Grounding and cabling of the drive system

Variable Speed Drives

Diagram:

A. Concentric Cu-shield
B. Concentric Al/Cu-shield
C. Separate protective grounding wire

ABB
Variable Speed Drives

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Chapter 1 - Introduction

The purpose of the manual

This manual describes the grounding and cabling principles of a variable speed drive system. System is composed of parts as transformer, mains cable, converter, motor cable and motor. Converter may be single drive or system drive a.c. frequency converter or d.c. converter. This manual is intended for persons involved in drive system installations and assembly. When the principles given in this manual are followed the installation fulfils the personal safety, electromagnetic compatibility (EMC) and availability requirements concerning grounding and cabling. Local safety regulations must be followed. Product specific instructions are in product manuals.

A short description of interference phenomena and literature references is included at the end of this manual.

Objectives of grounding

The traditional grounding is based on electrical safety. It ensures personal safety in all circumstances and limits material damages due to electrical faults. For interference-free operation and long-term availability of the drive more profound methods are needed: high frequency grounding and equipotential ground planes on building floor, equipment enclosure and circuit board levels.
Grounding and cabling of the drive system

**Availability**

Proper cabling and grounding strongly attenuates motor shaft and frame voltages, which may cause high frequency bearing currents and lead to premature bearing replacements.

**Bearing currents**

Two types of bearing currents are shown schematically below: high frequency circulating current (5) and shaft grounding current (7).
The grounding structure

Interference-free operation of electronics is facilitated by establishing equipotential areas on all structural levels. Building floors, equipment enclosures and circuit boards are using local ground planes on each level. The ground planes can also be mesh structures.

The best result is achieved by means of a well structured grounding. It begins with ground electrodes connected to each other reliably to form a network. The electrical equipment is connected to the network of electrodes through a short wiring to minimise the impedance (Figure 1-1).

![Figure 1 - 1. Recommended configuration for the ground electrodes and grounding networks.](image)

1. Power and communications ground, as needed
2. Soil
3. Multiple, bonded ground electrodes

In buildings where the ground plane model is not carried out, a radial conductor system is used for potential equalisation. This is the practice in many old buildings.

Cabinets PE busbar shall be connected to factory ground only at one point if the ground electrode system is of single electrode type and not well structured (Figure 1-2).
Grounding of drive modules

Figure 1 - 2. Grounding of the single electrode drive system.
Chapter 2 - Grounding of drive modules

General

When drive modules are assembled into the cabinet, all modules must be for personal safety reasons grounded to prevent dangerous voltages under any circumstances. Connection to ground through fixing screws and cabinet chassis is not good enough. To ensure the continuity of the protection bonding circuit modules must be connected to the cabinet PE busbar by a copper busbar or cable. The cross-sections must be in accordance with local regulations. From the EMC standpoint low impedance high frequency grounding (0.1 £, 25 A) is recommended. The best result is achieved with a flat copper braid.
Grounding of drive modules
Chapter 3 - Cabling of variable speed drives

General
Cables are dimensioned on a case-by-case basis in accordance with the local regulations concerning short-circuit protection, operating voltage, permissible touch voltage appearing under fault conditions and current-carrying capacity of the cable. In addition, the cable type must support the EMC protection and availability of installed equipment.

This manual describes examples of proper cabling and grounding practices. It is necessary to follow these instructions when selecting cables with the local vendor and implementing the grounding of the system.

Supply

Transformer
A VSD-dedicated transformer with static shield between the primary and secondary is recommended.

Grounded secondary (TN, TN-S)
If no frequency converter input filter is used, the grounding impedance of the transformer secondary must be especially low: minimum 70 mm x 0.75 mm copper plate or at least two separate 50 mm² cables. Distance between the cables must be at least 150 mm. If the installation specific drawings specify larger cross-sections for grounding, those must be followed. The length of the grounding conductor should be as short as possible.

Floating secondary (IT)
Frequency converter input filter can not be used due to specific safety requirements of this type of network. The common mode impedance of the mains is given by the size and construction of the feeding network.

Cabling

Low power supply
At low current (< 300 A) when one cable is sufficient, a shielded symmetrical multicore cable is recommended. The shield is connected to PE at both ends. When the converter incorporates input filter, also unshielded cable can be used.
Figure 3 - 1. Low power supply with cable.

The reactance of a multicore cable is low enabling the longest supply cabling. With parallel multicore cables, also high currents are possible.
High power supply

The supply of a high current (> 300 A) variable speed drive can be either a busbar or a cable bus system.

Figure 3 - 2. Busbar supply.

Metal conduit (shield) of the busbar system shall be connected to PE (Figure 3-2) at either one or both ends.

A cable bus system consists of parallel single core cables for phase leads. It is designed to reduce the conductor material, because of better cooling of separate conductors. The lower reactance cable bus systems allows longer distances than an alternative busbar system.

Figure 3 - 3. Cable bus system.
Cabling of variable speed drives

It is recommended to arrange the cables as shown in Figure 3-4 to achieve an as accurate distribution of current as possible.

\[ L_1 \quad L_2 \quad L_3 \quad N \quad L_1 \quad L_2 \quad L_3 \quad N \quad L_1 \quad L_2 \quad L_3 \quad N \]

Figure 3 - 4. Cable bus arrangement.

When single-core cables equipped with concentric protective shields (armours) are used, the phase current will induce voltage to cable shield. If shields are connected to each other at both ends of the cable, current will flow in the cable shield. In order to prevent this current and to ensure personal safety, the cable shield must be connected to PE only at the feeder side and must be insulated at the converter side (Figure 3-5).

Figure 3 - 5. Single core shield connection.
**Motor cables**

**AC drives**

To meet the EMC and availability requirements, only shielded, symmetrical, multicore cables shall be used. Some exceptions to this rule are given in the product specific manuals.

To be effective at high frequency, the shield conductivity shall be at least 1/10 of the phase conductor conductivity. One way of evaluating the effectiveness of the shield is the shield inductance, which must be low and only slightly dependent on the frequency. These requirements are easily met with a copper or aluminium shield/armour. The cross section of a steel shield has to be ample and the shield helix of low-gradient. Galvanizing will increase the high frequency conductivity.

Connect aluminium and copper shield at both ends to PE. 360° bonding of the shield will utilize the full high frequency capability to correspond the EMC rules and availability requirements. To operate as a protective conductor, the shield conductivity must be at least 50% of the phase lead.

The first alternative is a three-core cable equipped with concentric protective copper shield. In that case the phase wires are at an equal distance from each other and from the shield, and the shield is used as a protective conductor. The cross-section must be sufficient according to safety regulations. (Figure 3-6. A).

![Diagram of motor cable connection](image)

Figure 3 - 6. Approved motor cable connection.
An equally suitable cable type, 3+3+Cu/Al -shield + possible armour has three symmetrical conductors for protective grounding. The aluminium shield of this cable type is usually a solid corrugated armour. The shield is connected on the frequency converter side to the PE bar and on the motor side to the PE-terminal. Figure 3-6. B.

The third type has galvanized iron, low pitch, stranded armour/shield. The shield is connected to PE at both ends. However, a separate high-conductivity PE conductor is needed unless sufficient cross-section of copper is incorporated in the strand, as some manufacturers do. Figure 3-6. C.

The length of unshielded part of the cable should be as short as possible at the frequency converter side and at the motor junction box as specified in the drive and motor specific documentation.

Availability

The bearing current risk depends on voltages affecting across the motor bearings. Three basic types of voltages can be identified in AC drive applications, measurable as shaft end to end voltage, shaft voltage to ground or motor frame voltage to ground.

On medium and high power motors, improper motor cabling strongly increases these voltages, thus reducing the lifetime of the motor/gearbox/driven machine bearings. On the other hand, proper cabling and 360° termination of cable shield at both ends effectively reduces these voltages. Symmetrical, shielded cables reduce the motor frame voltage, the effect being more significant with high motor current. Thus unsymmetrical cables can be used up to 10 mm² cable size and up to 30 kW motor power, but shielded cable is always recommended. Foil shield is common in this power range.

Cable routes

The cable trays shall have good electrical bonding to each other and to the grounding electrodes. Especially aluminium tray systems can be used to improve local equalization of potential.
When cabling a high power frequency converter and motor, several conductor elements have to be used in parallel. In this case the cabling shall be done according to Figure 3-7.

Always use symmetrical cabling.

Figure 3 - 7. Symmetrical cabling of high power frequency converter and the motor.
Additional grounding of motors

With motors from 100 kW upwards, a potential equalization connection between the motor frame and the machinery is sometimes needed due to grounding conditions of the driven machinery. Typical applications are pumps (grounded by water) and gearboxes with central lubrication (grounded by oil pipes). As low inductance is the objective, a copper plate/strip with a cross section of 70 mm x 0.75 mm is the minimum between the motor frame and the gearbox/pump frame. Alternatively, at least two separate 50 mm cables can be used. The distance between the cables must be at least 150 mm. Install the potential equalization through the shortest possible route. If protection from dirt is needed, use a plastic tube, not a metal conduit.

The purpose of this connection is to equalize the potentials. It has no electrical safety function. When the motor and the gearbox are mounted on a common steel fundament no potential equalization is needed.

Figure 3-8a. Potential equalization between the motor frame and the machinery. The purpose of this connection is to equalize the potentials. It has no electrical safety function. When the motor and the gearbox are mounted on a common steel fundament, there is no need to make the connection.
Large motors may have additional grounding terminals outside the terminal box. Connect them to the PE on the motor frame (Figure 3-8b) to ensure proper connection between the terminal box and the frame.

Figure 3 - 8b. Equalization of the potential of the motor frame and the terminal box of large motors.
If other than recommended cable types are used, the following rules must be followed. Following these rules do not exclude problems caused by improper cabling.

In four-core cables (one is ground), three cores are not at an equal distance from the ground wire. The ground wire must not be used as a protective conductor. Ground wire shall be connected to PE only at the frequency converter side, and it shall be isolated at the motor end. Use a separate protective conductor with cross-sectional area at least half of the phase conductor cross section. The power cable and the protective conductor shall be placed at least 300 mm apart (not on the same cable tray) in order to prevent inductive disturbance currents in the protective conductor (Figure 3-9A). **This lay-out can in some countries violate the regulations. In this case use other type of cable.**

When a high gradient/interlaced steel plate armour is provided, the high frequency capability of the armour is insufficient. The armour can be terminated to the PE at both ends if the conductivity is at least 1/10 of the phase conductors. If the conductivity is less than 1/10, leave the motor end open. Do not use the internal unsymmetrical ground wire (no. 4) as a protective conductor (Figures 3-9.B and 3-9.C). Apply the same rules also to three-core cables.

Make the potential equalization connection between the motor frame and the machinery as described in page 3-8.

**Single core cables are not suitable for motor cables!**
Figure 3 - 9. Motor cable connections to be avoided.
**DC-drives**

The same basic rules apply as for AC motors. The most economical power cable has an even number of conductors. Also three-core cables with shield can be used. For larger motors, where several cables are needed, power sharing of three-core cable is made based on the 2+1 / 1+2 principle (Figure 3-10).

The field cable is a heavy source of interference because of the abrupt commutation. Therefore, always use shielded field cable.

Single core cables shall be rejected for DC drives.

Motors with stator serial winding must have brush on shaft to avoid bearing problems.

![Diagram](image)

*Figure 3-10. Symmetrical cabling between the DC converter and the motor*
**Signal cables**

**PE, protective ground vs. TE, technical ground**

The ABB policy is to use uniform, equipotential PE grounding with drive systems. The principle is extended to all structural levels of installations in large buildings containing electrical equipment. Examples of levels are floor, equipment cubicle and circuit board level.

It is not possible to keep all the levels of a large system at the same high-frequency potential, but applying the uniform PE grounding at all levels will ensure the electromagnetic compatibility.

The end users also apply other installation philosophies, for example, systems with PE & TE. This is usual with electronic equipment of other manufacture. It has also been used with some previous ABB products.

The TE-system of the co-operating equipment can be either general or only part of the equipment is built based on this principle (Figure 3-11).

In the sense that the PE and TE systems are connected at only one point, the PE/TE structure has a resemblance to the ground plane model of one level in the universal PE-system. Therefore, a large TE-system may also need local effective HF-ground and become more like the universal PE approach (Figure 3-12).

![Figure 3 - 11. PE- TE-system](image-url)
Most of the existing installations today have been made by applying other principles of grounding than given in this manual, specially concerning low frequency EMC, even starting from the ground electrodes.

New deliveries, which employ the uniform PE system, are usually additions which have to operate together with the old equipment.

Other systems, implemented with a different philosophy, usually operate well, and making of changes in the systems is out of the question.

The dissimilarity may create matching problems, which have to be solved case by case. Physically large installations (dimensions, power) normally need some kind of matching.

Matching is done to obtain sufficient compatibility. Sometimes it is reasonable to accept a lower immunity level. However the legal requirement of emission and immunity must be fulfilled.

Usually matching elements between the systems are transformers, optocouplers, optical fibre links, galvanic analogue isolation and common mode interference filters, inductors. All these methods can improve signal transmission. Isolation transformers are used for power supply.

This guide will not go deep into the interfacing practice, but it is important to be aware of the problem areas of interfacing before implementation.
Control cable shielding

It is very important to use correct cable types to meet the EMC compatibility. Wrong cable type can cause severe interference problems. A shielded control cable will reduce disturbances.

Always use shielded cable for safety low-voltage (SELV) control signals.

Analogue and low voltage (SELV) digital I/O signals

Twisting the signal wire with its return wire reduces disturbances caused by inductive coupling. Pairs should be twisted as close to terminals as possible.

A double shielded twisted pair cable shall be used for analogue signals. Employ one individually shielded pair for each signal. Do not use common return for different analogue signals (Figure 3-13).

A double shielded cable is the best alternative for low voltage digital signals but single shielded twisted multi pair cable is also possible (Figure 3-14).

Never mix 24 VDC and 115 / 230 VAC signals in the same cable.

Figure 3 - 13. A double shielded twisted pair cable

Figure 3 - 14. A single shielded twisted multi pair cable
There are several alternatives depending on the type of communication. The communication systems employ either double shielded (Figure 3-13) or coaxial cables in internal communication. A part of the serial communication is implemented with optical cables (Figure 3-17), (Figure 3-18).

A communication system may also have its own cable specification.

Note that serial communications will operate properly only with correct terminating resistors. See system specific instructions.

A shielded cable with proper voltage rating is the best alternative but an unshielded multi core cable can also be used. (Figure 3-15).

Always connect the shields of the control cables to ground terminal at the converter side. The unshielded part of the cable shall be minimized. The ground connection of the shield shall be kept as short as possible. The ground terminal can be a special clamp, a separate screw marked with the symbol or a terminal block. The marking of the ground terminal can be PE, TE, GND or the symbols.

An unconnected or only at one end grounded shield has reduced effect on suppressing electromagnetic field or inductive disturbance. Grounding the shield of the signal cable at both ends will improve suppression above a certain frequency, but grounding at both ends forms a closed ground loop, and if the ends of the cable screen are at different potentials, as in a short circuit situation of high power equipment, a low frequency current will flow through the screen. Therefore, if HF grounding is needed, the other end of the shield can
be grounded via a capacitor. In some equipment the capacitor is incorporated. (Figure 3-16).

![Grounding of signal cables](image)

Figure 3 - 16. Grounding of signal cables

Cabling and insulation of tachometer, pulse encoder

The tachometer shall be insulated electrically from stator or rotor to prevent forming of current path through the tachometer. The usual coupling-type encoder must have an electrically insulating coupling. When a hollow-shaft type tachometer is used, the insulation can be implemented by insulating the ball joints of the engaging arm, or insulating the bar of the engaging arm. Shield of the tachometer cable should be insulated from the tacho frame. The other end of the shield is grounded at the converter PE see figure 3-17 and figure 3-18.

Always use double shielded cable for the pulse encoder. In case of HF interference problem the shield can be grounded at the encoder end via capacitor. Single shield cable can be used with the analogue tachometer.

There will be available hollow-shaft encoders with electrical insulation between the hollow-shaft and the tacho frame. This construction will allow connection of the cable shield to the tacho frame.
Examples of cabling system drives

Typical examples of cabling in AC and DC drive systems are shown in figures 3-17 and 3-18.

Figure 3 - 17. Typical example of AC drive system grounding
Figure 3 - 18. Typical example of DC drive system grounding
Galvanic isolation

Galvanic isolation of control signals improves the interference immunity and is recommended specially at long distances. Isolation prevents interference caused by common impedance coupling (ground loop) and suppresses inductive coupling interference. Weak signals are isolated and amplified at the source, normal signals can also be isolated at the receiving end.

Cable routes

Avoid parallel running of power cables and signal cables. The distance between power and control cables should be 300 mm at least. When control cables must cross power cables, make sure this is done at an angle as near to 90 degrees as possible.

The cable trays shall have good electrical bonding to each other and to the grounding electrodes. Especially aluminium tray systems can be used to improve local equalization of potential.

Common mode inductor

In particular cases due to high emission level common mode inductors can be used in signal cables to avoid interfacing problems between different systems.

Common mode disturbances could be suppressed by wiring signal conductors through the common mode inductor ferrite core (Figure 3-19). Ferrite core increases inductance of conductors and mutual inductance, so common mode disturbance signals above a certain frequency are suppressed. An ideal common mode inductor does not suppress a differential mode signal.

Figure 3 - 19. Common mode inductor
**Chapter 4 - Interference coupling, informative annex**

**Common impedance coupling**

Common impedance coupling appears, if interference source circuits have a common path of current (Figure 4-1). Usually this impedance can be found in the grounding or power supply circuit. Current changes in the interfering circuit causes potential changes in the common impedance’s: \( u = R \cdot i - L \cdot \frac{di}{dt} \).

Coupling via ground loop can be reduced:

- Low-frequency coupling can be prevented by using one-point grounding
- For high frequency, it is most essential to keep inductance as low as possible. To achieve low-impedance, the relation between length and width should be less than five. In practice, this rule is implemented by multi-point grounding.

![Figure 4 - 1. Common impedance coupling](image)

*Figure 4 - 1. Common impedance coupling*
**Capacitive coupling**

Capacitive disturbance is coupled by a changed electric field. Capacitive coupling appears in circuits that have stray capacitance with each other. Interference current (IN) is proportional to frequency (f), voltage level (V1) of the interfering conductor and stray capacitance between conductors (C12).

\[ V_n = j2\pi f \times V_1 \times C_{12} \times R \]  

(Figure 4-2)

Capacitive coupling can be reduced by:
- Reducing stray capacitance between circuits
- Reducing impedance level of victim circuit
- Limiting frequency level of interfering circuit
- Limiting voltage level of interfering circuit

Stray capacitance can be reduced by:
- Using metal casings for devices
- Using shielded conductors
- Increasing distance between conductors
- Using ground plane between conductors.

![Capacitive coupling diagram](image)
Inductive coupling

Inductive disturbance is coupled via magnetic field. Current in the interfering circuit will generate magnetic flux around the conductor. When a changing magnetic flux perforates a closed loop, an alternative voltage will be induced to the victim circuit and interference current will flow in the closed loop. Interference voltage \( V_N \) is proportional to frequency \( f \), current \( I_1 \) of the interfering conductor, mutual inductance of circuits \( M_{12} \). Mutual inductance can be calculated by the area of the loop perpendicular to the magnetic lines \( A \cos \theta \) and distance between conductors \( r \).

\[
V_N = j2\pi f M_{12} I_1 \quad \text{(Figure 4-3)}
\]

\[
M_{12} = \mu A \cos \theta \frac{1}{2\pi r} \quad \text{(long, straight conductors)}
\]

Inductive coupling can be reduced by:
- Reducing mutual inductance between circuits
- Filtering the high frequency content of interfering circuit
- Reducing current of the interfering circuit

Mutual inductance can be reduced by:
- Using twisted pairs signal cables
- Increasing the distance between conductors
- Reducing the loop area by galvanic isolation
- Avoiding parallel conductors and coils.

By shielding the victim conductor with a material that has high permeability, some extra suppression is achieved. (High permeability material "short-circuits" magnetic circuits, so most of the flux flows through this material.)

High frequency disturbance is reduced by using a metal enclosure or shield

Highly conductive metals as aluminium and copper are good shield materials

![Figure 4-3. Inductive coupling](image)
Electromagnetic energy can propagate in free space as a wave motion. Each conductor carrying a changing current is a potential transmitter antenna of electromagnetic waves.

Reciprocally, all conductors can operate as a receiver antenna. In addition, each conductor, whether part of the active circuit or not, will shape the fields and perhaps amplify the antenna operation. Sometimes a solid insulator may behave in the same way. The antenna efficiency will increase at a high frequency when the antenna dimensions exceed about 1/100 of the wave length. Therefore, the problem gets worse from 10 MHz onwards due to improved antenna function and because of the suitable dimensions of normal digital electronics and because they operate at those speeds. Also part of the climatic interference is 10 to 100 MHz, applying to lightning at a long distance. A stroke of lightning close to electronic equipment easily stops normal function.

The coupling will decrease as distance increases.

How to protect against EM waves?

- Use ground planes or mesh structures as local ground
- Shielding of cables
- Metal enclosure for equipment, leaky doors are problematic
- Enclosure openings have to be small
- No unintentional antenna structures
- Grounding systematically at short, <1/10 wavelength intervals
- Pay attention to HF grounding, i.e. capacitive grounding of coaxial cables, for instance.

Due to reciprocity these rules apply to both sides, the source and the victim.

Terms

**EMI**

Electromagnetic interference

**Shield**

The cable shield is a part of an electromagnetic barrier that separates the shielded circuits from the external sources of EMI (or confines EMI effects to the shielded volume). An electromagnetic barrier is a closed surface made up of shields and other elements to exclude (or to confine) electromagnetic waves propagating in space or guided along conductors. The barrier may be made up of metal or conductively coated equipment cases, interconnecting cable shields, filters or surge arresters on wires that penetrate the shield, and mesh or wave guides (below cut-off frequency) at ventilation openings. In a protected system the barrier is everywhere sufficiently impervious.
to guided and space waves that EMI sources outside the barrier do not degrade the performance of the protected system.

**Armour**

Armour is a metal sheath commonly of woven wire, spiralled tape or solid corrugated metal covering the insulation of an electrical conducting cable and serving both as a mechanical protection and as a shield against electrostatic or electromagnetic induction.

Note that sometimes a cable may contain both an electromagnetic shield and a separate armour for mechanical protection, but both are electrically bonded.

**Availability**

The capability of a device or a system of being used for the intended purpose.

**Literature**

**EMC**

"Interference-free electronics" by Dr. Sten Benda.
Ordering number ABB 3BSE 000877R0001,

**Bearing currents**

“Bearing Currents in AC Drive” by FIDRI and FIMOT. Set of overheads in LN database “FIDRI Document Directory” on ABB_FI01_SPK04/FI01/ABB

