Installing of IEDs in MV and HV Switchgear

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1 Scope

Generally, switching operations in MV (medium voltage) and HV (high voltage) switchgear generate EM (ElectroMagnetic) disturbances. Depending on level of the EM disturbances IED (Intelligent Electronic Device) installed in the proximity could be severely impacted. In a worst case situation unwanted operation or missing operation of an IED cannot be excluded.

This document is a guide for installing IEDs in MV and HV switchgear. The objective is to limit disturbances to a level compliant with the EMC (ElectroMagnetic Compatibility) requirement for IEDs according to the related standards.

KEYWORDS: EM disturbances, EMC, IED installation

2 Abbreviations and Definitions

2.1 Abbreviations

EM	Electromagnetic
EMC	Electromagnetic compatibility
HF	High frequency
HMI	Human machine interface
HV	High voltage
IEC	International Electrotechnical Commission
IED	Intelligent electronic device
LF	Low frequency
LV	Low voltage
MV	Medium voltage

2.2 Definitions

EMC [IEC02]:
The ability of a piece of equipment or system to function satisfactorily in its electromagnetic (EM) environment without introducing intolerable EM disturbance to anything in that environment.

EMC level [IEC02]:
The specified maximum disturbance level to which a device, equipment or system operated under certain given conditions is likely to be subjected.

Note:
In practice, the EM level is not an absolute maximum level but there is just a small probability that it will be exceeded.

EM disturbance [IEC02]:
Any EM phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter.

Note:
An EM disturbance may be an EM noise, an unwanted signal or a change in the propagation medium.

EM susceptibility [IEC02]:
The inability of a device, equipment or system to perform without degradation in the presence of EM disturbance.

Disturbance level:
Level of an EM disturbance of a given form, measured under particular conditions.

Disturbance limit [IEC02]:
The maximum permissible EM disturbance level, measured under particular conditions.

Immunity level [IEC02]:
The maximum level of a given EM disturbance on a particular device, equipment or system for which it remains capable of operating at a required degree of performance.

3 Introduction

Microcomputer based IEDs have been widely applied over the last 10 years, providing improved functionality and flexibility, integrated into a small low-cost device. These microcomputer based devices are placed in very “noisy” substation environments where they are expected to perform without problems. Mounting them directly into an MV switchboard (in close proximity of the primary switching process) is especially demanding [ABB01]. The EMC problem involves understanding and catering for capabilities of the device (protection relay) to produce and withstand noise in an environment comprising all other connected or coupled devices.

EMC means that a device is compatible with its EM environment. It means the equipment can work correctly without creating disturbances for other electrical equipment or being influenced by other equipment. An electrical (victim) device can have an uncontrolled behaviour, if the level of EM energy emitted by another (source) device exceeds the EM immunity level to which the device was designed, tested and approved. In that case, it can not be excluded, that internal sensitive electronic circuits of the victim device even could be damaged.

The different forms of EM disturbances are conducted and radiated disturbance, and electrostatic discharge. Because in the following document only EMC in the context of switching operations in MV or HV switchgear will be described, the impact by occurrence of electrostatic discharge will not be given any further consideration. But generally, it can be generally stated that the effect of electrostatic discharge can be limited by the same measures as used against EM disturbances. Figure 4.1 shows the principle for the different coupling mechanisms of EM disturbances.

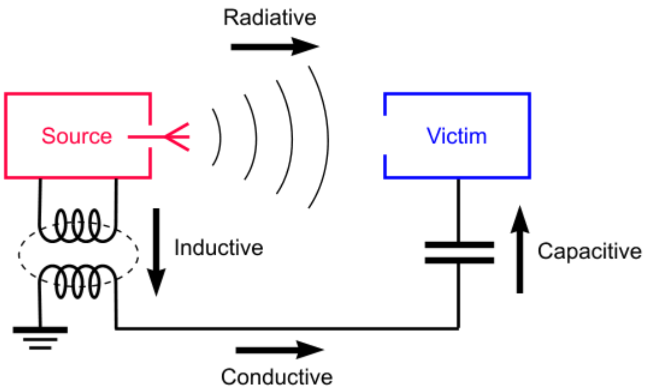

Figure 4.1: Different EMC coupling mechanisms

In the following sections the different coupling mechanism are described in more detail.

3.1 Conductive coupling

There is a direct coupling between the source of the noise and the device considered as the receiver or the victim respectively. The transmission is enabled by wire or cable. It must be considered that a wire is composed of not only resistance but also inductance and capacitance. Consequently, a wire is to be treated as having impedance and not only resistance.

3.2 Inductive coupling

With a short distance between the noise source and the victim device (less than a wavelength of the HF disturbance), an inductive coupling can be generated by a varying magnetic field.

3.3 Capacitive coupling

If there is a varying electrical field between two conductors within a short distance (less than a wavelength of the HF disturbance) from each other, the noise source can be coupled to the receiver or to the victim respectively by means of capacitive coupling.

3.4 Radiative coupling

The EM waves emitted by the source are received by the victim device, although the distance is more than several wavelengths. In this case, everything could be considered as an antenna (bad antenna, but good enough for receiving the disturbance in the receiving or in the victim device respectively).

4 Sources of electrical noise in an MV/HV installation

As mentioned above, in MV or HV installations disturbances may be transmitted by means of different coupling mechanisms. These phenomena are today very well considered in the standardisation work of IEC, which can be used to assists the normal switchgear design process [IEC01]. Fundamentally, there are two sorts of disturbances existing:

- HF (High frequency) disturbances produced by:
  - Switching in primary circuits.
  - Lightning strokes on overhead lines or on earthed components of MV or HV installations.
  - Operation of surge arresters with gaps.
  - Switching in secondary circuits.
  - HF radio transmitters.

- LF (Low frequency) disturbances produced by:
  - Short-circuits.
  - Earth-faults.
  - EM fields generated by power system equipment (busbars, power cables, reactance, transformers, etc.)

5 Measures against EM disturbances

5.1 Reducing the effect of high frequency disturbance

The recommendations listed below are the most important ones for reducing the effects of high frequency EM disturbance:

- Suitable construction of instrument transformers (voltage transformers, current transformers), effective shielding between primary and secondary winding, testing of high frequency transmission behaviour.
- Protection against lightning strokes.
- Improvement of the earthing system and earthing connections.
- Shielding of secondary circuit cables:
  - Shields shall be continuous.
  - Shields shall have low resistance (few ohms per kilometer).
  - Shields shall have low-coupling impedance within the disturbance frequency range.
  - Earthing connection of the shields shall be as short as possible.
  - The shields shall be earthed at least at both ends, additional earthing of intermediate points (bonding) where possible shall be carried out.
  - The shields shall be earthed at their entry to the control cabinets so that the currents circulating in the shields do not affect the unshielded circuits. Connections shall preferably be circular by using suitable cable glands or a welding procedure.
- Grouping of circuits:
  - In order to reduce differential mode overvoltages, the incoming and outgoing wires associated to the same function should be grouped within the same cable.
  - As far as possible, control cables shall be segregated from other power cables.

5.2 Reducing the effect of low frequency disturbance

The recommendations listed below are the most important ones for reducing the effects of low frequency electromagnetic disturbance.

- Measures concerning cable laying:
  - Separation of control cables from power cables by using spacing or different routes.
  - Power cables in trefoil formation shall be preferred instead of flat formation.
  - If possible, the control cable routes shall not be parallel to the busbars or the power cables, otherwise crossing in an angle of 90° shall be considered.
  - Control cables shall be laid away from inductances and single-phase transformers.

- Measures concerning the circuit arrangement:
  - Loops shall be avoided.
  - For DC auxiliary supply circuits, a radial configuration is preferred in stead of a ring configuration.
  - Protection of two separate DC circuits by the same miniature circuit breaker shall be avoided.
  - Parallel connection of two coils located in separate cubicles shall be avoided
  - All wires of the same circuit shall be housed in the same cable. When different cables must be used, they shall be laid in the same route.
- Twisted-pair cables shall be used for low-level signals.

5.3 Additional measures

The recommendations listed below are supplementary, when applicable, to the previously mentioned recommendations:

- Installation of control cables in metallic cable ducts is recommended. Continuity and earthing of ducts should be ensured along their whole length.
- Where possible, installation of cables along metallic surfaces.
- Use of optical fibre cables with appropriate equipment.

5.4 Conclusion

It can be concluded, that effective measures against EM disturbances can be based on two general principles:

- Reduction of the penetration of electromagnetic fields into the equipment;
- Establishment of equal potential between every piece of equipment and the earthing system.

Practical examples for establishing equal potential and proper earthing for the IED installation in the LV compartment of switchgear will be shown in the following section.

6 Installing IEDs in the LV compartment

6.1 Reducing the common impedance coupling

EMC becomes important when IEDs are to be installed in MV and HV switchgear. To achieve trouble-free operation in an environment with heavy disturbance, the complex phenomena involving sources, coupling and receiver or victims must be well understood. Therefore a certain guideline or rule must be followed, as already listed in previous sections.

The level of EMC in equipment depends on the coupling between circuits. Coupling is directly related to the impedance between circuits, especially at high frequencies. To improve EMC, these impedances must be effectively reduced.

First of all it is important to keep in mind that the impedance of a conductor is mainly a function of its inductance and becomes predominant starting at a few kilohertz for a standard wire. This value is much lower when the wire is run along a conductive metal plate as shown in Figure 6.1.1:

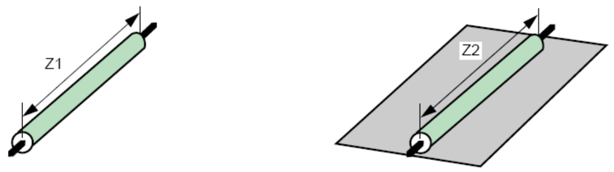

Figure 6.1.1: Reducing the inductance of HF disturbance by means of a metal plate

The inductance becomes a function of the distance between the wire and the metal plate and it can be decreased very effectively. Otherwise, at very high frequencies the wire must be considered a transmission line with a characteristic impedance of around one hundred ohm.

In this light, a relatively high value of common impedance can easily be created, for example with a few meters of green-yellow (earthing) wire. Consequently, the best way to avoid common impedance coupling is essential to introduce the use of the so called equipotential-earthing system, which can be obtained by applying metal plates or earthing grid schemes respectively. Therefore, the use of metal plates and metal cable ducts will effectively reduce the common impedance of the coupling mechanism of EM disturbances.

> **Note:**
> From the EMC point of view, the method of connecting all earths to a central point (star configuration) shall be replaced by metal plates or by grids respectively, which are far more effective in reducing disturbances that affect today's digital systems, e.g. protection, control and monitoring IEDs.

Protection, control and monitoring IEDs are normally installed in the LV compartment of switchgear normally made of sheet metals. By following the installation guidelines described here, the level of HF and LF disturbance can be effectively reduced to provide EMC compliance with the protection and control IEDs used as secondary component.

6.2 Earthing of the cable shielding

First of all, it shall be stated that all cables coming from primary components shall have a continuous conductive shield. To be effective, the thickness of the conductive shield must exceed the skin depth at the frequencies encountered and be earthed at least at both ends of the cable. The end of the shield entering the low voltage compartment can be earthed by using an appropriate cable gland, a metal fitting with shield termination, as shown in Figure 6.2.1.

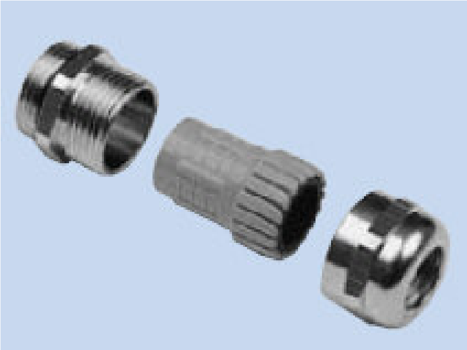

Figure 6.2:1: Metal fitting with shield termination

Besides, as mentioned before, power cables shall be routed separately from control and measurement cables. Where ever possible, the use of separate cable duct is to be recommended. Moreover, circuitry using low level signals shall have its own return wire (0V) to avoid common impedance coupling.

For the most sensitive cables, e.g. those used in measurement circuits, special treatment must be introduced. In Figure 6.2.2 the connection to electronic current and voltage transformers [IEC03, IEC04] is shown. The earthing requires that the shield of the sensitive cables carrying low-level measurement signals must be connected to the earthed mounting plate means of an appropriate metal clamp.

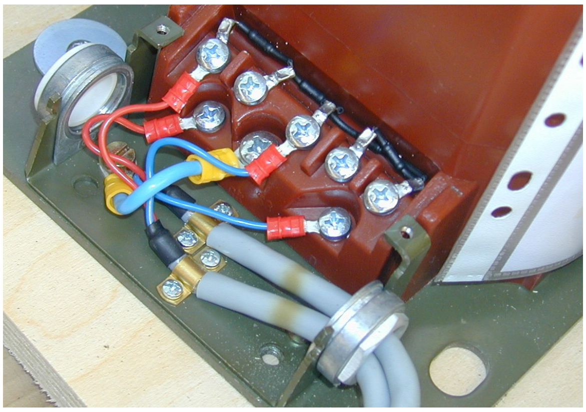

Figure 6.2.2: Connection to an electronic current or voltage transformer

Due to the sensitivity of the measurement cable, an earthing grid scheme will have to be applied. Therefore, bonding to earth at different places along the cable must be introduced. For example, when entering the LV compartment, the use of cable glands, i.e.metal fittings with shield termination, shall be considered. Alternatively, another similar bonding method using a specific copper clamp can be applied, as seen in Figure 6.2.3.

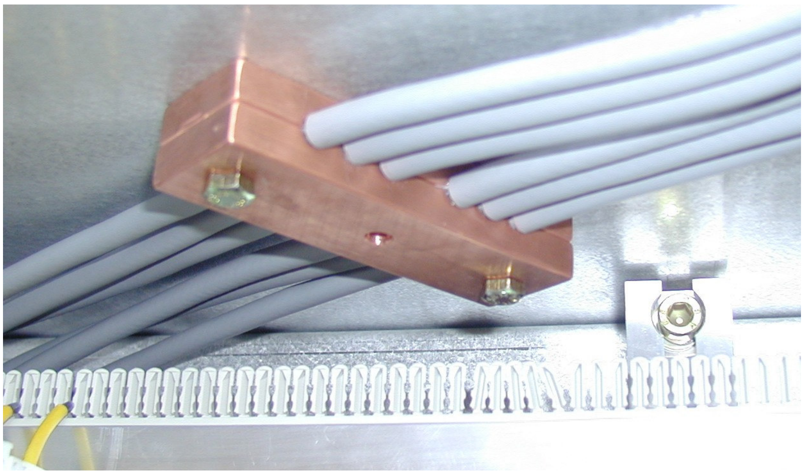

Figure 6.2.3: Bonding of the cables of electronic current and voltage transformers

As already mentioned in previous chapters before, the more bonding to earth that is applied to achieve a grid earthing scheme, the better result can be obtained for reducing coupling of HF disturbances to low.level measurement signals. Finally, the shield at the end of the cable, which is connected to the IED, shall be earthed too, e.g. to a dedicated earthing bolt.

6.3 Earthing of the low voltage compartment

In MV or HV switchgear the switching devices are located in panels. In MV switchgear the LV compartment is normally by design part of the panels while in HV switchgear the LV compartment can be located in a separate room. In general, all metal parts of the low voltage compartment are to be earthed to dedicated earthing facilities in the substation.

To ensure proper earthing of all metal parts, it is, for example, necessary to also earth the metal door of the low voltage compartment, where other electronic devices are mounted. From the EMC point of view, the shortest possible connection to earth shall be applied. Besides, to obtain a grid earthing scheme the metal doors need to be connected, at least at two different locations to other earthed parts of the LV compartment by means of a braided strap or flexible flat cable, see Figure 6.3.1. In the same figure it can also be seen that metal cable ducts for routing control or signal cables are provided too.

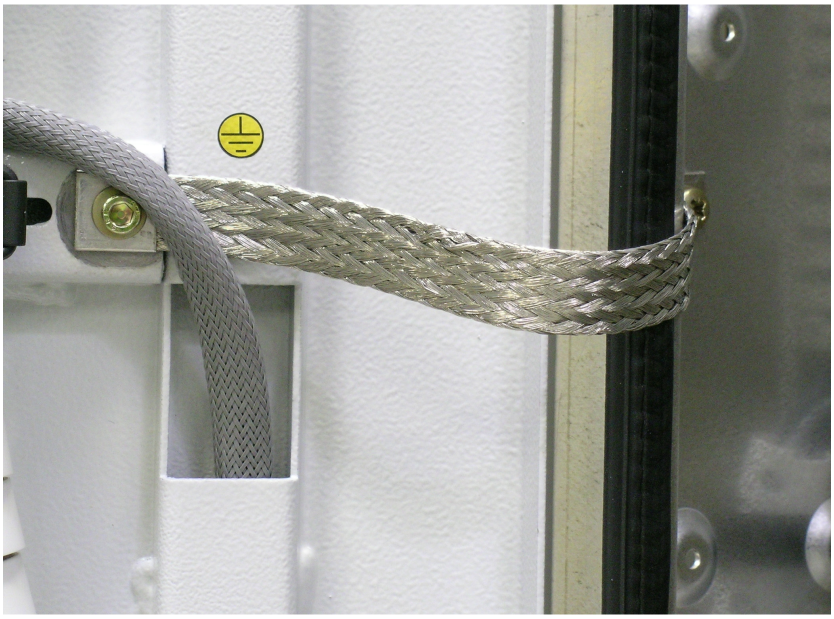

Figure 6.3.1: Earthing of the low voltage compartment door

> **Note:**
> The earthing bolt on the door and on the wall of the LV compartment shall have good conductivity. Therefore the location of the earthing bolt must be free from paint or other varnish.

6.4 Earthing of the IED enclosure

Figure 6.4.1 and Figure 6.4.2 show the earthing of the enclosure of different IEDs. As already mentioned before, the earthing shall be done with a braided strap or a flexible flat cable. The earthing cable shall be kept as short as possible. Here again, the precondition, that the LV compartment wall is earthed as mentioned above. To ensure the required conductivity the location of the earthing screw shall not be painted or varnished.

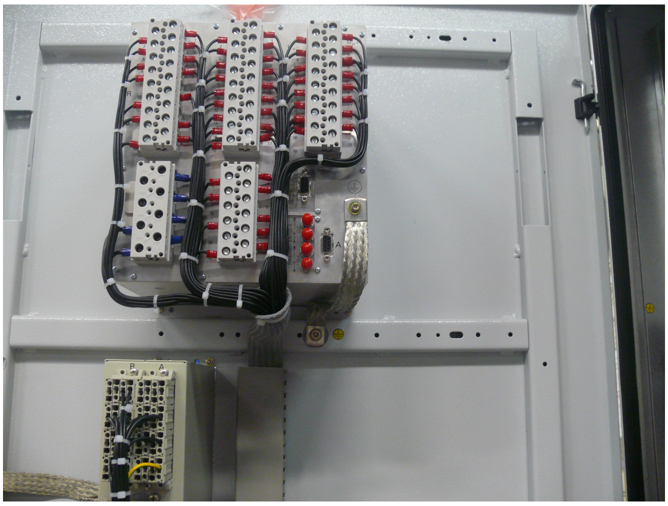

Figure 6.4.1: IED enclosure mounted on the door of the LV compartment

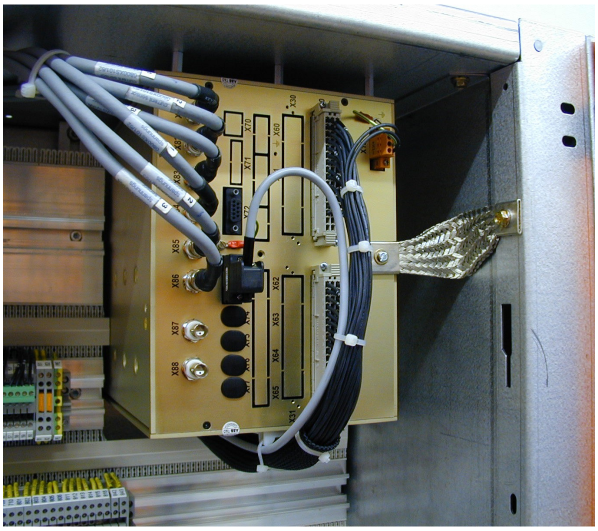

Figure 6.4.2: IED enclosure mounted on the inside wall of the LV compartment

In case the IED is housed in a metal enclosure, it is, from the EMC point of view, recommended to mount the enclosure directly on an earthed, unpainted metal wall of the LV compartment. Due to the good conductivity of the contact by the surface area, the HF as also the LF - disturbances, can be reduced effectively. Figure 6.4.3 shows a metal enclosure mounted directly on the wall of the LV compartment.

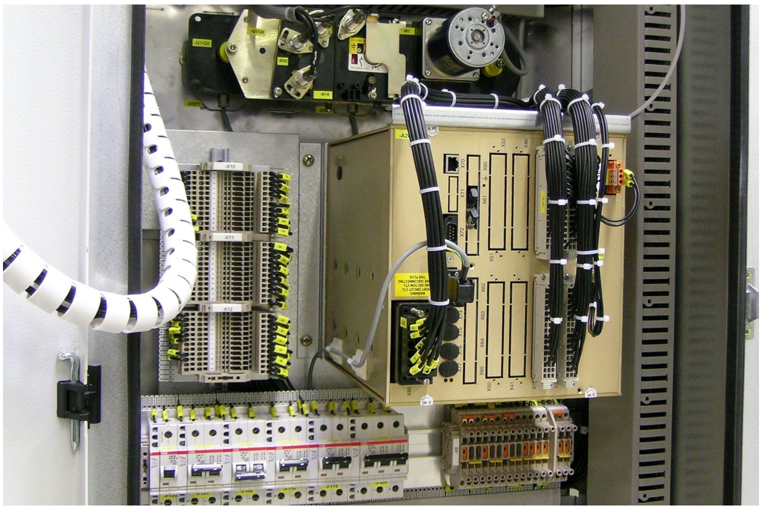

Figure 6.4.3: Metal IED enclosure mounted on the metal wall of the LV compartment

Figure 6.4.4 shows a locally separated HMI, which needs to be earthed too. The earthing connection shall be carried out with an as short as possible flat braided cable.

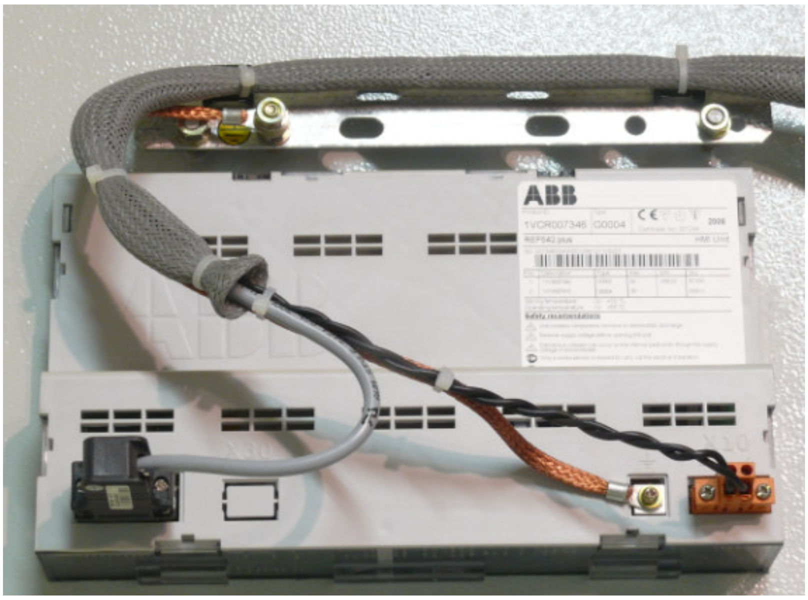

Figure 6.4.4: Earthing connection for separated HMI

6.5 Separation of different signal cable

Nowadays advanced IEDs are provided with detachable HMIs, which can be used for separated mounting of the HMI and the base unit. The connection cable from the HMI to the base unit is sensitive to disturbance. Cables for low-level signals shall be separated from other cables connected to sources of disturbance. In Figure 6.5.1 shows an example of how the cables can be separatred. The cable carrying low-level signal to the detachable HMI (upper installation) is separated from the cable carrying the signal for voltage indicator (lower installation), which is connected directly to the capacitive voltage detecting system. Earthing bars in the next vicinity shall again be provided to keep the earthing connection as short as possible.

Figure 6.5.1: Separation of wires for low-level signals from wires for power signals

The classification of signals is listed in Table 6.5.1. The low-level signals (victim) can be disturbed by interfering signals (disturbance source). Consequently, also the separation of cables carrying different signal classes shall be taken into account in order to achieve the required EMC.

Table 6.5.1: Classification of signals

Class	**Interfering**	**Sensitive**	**Example of signals or connected device**
Sensitive	--	++	Electronic current and voltage transformer
Slightly sensitive	--	+	0/4 to 20 mA analog output signals 4 to 20 mA sensor input signals
Slightly interfering	+	-	Current and voltage transformer Signal for remote indication in the substation
Interfering	++	--	Signal for controlling the switching devices Signal from capacitive voltage indicating system Inter-tripping via external cable

6.6 Earthing of spare wires

If there are spare wires left over, both ends of the wires shall be earthed. Figure 6.6.1 shows how spare wires, which are provided for future extension of the external control scheme within the LV compartment, are earthed.

Figure 6.6.1: Earthing of spare wires in LV compartment

6.7 External cable

The length of the external cable, for example if it is used in an inter-tripping protection scheme, shall preferably not exceed 200 m. If a longer distance needs to be bridged, the use of interposing relays, appropriate low pass filters or optical fibre cables shall be considered.

7 Summary

Based on the IEC 61936-1 standard [IEC01], the document, provides guidance for the installation of IEDs into MV and HV switchgear systems. By means of practical examples the document shows how EMC can be achieved for an IED installation in the LV compartment of a switchgear system. Consequently, unwanted or missing operation of IEDs caused by EM disturbance can be avoided completely.

8 References

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