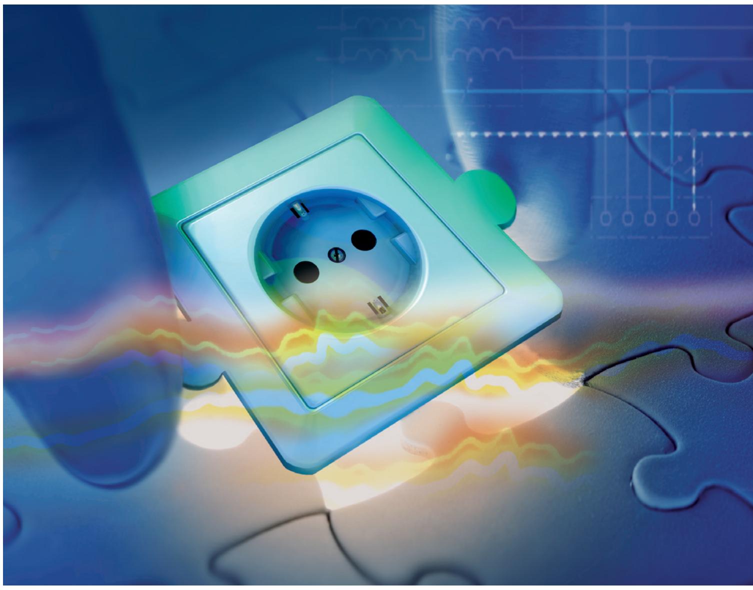
Are RCDs required in socket-outlet circuits in IT systems?

The use of Residual Current protective Devices (RCDs) in IT systems has been a controversial subject for many years, even among experts. A statement given in the German standard, DIN EN 61008-1 Supplement 1 (VDE 0664-10 Supplement 1):2012-10, is very clear about use of RCDs in IT systems in exceptional cases only. This statement can also be found in the new German edition of DIN VDE 0100-410:2018-10, which is, however, somewhat unclear regarding RCDs and IT systems and requires further technical clarification.



Residual Current protective Devices (hereafter referred to as RCDs) are used in many instances to provide what is known as additional protection. But what exactly does "additional protection" mean? In a sentence, additional protection is intended to increase electrical safety. To illustrate this, IEC 60364-4-41:2005 (DIN VDE 0100-410 (VDE 0100-410):2007-06), subclause 411.3.3 contains further protection requirements for socket-outlets and for the supply of mobile equipment for use outdoors. This subclause states that TN and TT systems require RCDs with a rated residual operating current ($I_{\Delta n}$) not exceeding 30 mA for socket outlets and for AC mobile equipment for use outdoors with a rated current not exceeding 20 A if intended for use by ordinary persons and for general use. The intended focus in this subclause is the electrotechnical layman and their exposure to a possible hazard due to direct contact. This can occur, for example, through unintentional contact with live parts, negligence, etc.

RCDs are recognized as additional protection but are not recognized as a sole means of protection. According to the German standard DIN VDE 0100-530 (VDE 0100-530):2018-06, subclause 531.3.6, an RCD may ensure fault and additional protection simultaneously if it is installed at the input of a final circuit or a group of final circuits. This is accepted and standard practice for TN and TT systems, as RCDs have been a proven protective measure in earthed systems (TN/TT systems) for decades.

However, in the new edition of IEC 60364-4-41:2005+AMD:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10), additional protection for socket-outlet circuits using RCDs with $I_{\Delta n} \leq 30$ mA is also required for IT systems if a fault current $I_d > 15$ mA flows in the event of a first fault. On closer inspection, it becomes apparent that this requirement is technically questionable. The updated German standard, DIN VDE 0100-410 (VDE 0100-410):2018-10, states that the correct function of RCDs in IT systems is not guaranteed and their use in socket-outlet circuits remains an exception (refer to the grey shading in 411.3.3). In the opinion of the authors, the standard, at both national and international levels, needs to be corrected and as quickly as possible.

To understand more about RCDs in IT systems, let's take a closer look at the IT system itself.

IT system – an overview

The most widely accepted argument in favour of installing IT systems is the advantage of continued operation in the event of a first insulation fault. A note to this effect can be found in IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10), in subclause 411.3.2:

"For IT systems, automatic disconnection is not necessarily required on the occurrence of a first fault (see 411.6.1). For the requirements for disconnection in the event of a second fault, occurring on a different live conductor, see 411.6.4 following the rules of this subclause."

DIN EN 61008-1, Supplement 1 (VDE 0664-10 Beiblatt 1):2012-10, sunclause 7.2.2.4, reiterates this by stating that an IT system is implemented because it has the advantage that when the first fault occurs, there is no interruption of the power supply to any of the connected electrical loads. However, this "first fault" should be eliminated as quickly as possible.

The proper use of RCDs in IT systems only makes sense if their function can be proven by measurement or calculation. However, because of the complexity and the difficulty in assessing the structure and expansion of an IT system, it cannot be guaranteed that RCDs will function as intended and therefore their use should remain the exception.

This statement holds true for other standards. Therefore, this raises the following questions about the use of RCDs in IT systems:

- **Can or should an RCD disconnect in the event of a first fault?**
- **Are the RCDs currently available on the market suitable for use in an IT system?**
- **Should the RCD perform other tasks?**

On the occurrence of a first fault, the touch voltage remains significantly below the permissible touch voltage. IEC 60364-4-41:2005+AMD:2017 subclause 411.6.4 requires that the exposed-conductive-parts are earthed either individually, in groups or collectively and that the following condition be fulfilled to limit the touch voltage in AC systems to:

$$R_A \times I_d \leq 50 \text{ V}$$

Where:

R_A The sum of the resistance in Ω of the earth electrode and protective conductor for the exposed-conductive-parts.

I_d the fault current in A of the first fault of negligible impedance between a line conductor and an exposed-conductive-part. The value of I_d takes into account the leakage current and the total earthing impedance of the electrical installation.

If this formula is rearranged, it becomes apparent, for example, that with an assumed earth resistance of 2 Ω, an I_d of 50 V/2 Ω = 25 A may flow before a hazard occurs.

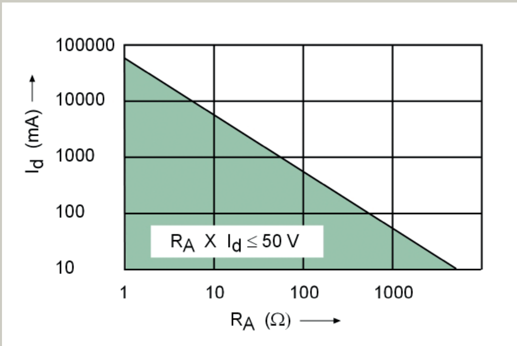


Fig. 1: Fault current I_d as a function of the earth resistance R_A

This becomes even clearer in Fig. 2. The ground resistance R_A is parallel to the body resistance R_K. This means that the touch voltage U_T results from the ratio of the insulation resistance R_{Iso} to the earthing resistance R_A. It should be noted that the protective conductor resistance which is parallel to the body resistance is significantly lower than the body resistance (indirect – direct).

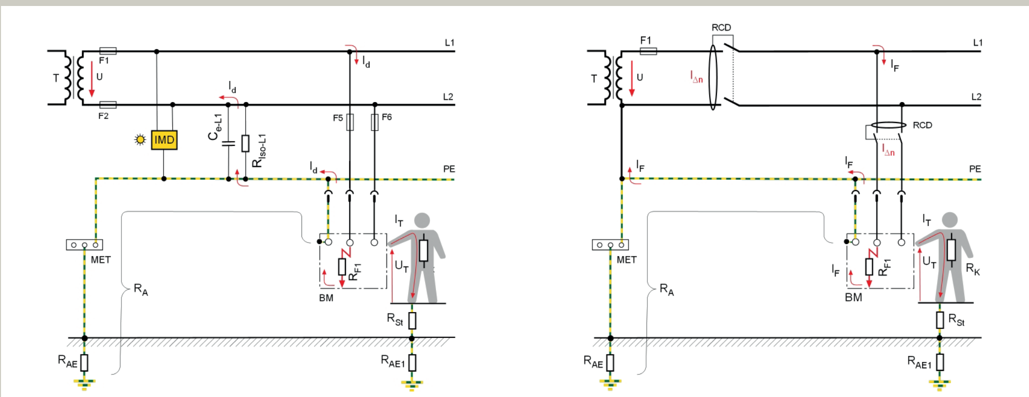


Fig. 2: The first fault in an IT system and in a TN system

An example showing how to calculate the touch voltage or body current in the IT system is given below:

$R_{\text{isol-L1}}$ = 1 MΩ

R_A = 10 Ω

U = 230 V

U_T = 230 V * $R_{\text{PE-BM}}/(R_{\text{isol-L1}} + R_{\text{PE-BM}})$ = 230V * 10 Ω /1 MΩ = 2.3 mV

I_T = U_T / 1 kΩ = 2.3 mV / 1kΩ = 2.3 µA

I_d = 230 V / 1 MΩ = 0.2 mA

What tasks should an RCD fulfil in an IT system?

IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10) contains the international requirement that, if the residual current I_d in the event of a first fault could exceed 15 mA, RCDs must be provided for the respective socket-outlet circuit. Apart from the fact that sockets are more the exception in IT systems, how can the residual current I_d be even determined in the planning phase?

The value of I_d corresponds to the residual current flowing between a live conductor and an exposed-conductive-part in the event of a first fault with negligible impedance. It considers the leakage currents (during operation) and the total impedance of the electrical system to earth. The current I_d is determined mainly by the type of cable, cable length and the number of loads. Also included are changes to the system due to unknown connections and disconnections. No planner can determine these values with even the best of planning.

What about the availability of RCDs for an $I_{\Delta n}$ of 15 mA?

RCDs currently available on the market have a rated residual current of $I_{\Delta n}$ < 30 mA, meaning a suitable product is simply not available to buy. DIN VDE 0100-530 (VDE 0100-530):2018-06, subclause 538.4 states that discriminating (i.e. direction selective) residual current monitoring devices (RCMs) are recommended in AC IT systems to avoid unwanted notifications/alarms due to leakage currents when high leakage capacitances are likely to occur downstream of where the RCM is connected. However, directionally selective RCDs (i.e. only residual currents in the direction of the load are detected) are also not available to buy!

RCDs in TN systems – the first fault

In TN or TT systems, automatic disconnection is mandatory in the event of a first insulation fault, as a hazard is possible in this situation. In the TN system, the fault loop is formed by a live conductor and by PE or PEN. These conductors are largely identical in length, cross-section and material. The resulting fault voltage is approximately half the conductor-earth voltage U_0. RCDs must therefore disconnect equipment or circuits from all poles within a certain time (immediately) if there is the possibility of a hazard occurring due

to a fault current or a possible body current (see Fig. 3). If an RCD with a rated residual current of $I_{\Delta n} \leq 30$ mA is installed at the input of a final circuit or a group of final circuits, this RCD may simultaneously ensure fault protection and provide additional protection.

RCDs in IT systems – the first fault

IT systems are designed so that no active conductor is connected to earth; the exposed-conductive-parts must be earthed individually, in groups or collectively; and the touch voltage must be limited to $R_A \times I_d \leq 50$ V. Under these conditions, the residual current I_d is low in the event of a first fault to earth or to an exposed-conductive-part, and automatic disconnection is not necessary since no dangerous residual current can flow due to the unclosed fault circuit (and high-impedance insulation resistance) - see IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-010 subclauses 411.6.1 and 413). The touch voltage that occurs on the exposed-conductive-part is divided approximately according to ratio of the resistance between the insulation resistance R_{Iso} and the actual insulation fault R_F or earthing resistance R_A (> 500 kΩ, between the live conductors and PE).

IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10), subclause 411.6.3 requires the installation of an Insulation Monitoring Device (IMD) at this point to detect or report the first fault as early as possible before a second insulation fault occurs. If the insulation resistance falls below the typical response value of 100 Ω/V, the IMD shuts down the output circuit. With the knowledge that an RCD requires a fault loop or fault

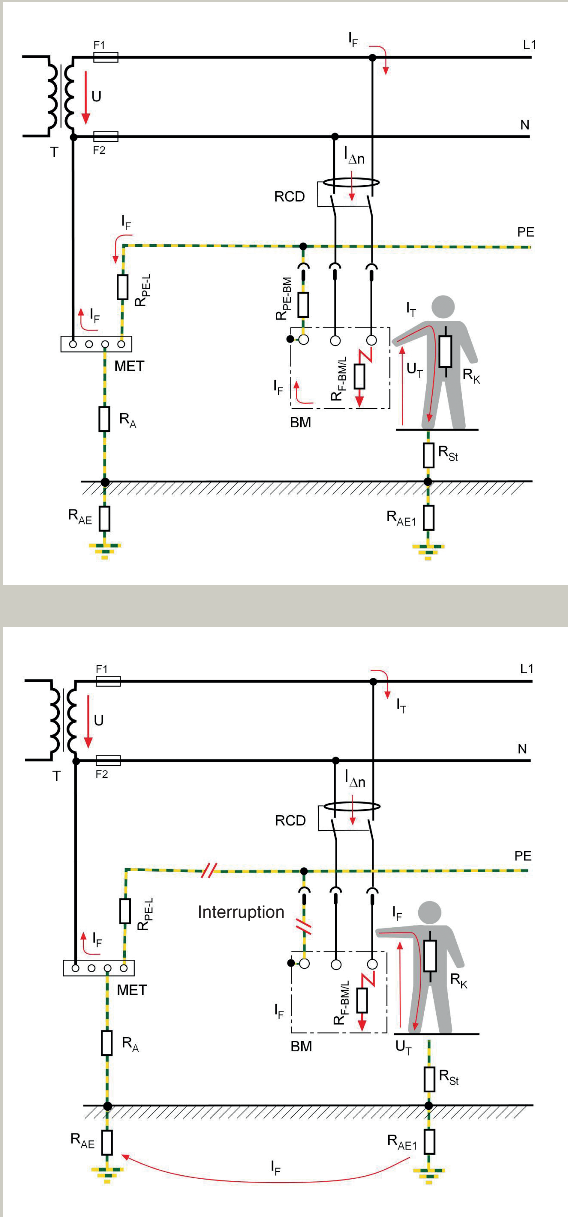
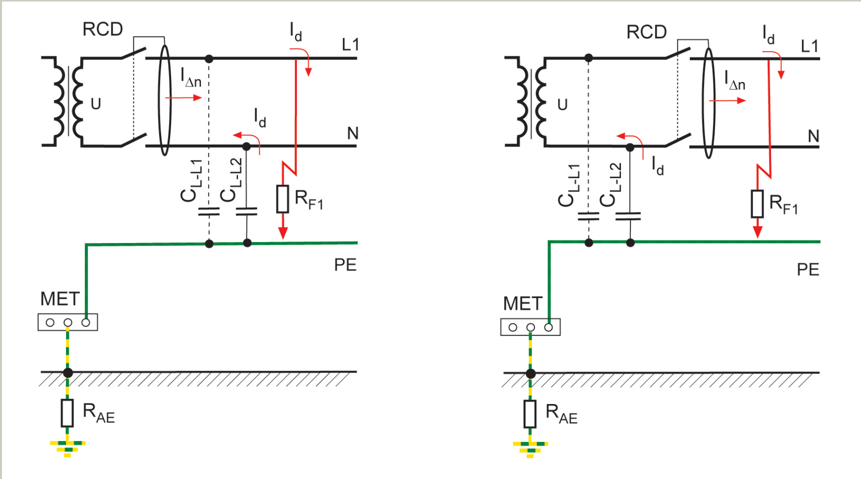


Fig. 3: RCD in an earthed system with indirect and direct contact

Fig. 4:
An RCD in an IT system. The system leakage capacitance is “behind“ (left figure) or “before“ (right figure) the RCD.



current I_F smaller than 30 mA to trip, it is worth taking a closer look at an IT system with an RCD (see Fig. 4).

If a first fault (R_{F1}) occurs, the fault current path also depends on how the $C_{L\text{-}L2}$ network leakage capacitors are divided "before" and "behind" the RCD, which in turn depends on the length and type of cable.

The RCD is only tripped if $C_{L\text{-}L2}$ is large enough or the impedance Z is low and forms a corresponding fault loop (Fig. 4, right). To obtain a high line capacitance C_L before the RCD, the RCD would have to be installed as close as possible to the load and not at the beginning of the final circuit. This contradicts current installation practice in the distribution at the feed-in. The German standard DIN VDE 0100-530 (VDE 0100-530):2018-06, subclause 531.3.6 says that an RCD for the protection of socket-outlets shall be installed at the origin of the final circuit except where this additional protection is provided by RCDs integral with all the socket-outlets of the circuit.

DIN VDE 0100-410 (VDE 0100-410):2018-10 contains a further reference in subclause 411.3.3 with regard to RCD tripping: because of the complexity and the difficulty in assessing the structure and expansion of an IT system, it cannot be guaranteed that RCDs will function as intended and their use in socket-outlet circuits remains an exception. Likewise, DIN VDE 0100-530 (VDE 0100-530):2018-06 subclause 532.3 points out that to protect against fire risks in IT systems, the requirements of DIN VDE 0100-410 (VDE 0100-410):2007-06, 411.6.3.1 for IMDs are to be given priority over RCMs, which can be used as an alternative to RCDs.

An RCD may not be able to trip in the event of a first fault due to insufficient residual current and this is supported in IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10) in subclause 411.6.1: "The fault current is then low in the event of a single fault to an exposed-conductive-part or to earth and automatic disconnection in accordance with 411.3.2 is not imperative, provided the condition in 411.6.2 is fulfilled". The condition referred to is that the exposed-conductive-part are grounded individually, in groups or collectively.

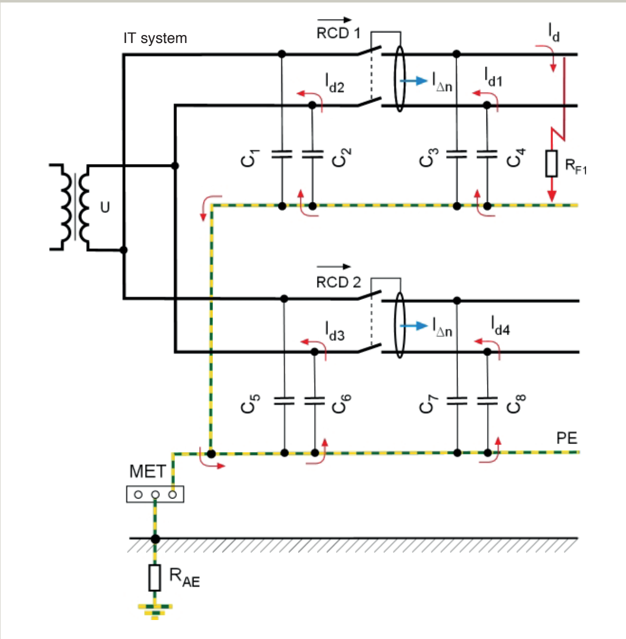


Fig. 5: RCDs in a branched IT system

RCDs in branched IT systems

The behaviour of RCDs in branched IT systems is even more complex, with one RCD present in each branch (see Fig. 5).

Depending on the distribution of the system leakage capacitances C_1 to C_4 or C_5 to C_8, any RCD could be triggered even though the insulation fault R_{F1} may be located in a different branch. Instead, DIN VDE 0100-530 (VDE 0100-530):2018-06 subclause 538.4 recommends the use of discriminating (i.e. direction selective) RCMs in order to avoid unwanted notifications caused by high leakage currents resulting from high leakage capacitances downstream of the RCM current transformer. Direction-selective in this case means only evaluating residual currents to the load.

This example shows that the use of RCDs in IT systems is not a solution and clearly contradicts the actual goal of an IT system, i.e. trouble-free continued operation in the event of a first fault.

Disconnection using RCDs and OCPDs in the event of a second fault?

In contrast to TN or TT systems, the second fault must always be considered with IT systems because a second fault on another line conductor must lead to an automatic disconnection, taking into account the disconnection times specified in Table 41.1 of IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10). Depending on the design of the earthing, the disconnection conditions for a TN system must be fulfilled when exposed-conductive-parts are collectively earthed, and the disconnection conditions for a TT system must be fulfilled when exposed-conductive-parts are earthed individually or in groups (subclause 411.6.4). The impedance of the fault loop is always decisive so that the required disconnection times can be achieved.

It is easy to see that, for example, in the case of a socket-outlet, a second fault on another conductor corresponds to a short-circuit which then leads to disconnection by the Overcurrent Protection Devices (OCPDs). This requires at least a current source that can supply the appropriate short-circuit current or a suitably designed OCPD. This must be observed, for example, in PV systems.

IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10) subclause 411.3.2.6 points out that if the maximum disconnection times cannot be achieved, supplementary protective equipotential bonding shall be provided in accordance with subclause 415.2. In the German standard DIN VDE 0100-410 (VDE 0100-410):2018-10, subclause 411.3.2.5 also points out that an RCD should be used if the disconnection times are not observed. In IT systems, however, this only works in certain cases because the fault location must also be considered. If the second fault occurs behind an RCD, there is no shutdown as there is no residual current to trigger the RCD. In this case, the RCD only gives the impression of safety as opposed to actually being safe.

In an earlier edition of DIN VDE 0100-530:2011-06, there was a note to this effect in subclause 531.3.5.3, which said that symmetrical faults on different line conductors do not generate a fault current leading to disconnection. IEC 60364-4-41:2005+AMD1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10) subclause 411.6.3 also points out that in the event of two faults on different line conductors, the operation of the RCD is only likely to be achieved if every single item of current using equipment is protected by its own RCD and that in these cases the use of overcurrent protective devices is also considered a suitable measure.

SUMMARY

The previous edition of IEC 60364-4-41:2005+AMD 1:2017 (DIN VDE 0100-410 (VDE 0100-410):2018-10) focused, and with good reason, on TN or TT systems only when using RCDs for additional protection. The use of RCDs in socket-outlet circuits of IT systems as described in the current standard cannot be approved in principle and requires a great deal of specialist knowledge of the existing or planned electrical system.

Because of the complexity and the difficulty in assessing the structure and expansion of an IT system, the use of RCDs in socket-outlets of IT systems should always remain the exception because it cannot be guaranteed they will function as intended. Here, the emphasis should be on proper notification at a suitable point or rapid localization using an Insulation Fault Location System (IFLS). This also avoids unwanted disconnection as IT systems are always installed where a first fault must not lead to disconnection. ■

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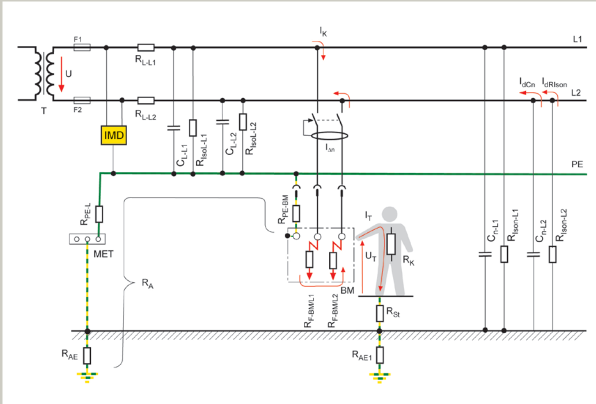

Fig. 6: RCD is not triggered in the event of a second fault "behind" or downstream of the RCD

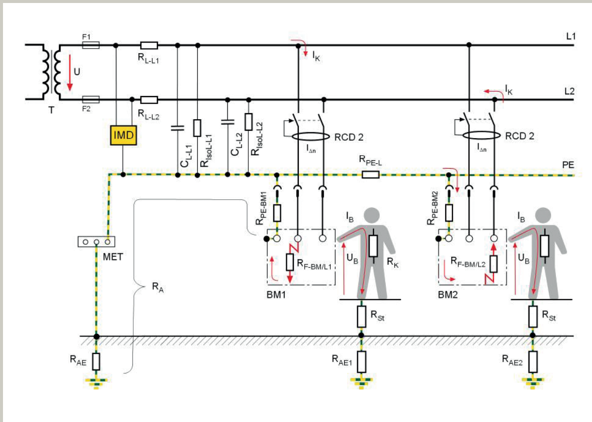

Fig. 7: Triggering of one of the two RCDs in the event of two faults. The faults must occur on different conductors and in different circuits.

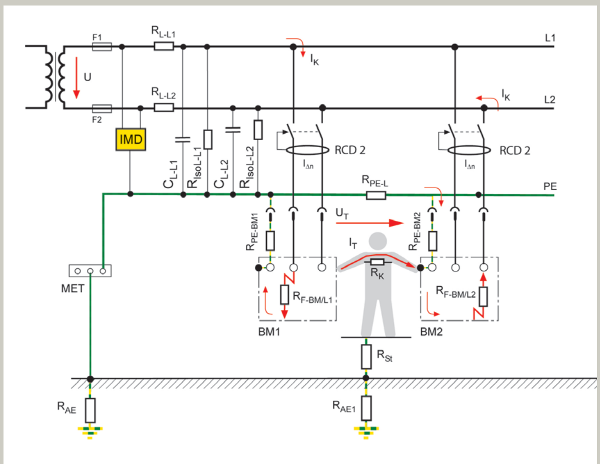

Fig. 8: When simultaneously touching different safety-class 1 equipment, safety is provided by the protective conductor or equipotential bonding parallel to the body.

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DIN EN 61008-1 Beiblatt 1 (VDE 0664-10 Beiblatt 1):2012-10
Fehlerstrom-/Differenzstrom-Schutzschalter ohne eingebauten Überstromschutz (RCCBs)
für Hausinstallationen und für ähnliche Anwendungen
Teil 1: Allgemeine Anforderungen
Beiblatt 1: Anwendungshinweise zum Einsatz von RCCBs nach DIN EN 61008-1 (VDE 0664-10)

NOTE: The standards can be obtained from VDE (www.vde.com) or Beuth (www.beuth.de).

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