

## Electrical safety for DC systems

Low voltage DC systems (LV DC systems) play an important role in an ever increasing number of applications. The increasing importance of renewable energies is one of the reasons. Photovoltaic installations generate DC that can be stored in decentral battery installations. In addition there are a large number of loads that can be operated in an energy efficient manner with DC, such as electric vehicles and railway rolling stock or lighting installations. The DIN VDE 0100 series of standards is also definitive here for the electrical safety in the DC installation, however the specific requirements for DC systems must be observed.

### Protection against electric shock

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### Underlying standards

From the standards point of view, in accordance with DIN VDE 0100-100 (VDE 0100-100):2009-06, the types of system familiar from the AC area, that is TN, TT and IT systems, are initially also applicable to LV DC systems and therefore also the protective measures described in DIN VDE 0100-410 (VDE 0100-410):2007-06. However, it is to be noted that, in accordance with DIN VDE 0100-410 (VDE 0100-410):2007-06, the permissible touch voltage  $U_B$  DC is  $\leq 120$  V (AC  $\leq 50$  V) and the required shut





down times also have different values (see Table 1). The exception here is the IT system for which shut down on a first fault is not necessary in accordance with section 411.6.1. Only on a second fault on a different active conductor are shut down times to be observed.



**TABLE 1: Maximum shut down times in accordance with DIN VDE 0100-410 (VDE 0100-410):2007-06**

System	50 ... ≤ 120 V		120 ... ≤ 230 V		230 ... ≤ 400 V		≥ 400 V	
	AC	DC	AC	DC	AC	DC	AC	DC
TN	0,8 s	*)	0,4 s	5 s	0,2 s	0,4 s	0,1 s	0,1 s
TT	0,3 s	*)	0,2 s	0,4 s	0,07 s	0,2 s	0,04 s	0,1 s
IT	In acc. with 411.6.1 no shut down necessary on 1st fault, only on 2nd fault							

\*) A shut down can be required for reasons other than protection against electric shock

**TABLE 2: Protection against electric shock in accordance with DIN VDE 0100-410 (VDE 0100-410):2007-06**

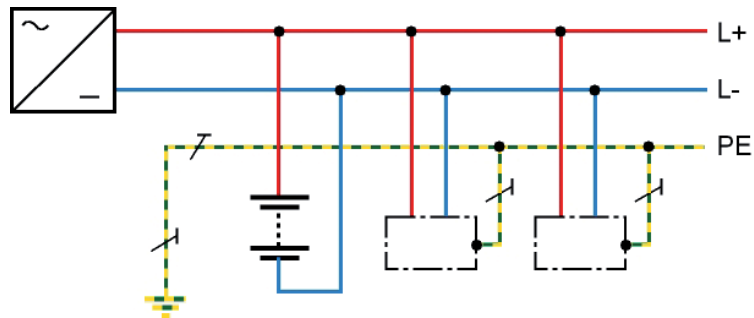
Protective and monitoring devices	TN system	TT system	IT system
Insulation monitoring devices (IMD)	-	-	First fault signal
Overcurrent protective devices	First fault shut down	First fault shut down	Second fault shut down
Residual current devices (RCDs)	First fault shut down	First fault *) shut down	Second fault shut down
Insulation fault location systems (IFLS)	-	-	First fault locate
Residual current monitoring devices (RCM), designed as MRCD with switching element *2)	First fault shut down	First fault shut down	Second fault shut down
Residual current monitoring devices (RCM)	Not a permissible protective device, only for signalling		

\*) In certain situations, see DIN VDE 0100-410 section 411.5

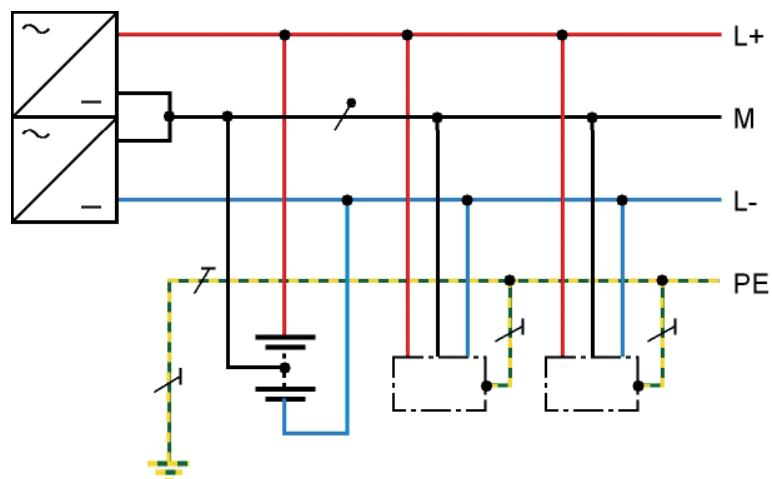
\*2) Switching element in accordance with DIN EN 60947-2



**FIGURE 1:**  
IT DC system in accordance with Figure 31M1  
DIN VDE 0100-100(VDE 0100-100):2009-06



**FIGURE 2:**  
IT DC system with mid-point conductor in accordance with Figure A.31M2  
DIN VDE 0100-100(VDE 0100-100):2009-06



### ▶▶▶ Protective measure in earthed DC systems - residual current devices (RCD)

In AC systems, residual current devices (RCD) are a proven protective device of which millions are in use. However the residual current devices (RCD type A, B etc.) currently defined in accordance with the DIN VDE 0660 series of standards are not suitable for DC systems, as the integrated switching element is not suitable for DC load currents. In addition, the measuring technology in type B for the acquisition of DC residual currents is voltage-dependent and the necessary auxiliary voltage is drawn from the AC distribution network. So-called

MRCDs (**M**odular **R**esidual **C**urrent **D**evice) can be used for this task. These devices comprise a separate detection device (RCM) resp. a circuit breaker and are used in industrial applications. Here residual current monitoring devices (RCM) resp. corresponding circuit breakers suitable for DC applications could be used.

The DC switches or isolating devices must meet special requirements, as on opening the contact an arc may be produced. This arc will result in contact



- ▶▶▶ burning that reduces the service life of switchgear. The higher the load current and/or the voltage, the greater the energy in the arc. While with AC the arc is interrupted in a natural manner when the voltage crosses zero, with DC the arc must be extinguished by other design measures, e.g. by means of the high opening velocity of the contacts, adequately large contact spacing, plasma cooling and acceleration of the arc into the extinguishing chamber, e.g. by a permanent magnetic field.

### Unearthed power supplies (IT system) with insulation monitoring

To operate DC systems safely, these systems are often designed as an unearthed power supply (IT system) with insulation monitoring. Unlike an earthed system (TN, TT system) there is no direct connection between the active conductors and the protective earth conductor (earthing system). At this point it is appropriate to note that even an unearthed system (IT system) has, in accordance with sec. 411.3.1.1 DIN VDE 0100-410 (VDE 0100-410):2007, an earthing system that must meet the requirements of DIN VDE 0100-540 (VDE 0100-540):2012-06 and is therefore identical to an earthing system for TN or TT systems. If the conductive parts in an IT system are connected together and earthed via the same earthing system, in the event of a second fault comparable conditions to the TN system apply. If the conductive parts are earthed in groups or individually, comparable requirements to the TT system apply.

#### In principle the IT system offers two crucial advantages

- In the event of a first fault there is no shut down
- The possible touch voltage is significantly less than 50 V.



The reduced risk of a parallel arc is to be considered an additional advantage of IT systems in DC applications. In IT systems the insulation resistance is monitored continuously during operation by insulation monitoring devices in accordance with DIN EN 61557-8 and an alarm triggered if the resistance drops below the limit set (in accordance with DIN VDE 0100-410 (VDE 0100-410):2007-06 sec. 411.6.3.2). Modern **I**nsulation **M**onitoring **D**eVICES (IMDs) monitor the insulation resistance of the entire IT system including the loads connected and during this process measure the sum of the individual insulation resistances in the form of a parallel circuit.

In addition to monitoring the entire system, the section of the system with a fault can be indicated and located using insulation fault location systems (IFLS) in accordance with DIN EN 61557-9:2009-11. Insulation monitoring and insulation fault location are undertaken without interrupting the supply and do not affect system operation or the loads connected.



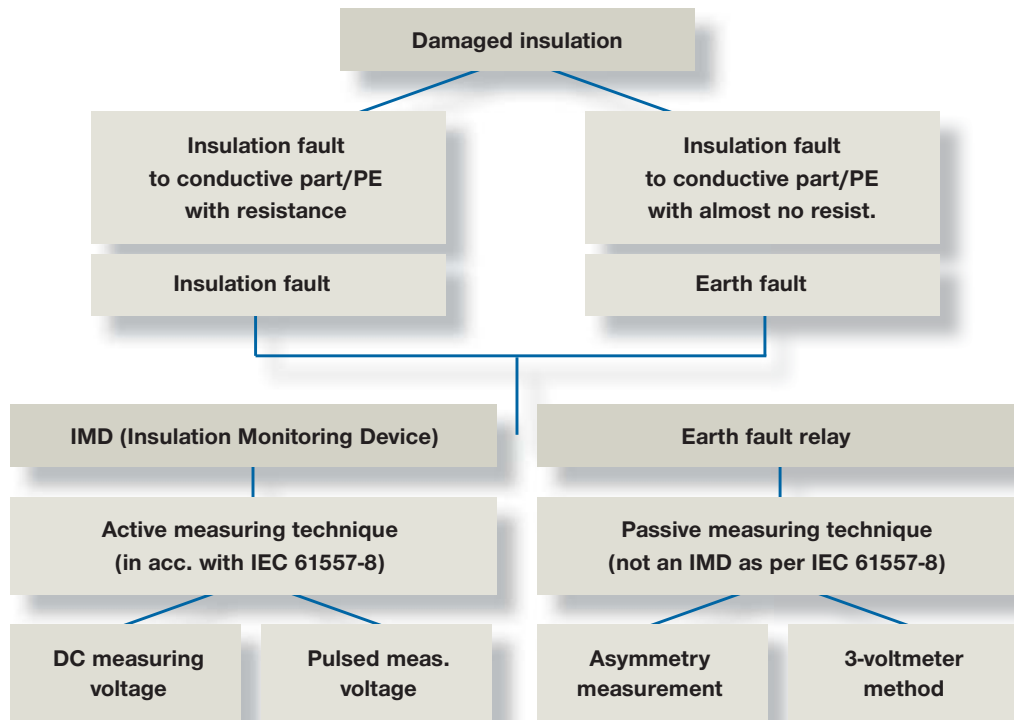


Figure 3: Differentiation insulation monitoring device/earth fault relay

## ▶▶▶ Measuring techniques

The measuring techniques for insulation monitoring devices and earth fault relays can be divided into two main groups.

- Active measuring techniques (insulation monitoring devices, IMD)
- Passive measuring techniques (earth fault relays).

At this point it is appropriate to state that insulation monitoring is not the same as insulation measurement. While insulation monitoring is undertaken continuously during operation, an insulation measurement is made as a snapshot only at specific intervals with the aid of an insulation measuring device in accordance with DIN VDE 61557-2:2008-02. The DC voltage used for this purpose mostly lies in the range of DC 500 V and above.

## Passive measuring techniques

Devices that use a passive measuring technique to determine the insulation resistance are termed earth fault relays. These passive measuring techniques have the major disadvantage that symmetrical insulation faults cannot be detected. A symmetrical degradation in the insulation occurs if the insulation resistance on all conductors in the system to be monitored drops to an (approximately) equal degree. This situation can of course have fatal consequences in certain circumstances. If, due to a symmetrical insulation fault, e.g., heating can occur at the location of the fault (hot spot) with a risk of fire. On the other hand this current is not enough to cause an overcurrent protective device to trip. Due to this serious disadvantage, earth fault relays are not monitoring devices in the context of DIN EN 61557-8:2007-12 and, according to DIN VDE 0100-530 (VDE 0100-530):2011-06, cannot be used for IT systems in Germany.



▶▶▶ **Asymmetrical measuring technique**

The asymmetrical measuring technique is based on the principle of a Wheatstone bridge. Here the two insulation resistances  $R_{F+}$  and  $R_{F-}$  form a branch of this bridge. The two coupling resistances  $R_1$  and  $R_2$  with which these devices are coupled to the system represent the other branch. Due a single-pole insulation fault between L+ or L- and conductive parts that can be touched and that are connected to the protective earth conductor, a current  $I_G$  and a voltage drop across the bridge resistance  $R_3$  is formed. This voltage drop provides an indication of the magnitude of the insulation fault. If the insulation faults  $R_{F+}$  and  $R_{F-}$  in the bridge circuit are the same (symmetrical insulation fault), a current does not flow through the bridge resistance  $R_3$ . As a consequence symmetrical insulation fault is also not detected. In addition, this measuring technique is dependent on the existing system voltage.

**Three voltmeter method**

With the 3-voltmeter method the displacement voltage between earth and the active conductors is evaluated. To obtain a value that is as accurate as possible, a voltmeter with the as far as possible decadic resistance  $R_i$

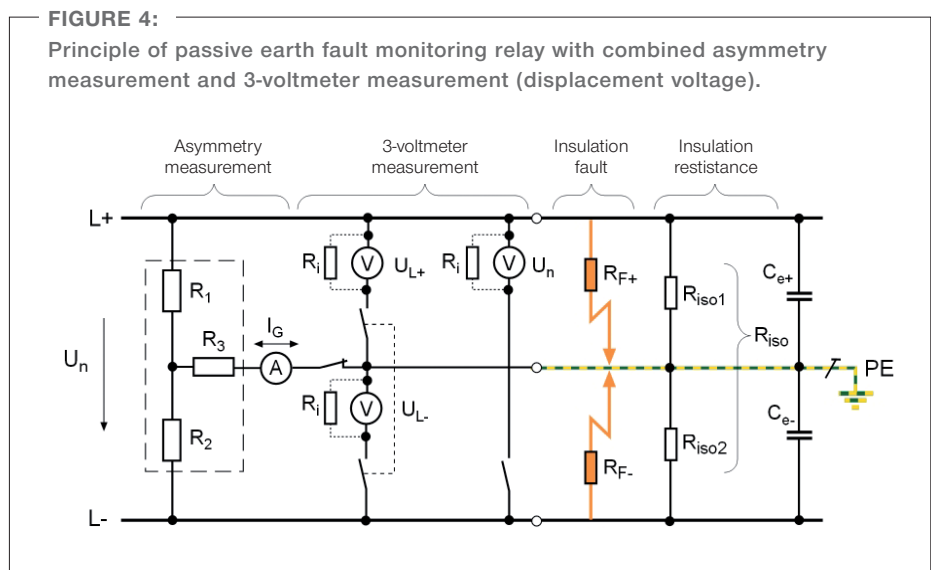


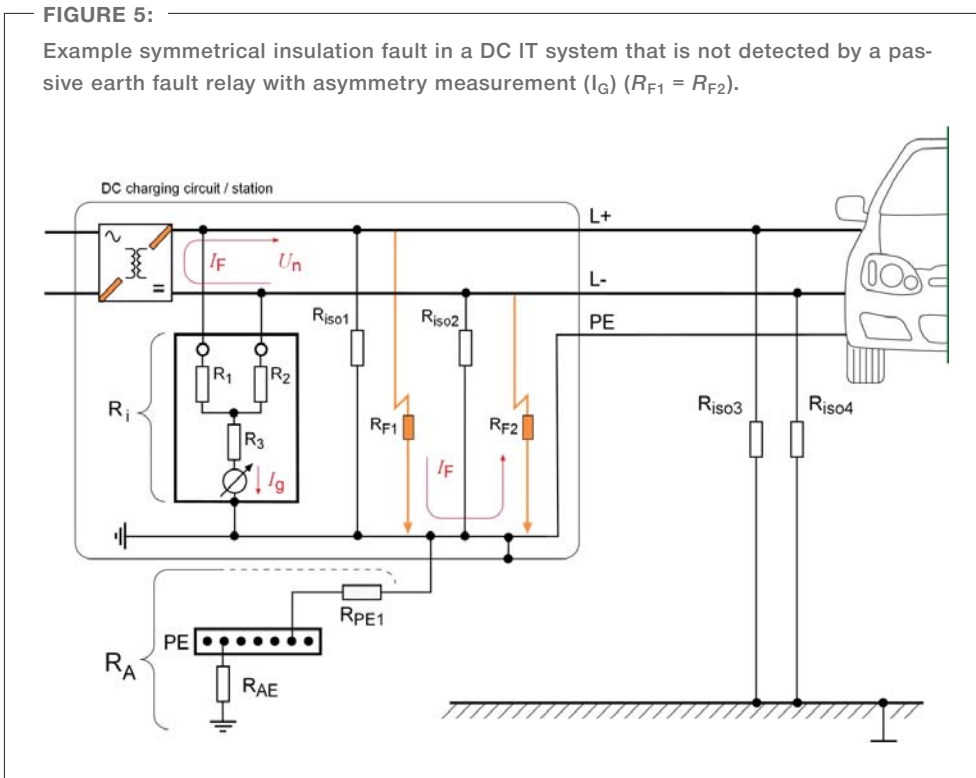
must be used. From the voltages measured it is also possible to determine the insulation resistance using the following formulas:

$$R_{F+} = R_i \frac{U_n (U_{L+} + U_{L-})}{U_{L-}}$$

$$R_{F-} = R_i \frac{U_n (U_{L+} + U_{L-})}{U_{L+}}$$

As a consequence there is also a dependency on the existing system voltage in this case.

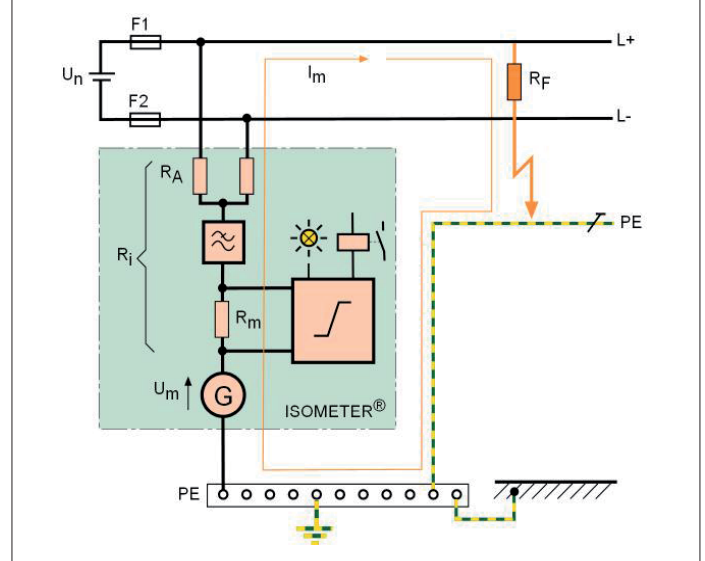




▶▶▶ **Active measuring technique**

Insulation monitoring devices with active measuring technique superimpose a measuring voltage on the system to be monitored. On the occurrence of the first fault, the measuring circuit closes and a small measuring current  $I_m$  flows. This measuring current is then proportional to the insulation fault  $R_F$ . To eliminate, e.g. the effect of the existing system voltage  $U_n$  or high system leakage capacitances  $C_e$ , normally a pulsed measuring voltage is used. This measuring principle also detects symmetrical insulation faults without problems and is also suitable for high system leakage capacitances. Due to the usage of an active source for the measuring voltage, these devices are independent of the system voltage and can, on connection to an auxiliary voltage source, also fully monitor disconnected systems.

**FIGURE 6:**  
DC IT system with active insulation monitoring device ISOMETER®



▶▶▶ SUMMARY

To realise protection against electric shock in accordance with the standards in low voltage DC systems (LV DC systems), IT systems with insulation monitoring devices in accordance with DIN EN 61557-8 (VDE 0413-8):2007-12 are the first choice.

Particularly in applications in which the failure of the power supply on the occurrence of the first fault must be avoided, e.g. computer centres, railway power supply systems etc., the IT system offers the clear advantage of higher availability. Also high protection against electric shock is ensured by very low touch voltages in the event of the first fault. ■



Figure 7: Insulation monitoring device (ISOMETER®) with active measuring technique (picture by Bender Gruenberg, www.bender-de.com)

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REFERENCES:

**Wolfgang Hofheinz:**

VDE series volume 114 3rd edition 2011 - Schutztechnik mit Isolationsüberwachung

**DIN VDE 0100-100 (VDE 0100-100):2009-06**

Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions

**DIN VDE 0100-410 (VDE 0100-410):2007-06**

Low-voltage electrical installations – Part 4-41: Protection for safety - Protection against electric shock

**DIN VDE 0100-530 (VDE 0100-530):2011-06**

Low-voltage electrical installations – Part 530: Selection and erection of electrical equipment – Switchgear and controlgear

**DIN VDE 0100-540 (VDE 0100-540):2012-06**

Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors

**DIN EN 61557-2 (VDE 0413-2):2008-02**

Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures, Part 2: Insulation resistance

**DIN EN 61557-8 (VDE 0413-8):2007-12**

Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures Part 8: Insulation monitoring devices for IT systems

**DIN EN 61557-9 (VDE 0413-9):2009-11**

Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures Part 9: Equipment for insulation fault location in IT systems

**DIN VDE 0100-530 (VDE 0100-530):2011-06**

Low-voltage electrical installations – Part 530: Selection and erection of electrical equipment – Switchgear and controlgear