-2).

In particular, the motor earth terminal (PE Earth Protection) must be connected directly to the drive earth terminal. One or more separate PE (Earth Protection) protective conductors are mandatory if the conductivity of the cable shield is less than 50% of the conductivity of the phase conductor.

4.2.2 - Equipotential bonding in variable speed drive cabinets

To ensure good equipotential reference in drive cabinets, it is strongly recommended to place the components (drives, EMC filters, input/output unit, etc.) on an unpainted conductive drive cabinet bottom plate that will be connected to the frame of the drive cabinet through the largest contact area possible. The side and rear panels will be connected to the PE bar or plates by large width grounding braids. Paint of the panels should be removed in the braid connection areas.

If several drive cabinet frames are combined side by side, the frames of the various drive cabinets must be screwed together at several regularly distributed points to provide a conductive connection (use of contact washers) and the bottom plates must also be connected to each other by several braids.

4.3 - Motor cables

Shielding of the power conductors is a preferred method that enables the common mode currents to return to their point of origin without dispersing into other possible paths (equipotential conductors, piping, building structure, etc.). It significantly reduces the levels of electromagnetic emissions, both conducted and radiated. For this reason, it is mandatory to use shielded cables between drive and motor to ensure compliance with the EMC emission standards (IEC 61800-3, etc.). Shielded cables are also used to limit shaft voltage and risks of damage to the bearings.

4.3.1 - Type of cables

4.3.1.1 - Shielded cables

Shielded cables must be symmetrical multicore cables with low leakage capacity. Cables with a single equipotential conductor can be used up to sections of approximately 10 mm^2. For higher sections, only use cables with 3 equipotential conductors.

The shield must be connected at both ends: drive side and motor side at 360°. The unshielded part of the cable must be as short as possible, and use metal cable glands (clamping on the cable shield) on the motor side; refer to the installation instructions for connection of the shield on the drive side.

Illustration 14 - Shielded motor cables

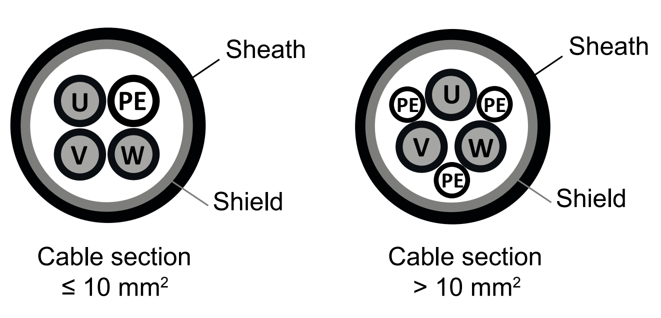
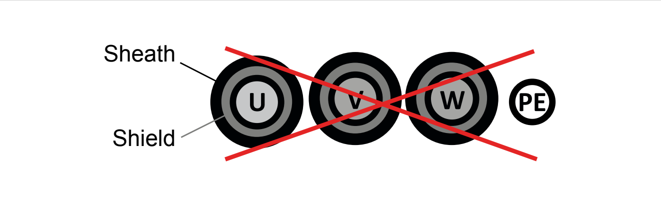


Illustration 15 - Configuration of shielded cables not to be used



The reinforced or shielded single-conductor cables should not be used.

For applications that so require, the shielded cables can be replaced by cables with external PE protection concentric conductor.

4.3.1.2 - Unshielded cables

In second industrial environment (according to the EN 61800-3 standards, an environment including all establishments other than those directly connected to a low voltage power supply network that powers buildings used for residential purposes), when the power supply cable of the motor is short (<10 m), the shielded cable can be replaced by a cable with 3 phase conductors combined in cloverleaf pattern + 1 earth conductor. All conductors must be placed in a metal conduit 360° closed (metal chute for example). This metal conduit must be mechanically connected to the electrical cabinet and the structure supporting the motor.

If the conduit consists of several pieces, these should be interconnected by braids to ensure earth continuity. The cables must be positioned and maintained in a clover duct.

Illustration 16 - Unshielded cables in a conduit.

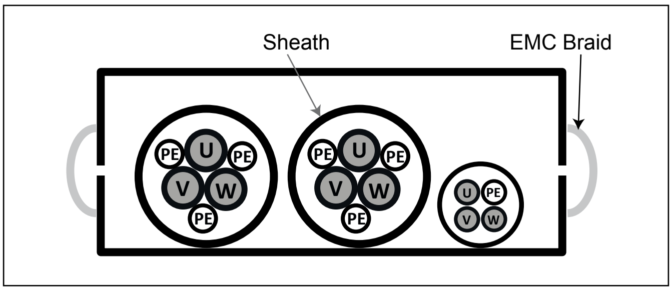


Illustration 17 - Unshielded cables in a conduit with several pieces.

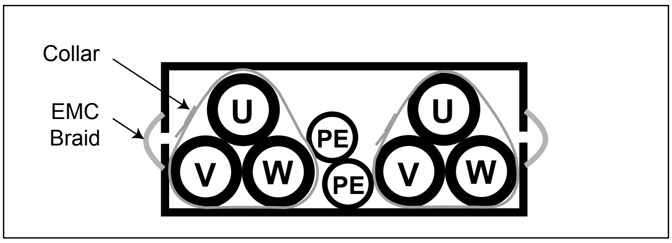
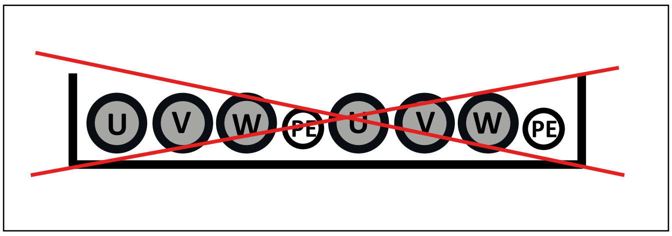


Illustration 18 - Configuration of unshielded cables not to use.



4.3.2 - Connection type of a motor-drive

An equipotential bonding between the chassis, the motor, the variable speed drive, the transformer and the earth carried out in accordance with best practices will significantly help reduce the voltage between the shaft and the motor engine, will reduce the passage of high frequency current via the shaft and, consequently, will prevent the risk of premature failure of the bearings and the encoders.

It is compulsory to connect the motor to earth , and earthing must be performed in accordance with applicable standards (protection of workers).

NOTE

The HF flat braid which connects the motor casing to the machine frame must have a minimum width/length ratio of 1/10. Paint must be removed from any contact area with the flat braid.

Illustration 19 - Use of a metallic cable gland with anchor for the motor cable.

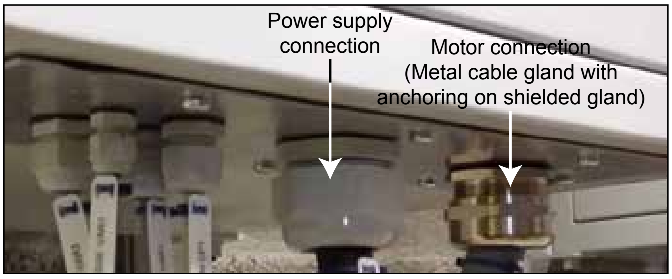


Illustration 20 - Connection type of a motor drive.

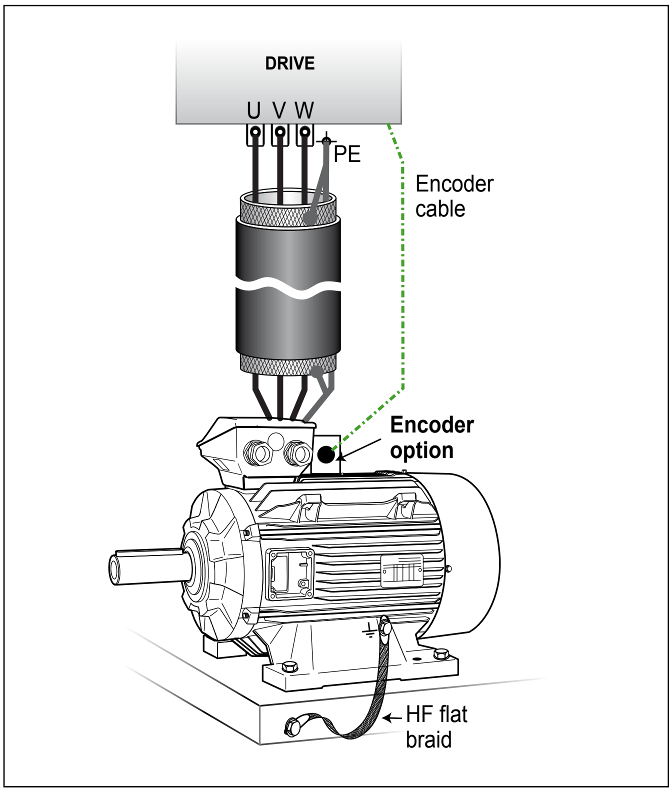
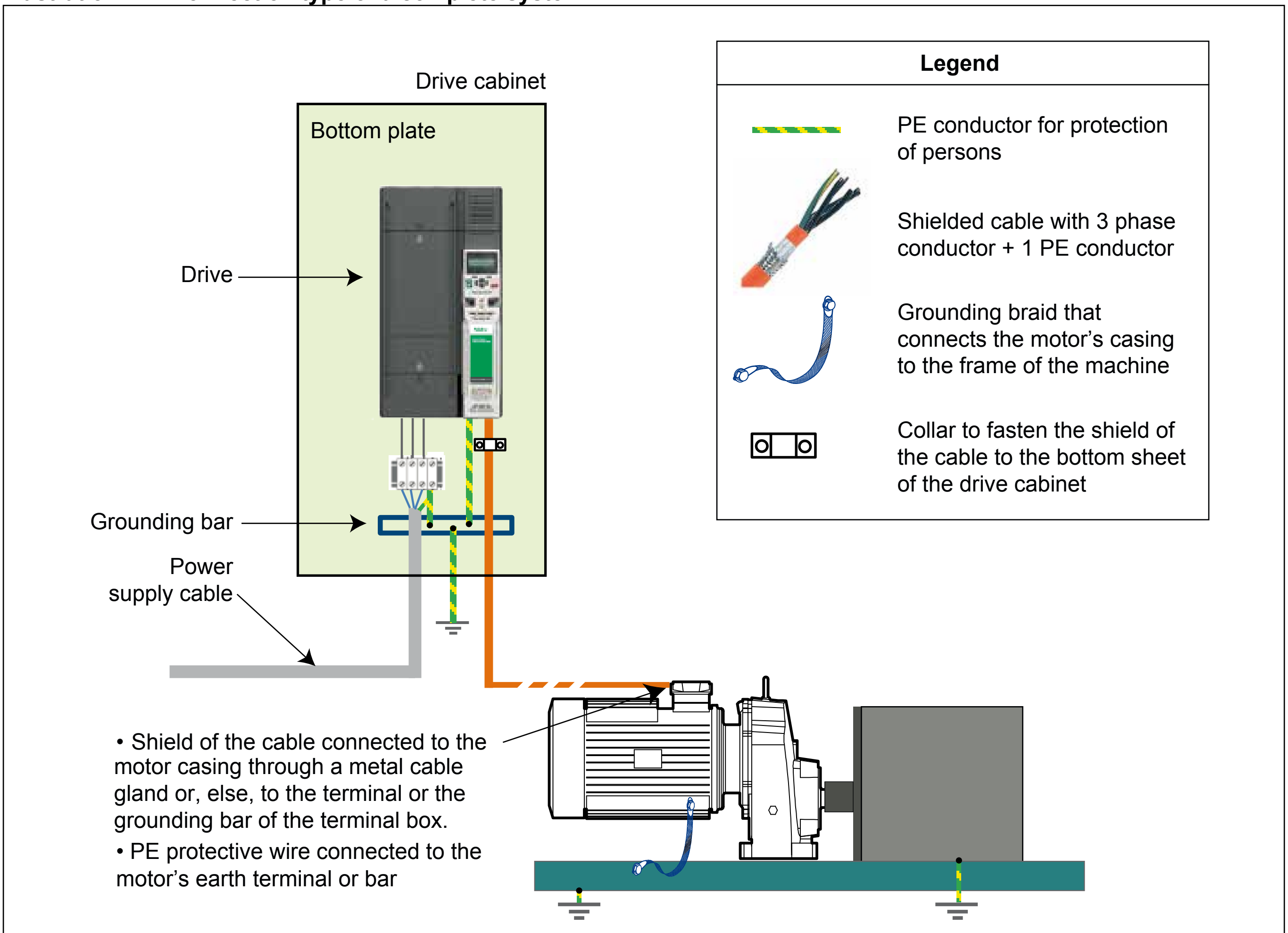


Illustration 21 - Connection type of a complete system.



4.3.3 - Special precautions for low power variable speed drive

At each voltage pulse switching of the drive, the capacitance of the motor cable must be charged and then discharged, which induces a succession of high frequency current peaks that must be supplied / absorbed by the drive. The amplitude of these current peaks is based on the length of the cable. The longer the cables, higher are the peaks.

For variable speed drives whose power is higher than a few kW, these peaks of capacitive currents are low in comparison to the motor current and have no effect on the functioning of the drive.

For low power variable speed drives used with long cables, these current peaks are significant and can affect the functioning of the drive and even lead to an over current trip.

These high-frequency currents can also induce excessive heating of the internal EMC capacitors of the drive.
To prevent the risk, it is recommended to insert a choke or a dv/dt filter between the drive and the motor as soon as the cable length exceeds 20 m for drive sizes less than 2 kW.

For more information, refer to "3.3.3.1 - dV/dt chokes", page 11 and "3.3.3.2 - dV/dt Filter", page 12.

4.3.4 - Cable sizing

The variable speed drive and the power supply cables must be sized according to the applicable standards, and according to the operating current, stated in the drive documentation. The different factors to be taken into account are:

- The installation method: in a duct, a cable tray, suspended, etc.
- The type of conductor: copper or aluminium

Once the cable cross-section has been determined, the voltage drop at the motor terminals must be checked. A high voltage drop causes a current increase and additional loss in the motor (heating).

The sections of conductors given below or in specific Leroy-Somer product manuals do not replace in any case the applicable standards in each country (NF C15- 100 in France).

Example of admissible intensities for multi-conductor shielded copper cables

Conditions:

- Maximum length: 50 m
- Maximum fundamental frequency: 100 Hz
- Installation in a single layer on perforated cable trays, ladders, corbels
- Ambient temperature: 40 °C

Number of cables x section conductors	Admissible intensity of cable (A)	
mm^2	70°C (1)	90°C (1)
1 x (3x35+PE)	108	142
1 x (3x50+PE)	132	174
1 x (3x70+PE)	170	222
1 x (3x95+PE)	206	270
1 x (3x120+PE)	240	314
1 x (3x150+PE)	276	358
1 x (3x185+PE)	316	408
1 x (3x240+PE)	374	488
2 x (3x50+PE)	230	305
2 x (3x70+PE)	300	390
2 x (3x95+PE)	360	475

Number of cables x section conductors	Admissible intensity of cable (A)	
mm^2	70°C (1)	90°C (1)
2 x (3x120+PE)	420	550
2 x (3x150+PE)	485	630
2 x (3x185+PE)	555	720
2 x (3x240+PE)	655	860
4 x (3x50+PE)	415	545
4 x (3x70+PE)	530	695
4 x (3x95+PE)	645	845
4 x (3x120+PE)	745	980
4 x (3x150+PE)	865	1120
4 x (3x185+PE)	985	1275
4 x (3x240+PE)	1165	1525

(1) Maximum permissible cable temperature (for 70 °C max., type Ölflex SERVO 2YSLCY-JB and for 90 °C max., type TOXFREE ROZ1-K or RHEYFLEX® Power EMC 2XSLSTCYK-Y).

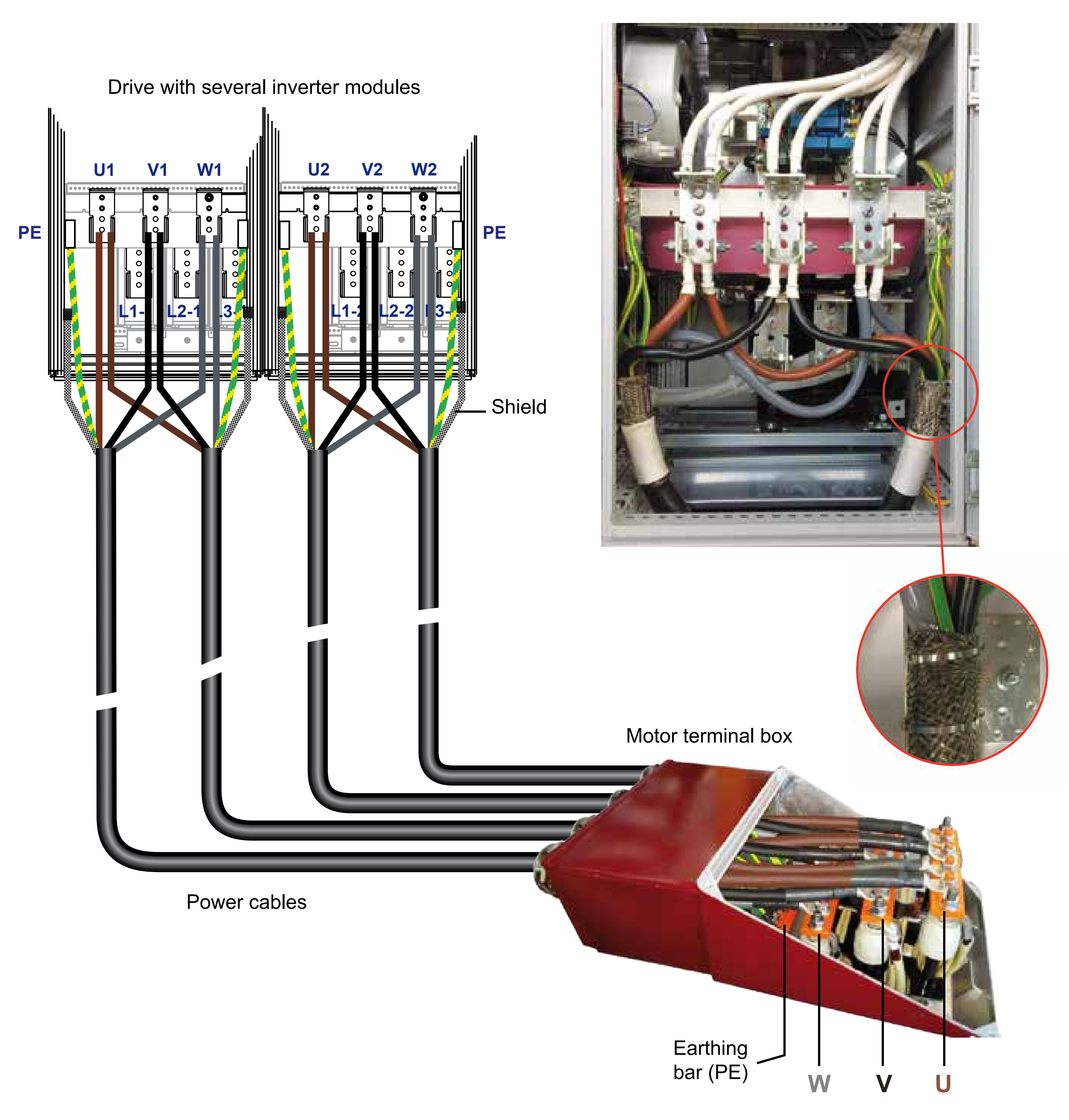
Example: 2 x (3x95 + PE) corresponds to two cables each comprising 3 phase conductors of 95 mm^2 section and 3 earth conductors (PE).

4.4 - Specific wiring

4.4.1 - Parallel wiring of several inverter modules to a single motor

In the situation where several inverter modules are used in parallel to feed a single high power motor, if no balancing chokes are added to balance the currents, the parallelization must be done in the terminal box of the motor. It is essential that the cables of each of the U/V/W phases of the motor are distributed symmetrically over the U/V/W connection bars of the inverter modules.

Illustration 22 - Several inverter modules – a motor



4.4.2 - Parallel wiring of several motors to a single variable speed drive

When a single variable speed drive is used to feed several motors:

- The charge/discharge current peak seen by the drive is amplified because the value of the cumulative capacitance of all cables is significant,

- There is a risk of over voltages at the motor terminals which exceed the usual factor of 2 due to the multiple reflections of the voltage fronts.

If the motors are star wired from the drive, an additional choke or dV/dt filter(s) must be inserted closest to the drive to attenuate the load current peaks of the cable capacity.
If the motors are wired in a chain, the addition of a choke or a dv/dt filter is not essential but is strongly recommended when the cable lengths are significantly long.
Each motor must be protected individually by a thermal relay.

NOTE

Only an open-loop voltage control mode can be used when multiple motors are connected in parallel on the same drive. The autocalibration procedures are not operational in this configuration.

Illustration 23 - Star wiring of motors

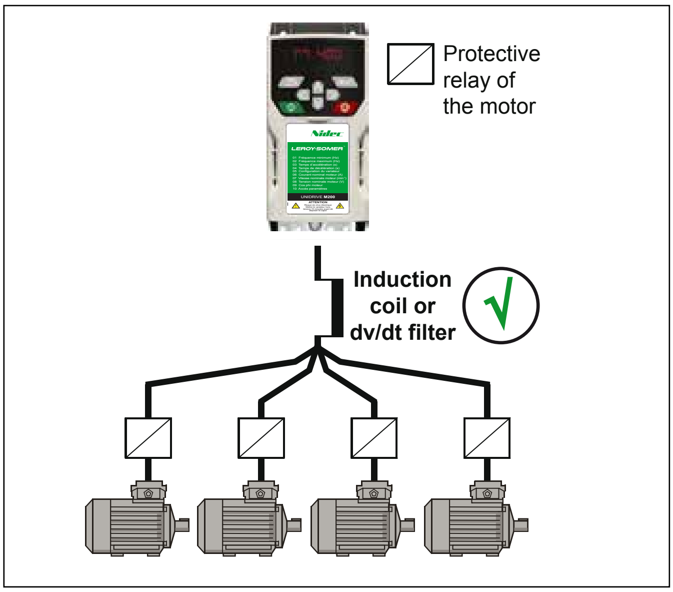


Illustration 24 - Chain wiring of motors

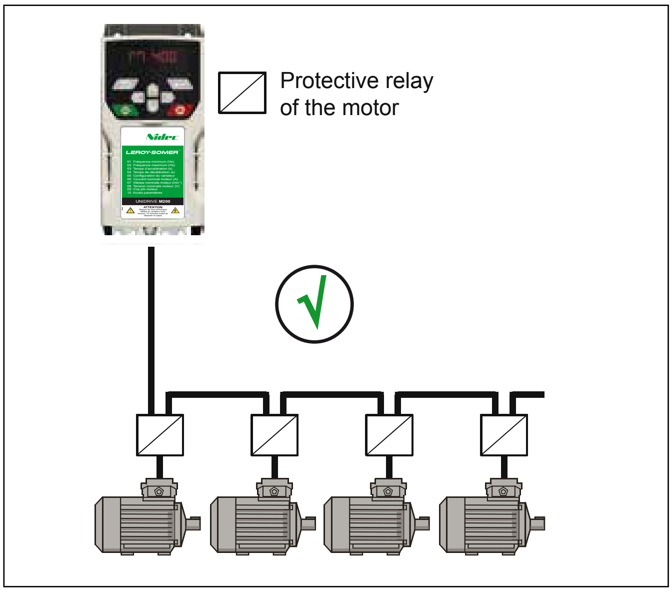
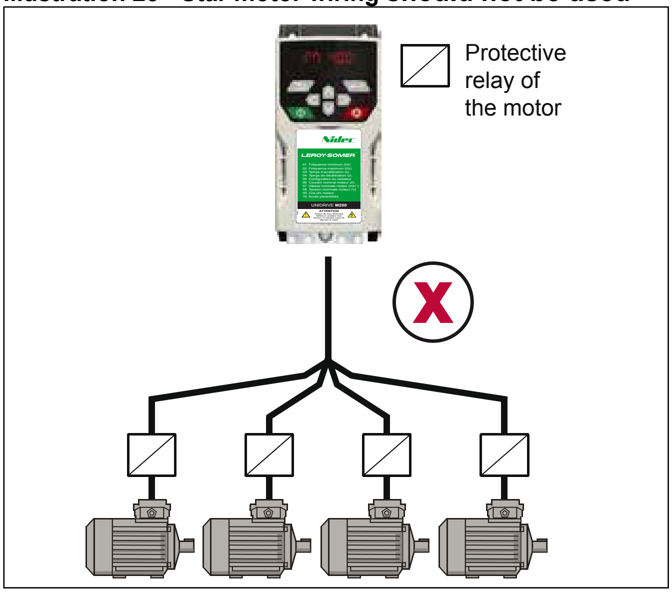


Illustration 25 - Star motor wiring should not be used



4.5 - Power supply cables

In general, there is no need to shield the variable speed drive power supply cables. In a few specific cases, a shield is required between the EMC filter and the drive. Please refer to the product manuals.

4.6 - Control signals

4.6.1 - General information on wiring

If shielded cables are used, connect the shields to the shielding support of the drive using the grounding brakets provided for this purpose.

Keep cables as far away as possible from the control cables for power cables, in order to avoid any coupling by mutual inductance.

The coils of the contactors and solenoid valves, as well as the relay contacts of the brake actuator, must have protection circuits (RC, varistors) in order to reduce disturbances during switching.

Signal cables connecting components outside the equipotential binding area shall be provided with galvanically isolated coupling blocks.

Illustration 26 - Connection of a shielded control cable on the drive end

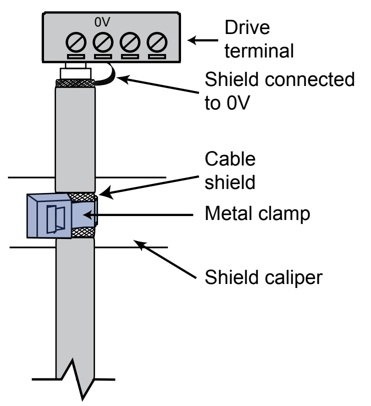
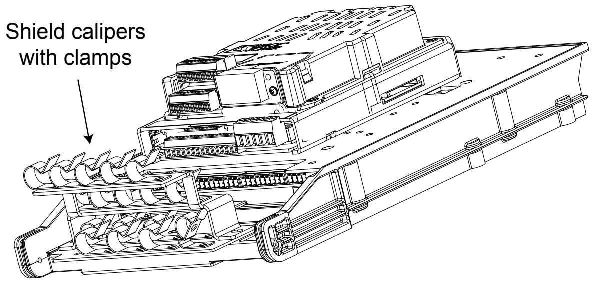


Illustration 27 - Illustration of a grounding bracket used to clamp drive control cables

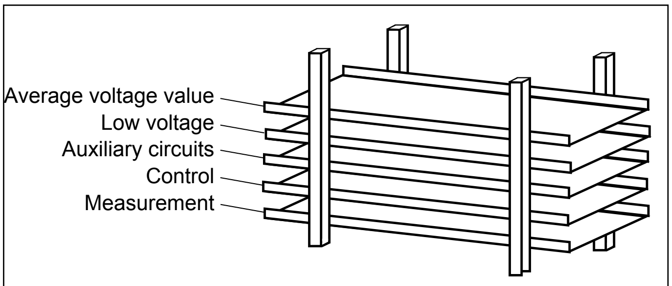


Separate the cables depending on their level of susceptibility and place them in separate cable trays.

Maintain a distance of at least 20 cm between the cable trays and the ducts as shown in Illustration 28.

Place the most sensitive cables in the corners of the metal supports.

Illustration 28 - Layout of a cable tray



4.6.2 - Connection of analog and digital signals

4.6.2.1 - Analog inputs/outputs and motor probe

Systematically shield the analog signals so that they can be used inside or outside the drive cabinet.

- **Differential inputs/outputs**

• They must be connected with twisted pairs to reduce the inductive coupling. In general, the outer shield must be earthed at both ends to reduce HF coupling either directly or through dedicated capacities.

• When the signal cables are doubly shielded (shielded twisted pair + overall shield), the pair shielding must be connected only to the drive end to cut the circulating currents and the outer shield must be connected at both ends.

- **Non-differential inputs/outputs**

• They must be shielded with a 0V shield.

• Always wire the 2 conductors (back and forth) from the same signal end to end.

• Do not use a common return to multiple analog signals.

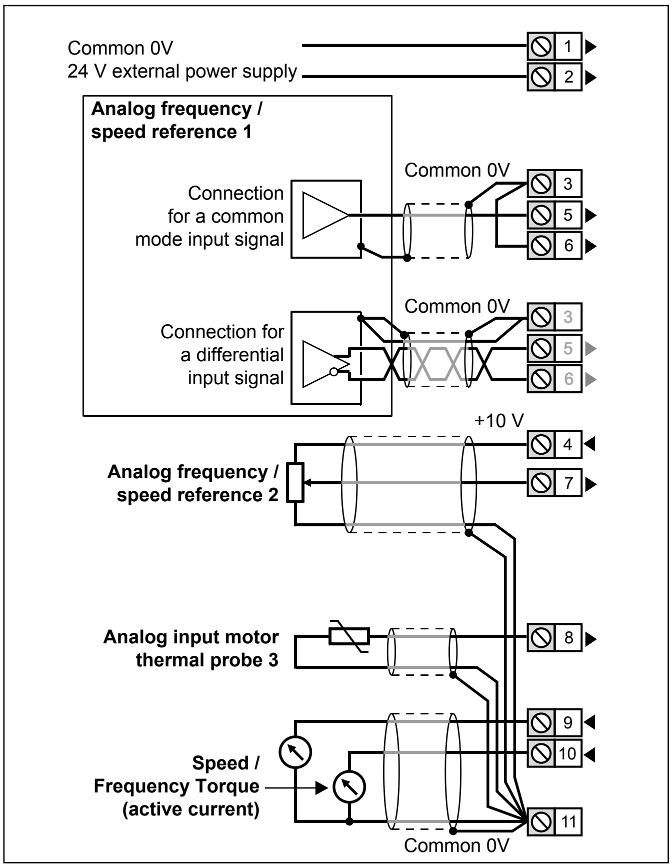
If possible, do not connect the 0 V common analog signals to the same terminal as the 0 V digital signals to improve measurement accuracy.

The use of the 10 V supply source of the drive terminal blocks to control an analog input must be limited to a perimeter close to the drive (a few meters).

The signal cables built into the motor cable (i.e. motor thermal sensor, motor brake) receive large impulse currents based on the cable capacity.

They must therefore have their own shield which must be connected on the motor end only.

Illustration 29 - Example of connection of analog signals



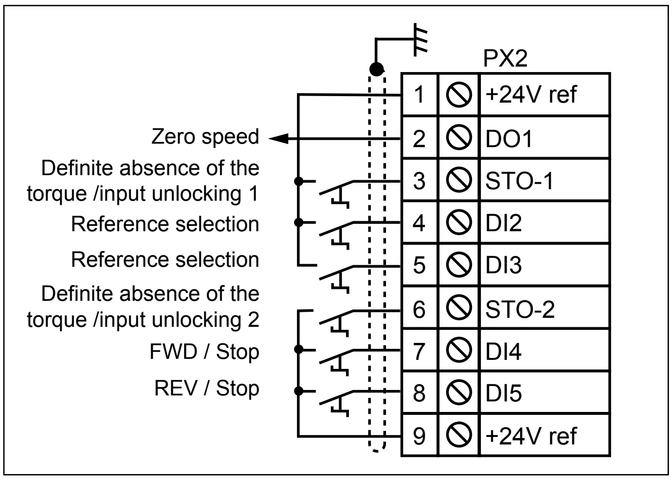
4.6.2.2 - Digital inputs/outputs

Both go and return conductors must be wired side by side.

Shield the cables when they are distributed outside the drive cabinet.

The use of the 24 V supply source of the drive terminal blocks to control a digital input/output must be limited to a perimeter close to the drive (a few meters). If the STO (Safe Torque Off) inputs or one of the digital inputs/outputs is to be used in a remote environment, it is necessary to relay them via a dry contact.

Illustration 30 - Example of connection of digital signals



4.6.3 - Speed feedback wiring

For more information, refer to the speed sensor technical guide and position ref. 5664.

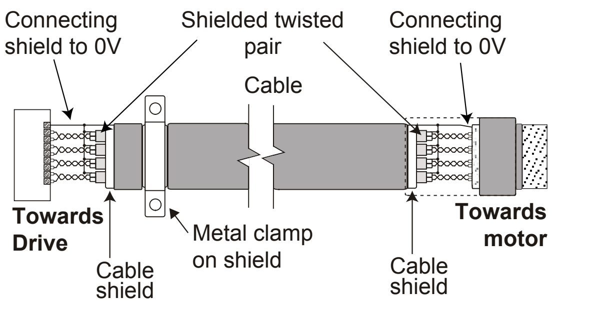
4.6.3.1 - General

The cable must not be interrupted in order to benefit from the protective shield. If the interruptions are unavoidable, the length of the unprotected signal cables by the shielding should be as short as possible and the continuity of the shielding should be ensured by connecting with clamps the 2 ends of the shield on the same metal surface.

4.6.3.2 - Encoder wiring

Use a cable with multiple twisted pairs with outer shielding. Connect the 360° shield at both ends: clamp the shield on the drive end and metallic cable gland on the encoder side. Each pair must connect a signal and its complement.
This cable must be laid at least 30 cm away from any power cables

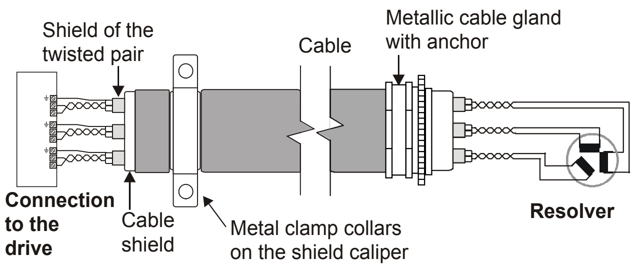
Illustration 31 - Cable encoder connection



4.6.3.3 - Wiring of a resolver

Use a cable with an outer shield that incorporates at least three pairs of twisted and shielded wires (differential signals "excit ", "sin", "cos").
Connect the 360° shield at both ends: clamp the shield on the drive end and metallic cable gland on the encoder side of the resolver box.
The shields of the twisted pairs must be connected to 0 V on the drive end as shown in the diagram. Do not connect them at the resolver end.

Illustration 32 - Resolver cable connection



4.6.4 - Field bus wiring

See associated manuals.

5 - GLOSSARY

Electromagnetic compatibility: A set of measures and regulations that allow electronic devices to coexist satisfactorily without interfering with each other.

Common mode current: Current flowing in the same direction on 2 or more conductors and which loops back by earth connections or via earth.

Differential mode current: Current that loops back on 2 or more of the conductors. In the case of a single two-wire circuit, the differential mode current flows in one direction in the "go" conductor and in the opposite direction in the "return" conductor. In the case of a 3-phase three-wire system, the sum of the currents flowing in each wire will be zero.

Partial Discharge (PD) Electrical discharge that partially bridges the insulation between conductors.
It can occur inside the insulation or be adjacent to a wire.

Electromagnetic emission: Ability of a product to emit electromagnetic radiation or common mode currents that are likely to disturb other devices located in its near or far environment.

Pulse Width Modulation (PWM): Quick succession of voltage pulses which allow the generation of a variable DC voltage from a fixed DC voltage source (see Figure 1, in "2 - Introduction", page 3)

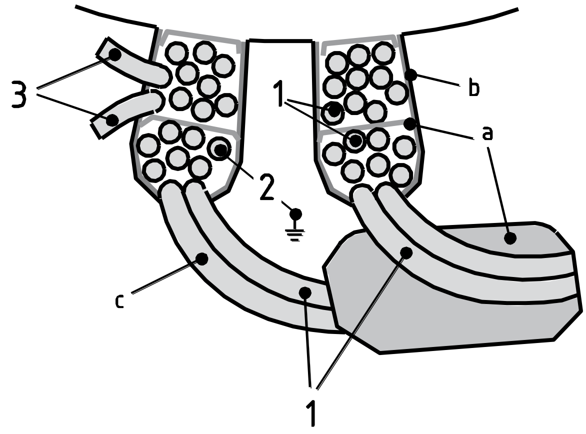
Partial discharge threshold (PDIV): Threshold voltage from which the partial discharges are initiated in the winding.
The abbreviation PDIV is derived from the English term "Partial Discharge Inception Voltage".

Electromagnetic susceptibility: Predisposition of a device to malfunction because of electromagnetic disturbances from other electrical devices located in its near or distant environment.

Voltage $\hat{U}_{LL}$: Peak phase-to-phase voltage following a PWM voltage rising or falling edge. Unit: V_{pk}

Voltage $\hat{U}_{LE}$: Peak phase-to-earth voltage that follows a PWM voltage rising or falling edge. Unit: V_{pk}

Illustration 33 - Exploded view of a winding



Legend

a	Insulation between phase	1	Between phases
b	Slot insulation	2	Earth phase
c	Enameled wire	3	Between coils

Appendix 1 - Information for determining the protections of a motor-drive system

This guide gives many recommendations on the installation of a motor-drive as well as useful information on different motor protections. To determine the specific protections required for an installation, you should know the following:

- influence of the mains voltage
- the type of application
- the motor range and its frame size (if the motor is not supplied by Leroy-Somer, it is necessary to know the PDIV),
- cable length between the drive and the motor.
- the range of the drive and its possible protections type filter/self (if the drive is not supplied by Leroy-Somer, it is necessary to know its dv/dt value).

Appendix 2 - Standards related to the motor-drive systems

The standards listed below set the rules for the design, use or installation of variable speed systems,

• **IEC 60034-18-41** (international standard): Electrical rotating machines - Part 18-41 Electrical insulation systems without partial discharge (Type I) used in rotating electrical machines powered by voltage converters - Qualification and quality control tests

• **IEC TS 60034-25**: Rotating electrical machines - Part 25 AC electric machines used in electric power drives - Application Guide.

• **IEC 61800-3**: Variable speed electric power drives - Part 3 EMC requirements and specific test methods.

• **IEC 61000-5-2**: Electromagnetic Compatibility (EMC) - Part 5 Installation and Mitigation Guides. Section 2: Earthing and wiring

• **NF C15-100**: Low voltage electrical installations

• **NEMA MG1** part 31: Definite Purpose Inverter-fed Polyphase Motors

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