Initial and periodic verification of IT systems

(unearthed power supplies)

The objective of electrical installations and equipment testing is a verification that there are no deficiencies and that the required personnel and equipment protection is ensured after commissioning and/or during use. Both the tests and the associated environment are described in various statutory technical rules and set of standards. The following technical paper describes the applicable requirements for unearthed power supplies (IT systems).

Standard requirements

When testing power supply systems it should always be distinguished between initial and periodic inspection and testing. In particular, the following standards have to be considered:

- **DIN VDE 0100-600 (VDE 0100-600):2008-06**
  Installing low-voltage systems
  Part 6: Verifications (IEC 60364-6:2006, modified)

- **DIN VDE 0105-100 (VDE 0105-100):2009-10**
  Operating electrical systems
  Part 100: General requirements

For initial verification the installation contractor has to verify that the installation has been set up according to the acknowledged rules of technology and that the installation does not represent a source of hazard. During initial verification also those parameters should be recorded which can later be used as a basis for periodic verification. Periodic inspection and testing is the responsibility of the system operator. As a contractor, the operator is obliged to carry out periodic testing according to the Accident Prevention Regulations (Germany). DIN VDE 0100-600:2008-06 stipulates the requirements for the initial verification of electrical installations and DIN VDE 0105-100:2009-10 describes a test and inspection to ascertain that the condition of an existing installation still fulfils the requirements of the initial verification. Periodic testing must be performed by a qualified electrician who is capable of assessing and evaluating the impact of changes. The associated test devices must comply with the requirements of the DIN EN 61557-... series of standards. The tests are performed in the usual sequence Inspection – Measurement – Tests. It is the responsibility of the person carrying out the inspection to specify the required test steps in detail.

Inspection

Before starting measurements the person carrying out the measurements should have a full picture of the IT system to be tested:

- Structure and size of the IT system
- Type and nominal values of the current source
- Number and distribution of the existing circuits
- Type and local conditions of the earthing system
- Type of earthing of the exposed conductive parts individually, in groups, sharing a common connection to earth
- Type of the protective earth conductor(s) used
- Number and type of the protective and monitoring devices used.

While looking at the existing documentation of the installation its correctness and completeness must already be checked. For periodic verification previous test reports, for example, allow a comparison to previous measured values and the resulting changes.

Before measuring – ensure absence of errors

When the structure and the use of protective measures in the IT system are known, first it is necessary to check that the IT system is fault-free, i.e. that the system is free from insulation faults. This can be checked by means of an insulation monitoring device (IMD). Alternatively, it is also possible to measure the voltage shift. The shift voltages in a fault-free IT system or on the occurrence of a low-resistance insulation fault at conductor L1 is illustrated in table 1. Shift voltage measurements, however, should only be carried out in very small IT systems with low system leakage capacitance, because balanced insulation faults and different system leakage capacitances between the respective active conductors and earth can have an impact on the shift voltage so that finally only one IMD reliably indicates the insulation resistance. Especially in 3AC IT systems the shift voltage cannot be applied with sufficient reliability since even relatively low resistance insulation faults can be compensated by an unfavourable distribution of system leakage capacitances.

FIG. 1:

Principle of shift voltage measurement in 1Ph IT systems

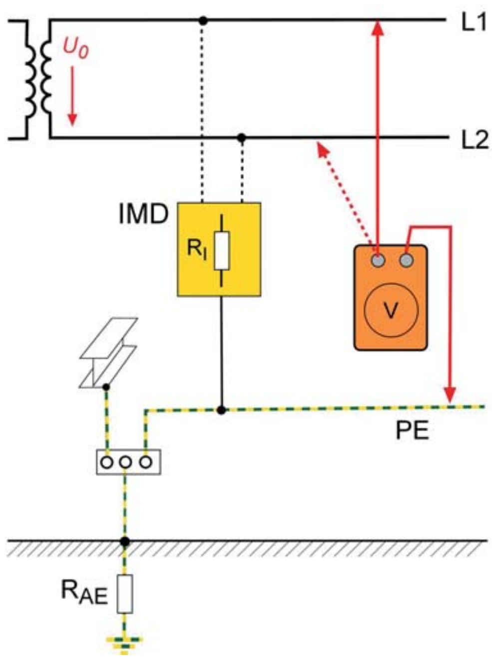
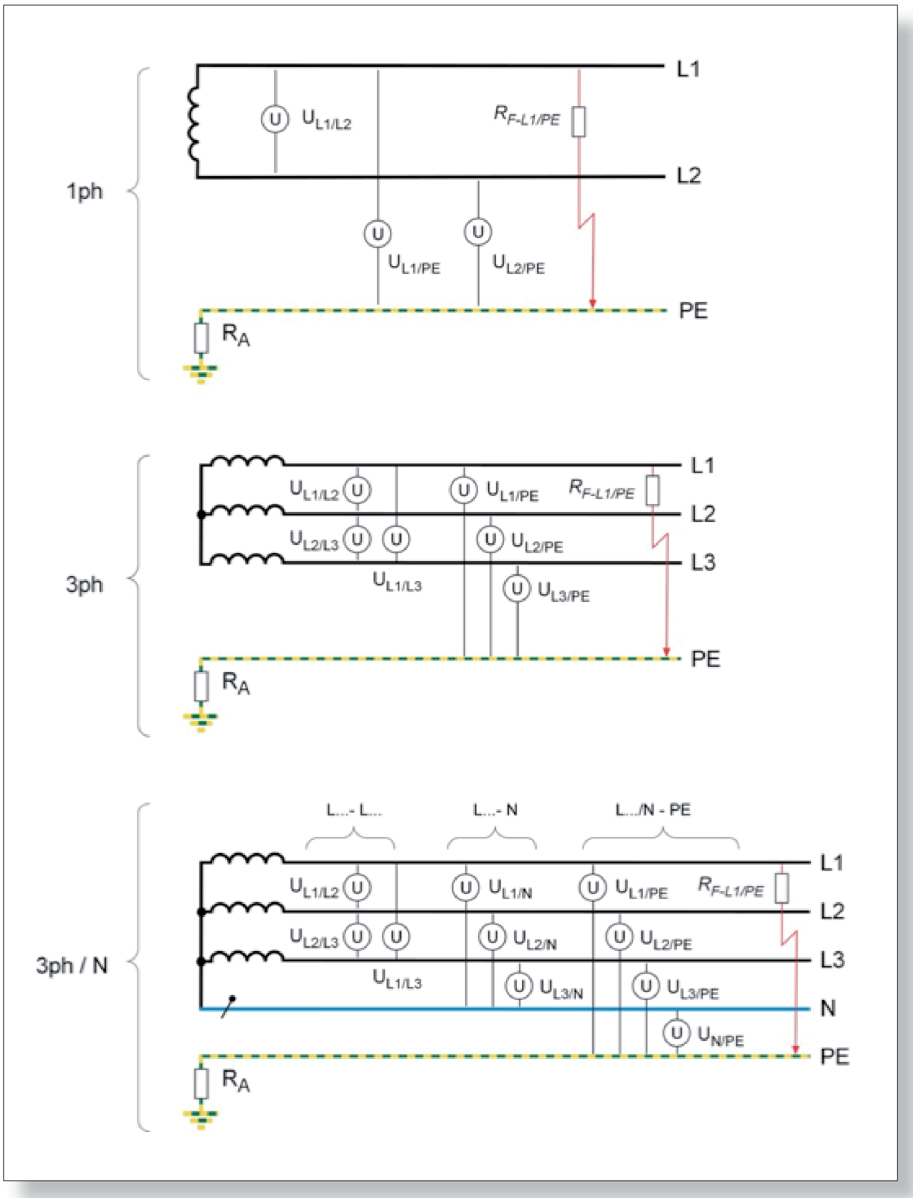


Table 1:

Measured values of the shift voltage in IT systems with and without an insulation fault R_F-.... with practically no resistance at L1



	$R_{F\text{-}L1/PE}$ = ∞ Ω	$R_{F\text{-}L1/PE}$ = 0 Ω
$U_{L1/L2}$	230 V	230 V
$U_{L1/PE}$	115 V	0 V
$U_{L2/PE}$	115 V	230 V

	$R_{F\text{-}L1/PE}$ = ∞ Ω	$R_{F\text{-}L1/PE}$ = 0 Ω
$U_{L1/L2}$	400 V	400 V
$U_{L2/L3}$	400 V	400 V
$U_{L1/L3}$	400 V	400 V
$U_{L1/PE}$	230 V	0 V
$U_{L2/PE}$	230 V	400 V
$U_{L3/PE}$	230 V	400 V

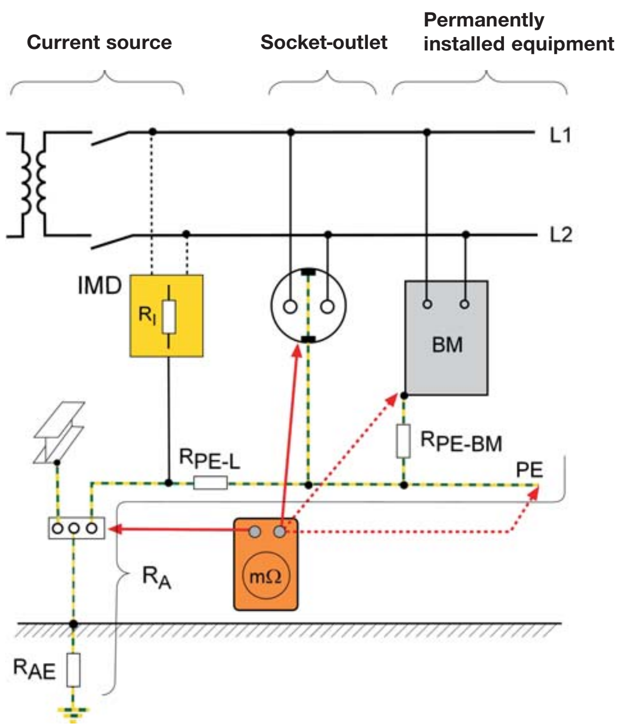
	$R_{F\text{-}L1/PE}$ = ∞ Ω	$R_{F\text{-}L1/PE}$ = 0 Ω
$U_{L1/L2}$	400 V	400 V
$U_{L2/L3}$	400 V	400 V
$U_{L1/L3}$	400 V	400 V
$U_{L1/N}$	230 V	230 V
$U_{L2/N}$	230 V	230 V
$U_{L3/N}$	230 V	230 V
$U_{L1/PE}$	230 V	0 V
$U_{L2/PE}$	230 V	400 V
$U_{L3/PE}$	230 V	400 V
$U_{N/PE}$	0 V	230 V

Test of the continuity of the protective conductor connections R_{PE}

To measure the protective conductor continuity and to check the protective conductors for proper status and trouble-free functionality are basic requirements for safe operation of the installation. A protective conductor in proper condition forms the basis for proper implementation of the protective measures against electric shock.

FIG. 2:

Example of a protective conductor continuity measurement



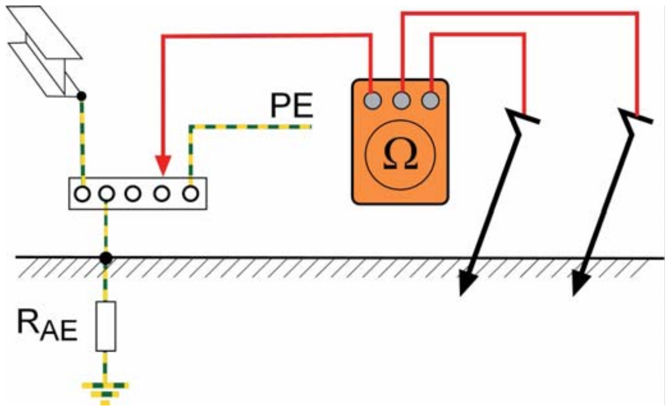
R_{PE} consists of the protective conductor resistance in the installation $R_{PE\text{-}L}$ and the protective conductor resistance of the power supply cable $R_{PE\text{-}BM}$ of the electrical equipment.

Measurement of the earthing resistance R_{AE}

The earthing resistance R_{AE} is the resistance between the reference earth and the earthing system connection. In IT systems the earthing arrangement is required in particular to bring the individual equipment parts and circuits to a common reference potential that is as close as possible to the reference earth potential. There are different measurement methods to determine the earthing resistance. In practice, the earthing resistance is often measured between several earthing points and the main equipotential bonding conductor.

FIG. 3:

Example of an earthing resistance measurement in an IT system



Determination of the earthing resistance R_A

For IT systems the fundamental condition $R_A \times I_d \leq 50$ V (AC systems) applies. R_A consists of the part resistors R_{AE} and R_{PE}. A maximum permissible value is not defined, the obtained values, however, should not be higher than the value to be expected with regard to the wiring system and contact resistance data. In practice, for example, according to DIN VDE 0100-551 a total value of 100 Ω is required for R_A. Taking a second fault and the required tripping of an RCD into account, the earthing resistance should not exceed the following values:

$I_{\Delta n}$	10 mA	30 mA	100 mA	300 mA	500 mA	1 A
R_A	5000 Ω	1666 Ω	500 Ω	166 Ω	100 Ω	50 Ω

Insulation resistance measurement

Insulation measurement and insulation monitoring are terms that are easily confused since in principle they are very similar. Insulation measurement is a test that is carried out in disconnected or deenergised systems using an insulation measuring device according to IEC 61557-2 to measure the insulation resistance between active conductors and the protective conductor. This measurement is not only intended for the IT system but also applied for TN and TT systems. Insulation monitoring is continuous monitoring of the insulation resistance of an IT system during operation and hence of all electrical equipment connected.

To carry out insulation measurement correctly, the installation or the part of the installation to be tested must be disconnected. The insulation monitoring device must also be disconnected. If the insulation monitoring device (IMD) cannot be disconnected from the system it has to checked whether the applied measuring voltage is suited for the insulation monitoring device. When the internal resistance is measured and the insulation monitoring device is not disconnected, the indicated measured value may differ from the extremely high insulation resistance (≥ 5 MΩ).

The insulation resistance is measured between the active conductors and the protective conductor connected to earth. During this test the active conductors may be connected together electrically. The DC measuring voltage and the level of insulation resistance have to comply with the requirements of table 2. The insulation resistance is considered adequate if each circuit reaches the required value without electrical loads connected. During the measurement it should be ensured that all switches in the circuit are closed. If it is not possible to close circuits, the electrical circuits that are not measured must be measured separately. Any existing connections between N and PE must be open.

Table 2:
Insulation resistance and measuring voltage according to DIN VDE 0100-600 (VDE 0100-600):2008-06

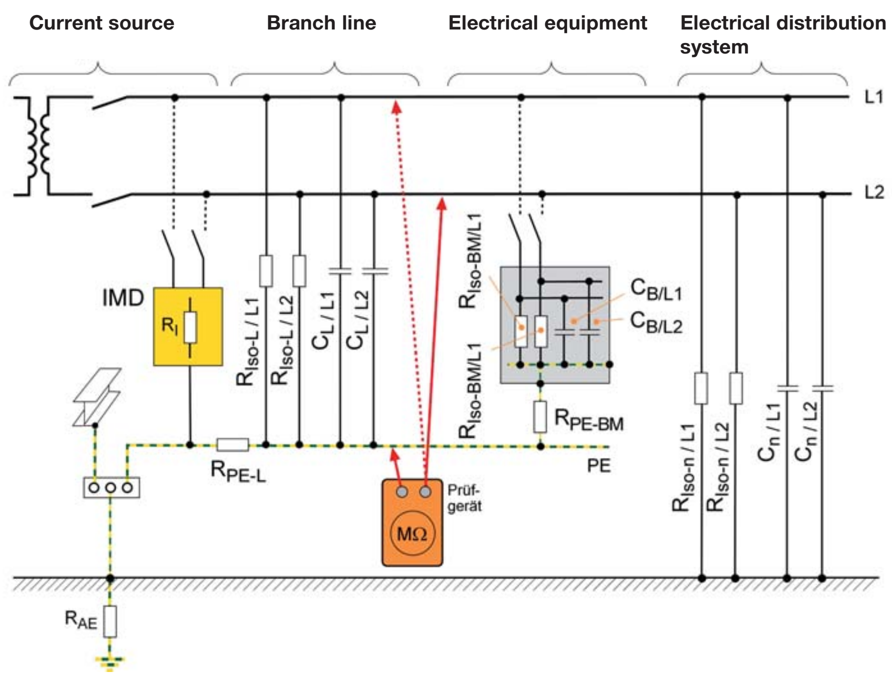
Nominal voltage of the electrical circuit (V)	DC measuring voltage (V)	Insulation resistance (MΩ) min.
SELV, PELV	250	0,5
Up to 500 V, as well as FELV	500	1,0
Above 500 V	1000	1,0

The measuring voltage is a DC voltage as only ohmic resistances are measured. The magnitude of the measuring voltage is based on the type of system or equipment to be tested and is defined in the applicable standards for safety-related tests (see table 2). The measuring voltage for 230/400 V systems is DC 500 V. The measuring current must at least be 1 mA and the peak value must not exceed 15 mA. The level of measuring voltage is also used to test a certain "dielectric strength". Therefore all items of the electrical equipment connected must withstand this measuring voltage for at least one minute. During insulation measurement, accessible conductive parts must not be touched in order to avoid the risk of electric shock, for example in the event of defective devices.

Continuous monitoring with an IMD facilitates insulation resistance measurement during operation considerably since after the initial measurement, the IMD fulfils this task with the electrical system in operation (acc. to DIN VDE 0100-600:2008-06 sect. 61.3.3). If an IMD exists, during periodic testing the single measurement of the insulation resistance is not required. This is also advantageous for electrical installations which cannot be disconnected for operational reasons. Ultimately, a selective measurement is being replaced by continuous monitoring. Since the DC measuring voltage of the insulation monitoring device is below the max. permissible touch voltage AC 50 V/DC 120 V no danger can arise.

FIG. 4:

Measurement of the insulation resistance using an insulation measuring device acc. to DIN EN 61557-2



Fault current measurement I_d

In IT systems compliance with the following condition has to be verified:

$R_A \times I_d \leq 50$ **V** (AC systems)

For DC systems < 120 V are permissible.

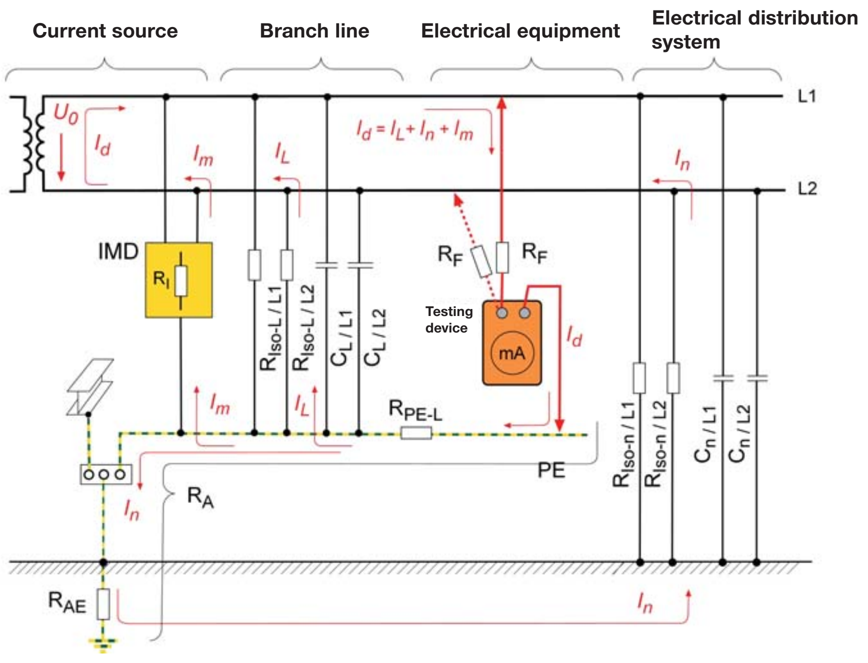
R_A the sum of resistances in Ω of the earth electrode and the protective conductor to the respective exposed-conductive part;

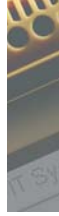
I_d the fault current in A of the first fault with negligible impedance between the line conductor and an exposed-conductive part. The value of I_d takes account of the leakage currents and the total earthing impedance of the electrical installation. Thereby, the value I_d can be determined arithmetically as well as metrologically. For fault current measurement an active conductor (e.g. L1) has to be connected to earth with a resistance that is almost null, then the current between earth and the other active conductors (e.g. L2) can be measured by means of an ammeter. From the measured fault current I_d and the earthing resistance R_A the possible touch voltage U_B can be calculated and compared to the local permitted touch voltage U_L.

When carrying out the measurement manually, appropriate precautions must be taken in order to avoid a hazard in the event of a double fault. Appropriate test device ruling out such risks are now available on the market.

FIG. 5:

Measurement I_d





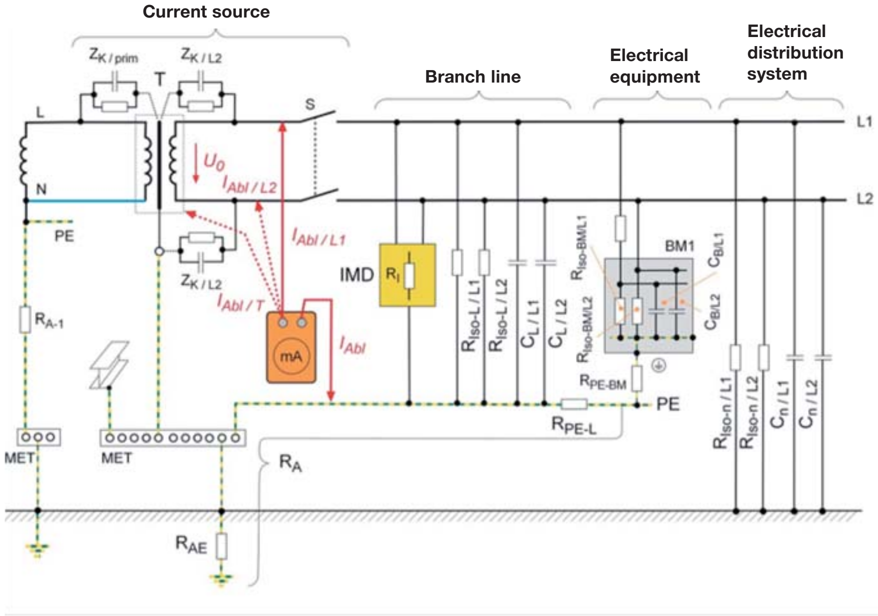
Measurement of the leakage current I_{Abl}

The leakage current is the current that flows from the active parts of the installation to earth, without the existence of an insulation fault. In IT systems this current is usually very small, since the common insulation resistances and the system leakage capacitances are placed almost symmetrically to earth. The leakage capacitance is especially relevant in medical IT systems. Therefore, according to DIN EN 61558-2-15:2012-09, for the isolating transformers a leakage current of the output winding of 0.5 mA under no-load conditions is permissible, whereby the leakage current I_{Abl} is measured with an ampere meter with a negligible impedance. The leakage current I_{Abl} is not to be confused with fault current I_d, which is measured with an insulation fault R_F with a resistance that is almost null. The measurement of I_{Abl} is carried out with an open switch S at L1, L2 and the transformer core respectively.

If the measurement is carried out with a closed switch S, information about the leakage current ratio of the entire IT systems is provided. Therefore, all items of the electrical equipment must be activated.

FIG. 6:

Leakage current measurement in the IT system



Measurement and test of the disconnection conditions in the event of a second fault

This test is used to check if the protective device in the circuit disconnects at least one point of fault within the specified time in the event of two insulation faults occurring at different active line conductors (double fault). When the IT system comprises only one circuit, the person carrying out the test measures the system impedance Z_S at the end of the circuit between two line conductors or, when the N conductor is also led out, the system impedance Z'_S Zs between one line conductor and the N conductor. The system impedance measured and the value of the maximum permissible disconnection current I_a of the overcurrent protective device can be used to check the correct functioning of the overcurrent protective devices. For fault loop impedance the following conditions in accordance with DIN VDE 0100-410:2007-06 section 411.6.4 apply:

a)

When exposed-conductive parts are interconnected by a protective conductor and are collectively earthed to the same earthing system, the conditions similar to a TN system apply and the following conditions have to be fulfilled:

AC systems without neutral conductor and DC systems without mid-point conductor:

$$Z_S \leq \frac{U}{2 \times I_a}$$

Systems with neutral conductor or with mid-point conductor

$$Z'_S \leq \frac{U_0}{2 \times I_a}$$

where

U_0 is the nominal AC or DC voltage between line conductor and neutral conductor or mid-point conductor;

U is the nominal AC or DC voltage between line conductors;

Z_S is the impedance of the fault loop comprising the line conductor and the protective conductor of the circuit;

Z'_S is the impedance of the fault loop comprising the neutral conductor and the protective conductor of the circuit;

I_a is the current causing operation of the protective device within the time required for TN systems.

b)

When the exposed-conductive parts are earthed in groups or individually the following condition applies:

$$R_A \leq \frac{50\ V}{I_a}$$

where

R_A is the sum of the resistances in ohms of the earth electrode and of the protective conductor to the exposed-conductive parts;

I_a is the current in A causing automatic disconnection of the disconnection device in a time complying to that for TT systems.

The second case is an IT system with several circuits. In this type of system it is not possible to know in advance in which circuits or even in which of the different locations the two faults in question occur simultaneously. This results in different fault loops depending on the point of fault and for each fault loop a special system impedance Z_s. Therefore, the system impedance should be measured at the end of each circuit. This gives the user an idea of the resistance ratio in the active part of the system.

FIG. 7:

Example of a system impedance measurement

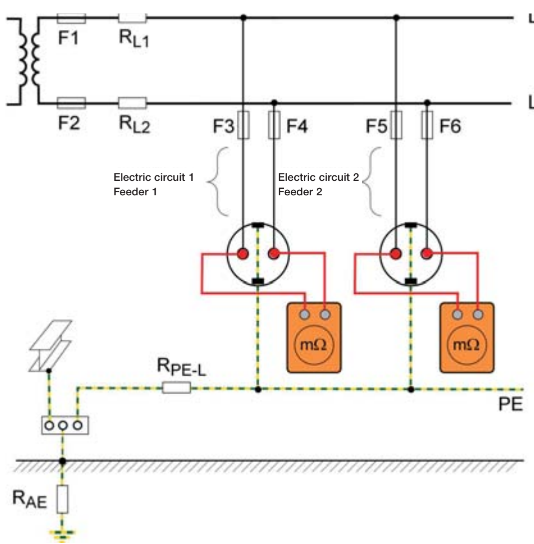
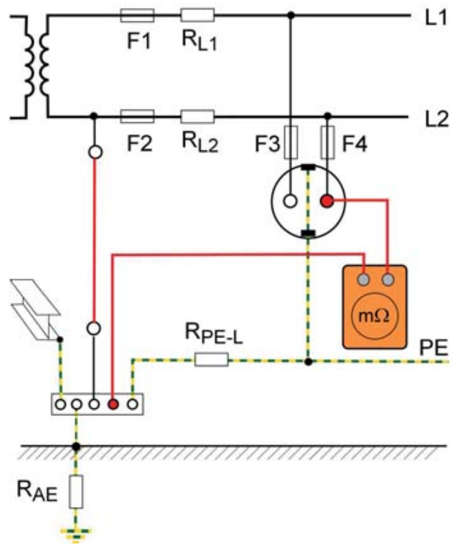


FIG. 8:

Example of a loop impedance measurement with the active conductor earthed before measuring



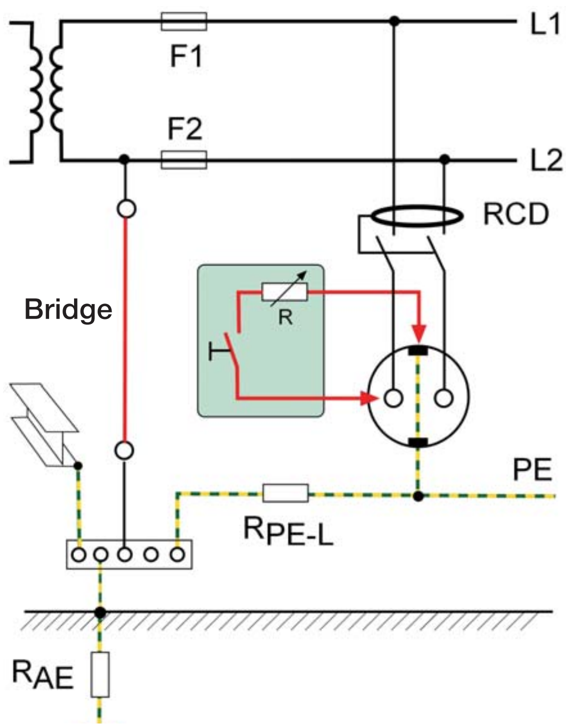
Testing residual current protective devices RCD

The residual current protective devices RCD primarily trip in the event of a second fault at a different conductor, i.e. the fault loop only closes via the protective conductor in the event of a double fault. Therefore, in practice, an artificial earth fault is generated to carry out this measurement. It should be considered that electrical equipment in a three-phase IT system with N conductor is exposed to high mechanical stress due to the fact that the voltage of the fault-free conductors against earth increases to the level of the line conductor voltage.

After creating an artificial earth fault (1st fault) proper tripping of the RCD can be tested and assessed by means of an RCD test device. In general, it should be noted that high system leakage capacitances can result in unwanted tripping of an RCD.

FIG. 9:

Functional test of RCDs in IT systems



Functional and operational tests

Groups of components like switchgear combinations, drives, control devices and locking devices must be subjected to a functional test to verify that they are correctly mounted, set up and installed according to the respective requirements of the standard. For protective devices it is essential to carry out a functional test to determine that they are set up and adjusted for the intended purpose.

Functional test of an insulation monitoring device

The insulation monitoring device (IMD) has to be tested and evaluated using the device documentation or suitable test equipment. The following points have to be observed:

- Device conformity with the product standard DIN EN 61557-8
- Suitability of the IMD for the application in question at the site of operation
- Setting of the response value(s) R_{an}
- Execution, effectiveness and visibility of the optical and, if required, acoustical indication in the event of an insulation fault
- Functionality of the test button on the IMD.

a) Testing the internal monitoring functions of the IMD

Insulation monitoring devices may include internal monitoring functions in order to ensure the correct function of the IMD. This is, for example, the connection monitoring to the system and to earth. Each of these connections have at least two poles. If the person carrying out the test opens one of these connections between the IMD and the protective conductor or earth, this fault has to be indicated by the IMD. The same applies for the mains side connection.

b) Correct setting of the response values

If no specific response value is set, a response value of 100 Ω/V should be set on the IMD as main alarm. If the IMD utilises a second alarm level, a prewarning level of 300 Ω/V can be set. This has the advantage that a possible change in the electrical installation comes to the operator's attention at an early stage without the need to take prompt action. He can postpone the service date to a later scheduled point in time. In medical locations a minimum value of 50 kΩ is required.

c) Testing the response value

The tripping function of the IMD is tested according to IEC 61557-8 section 6.1.2 using a test resistance, the value of which has to comply with half the value of the response value set for the IMD. The testing procedure of the response time is described in the standard IEC 61557-8:2007-01 section 6.1.2 Response time. Afterwards, with a system leakage capacitance of max. 1 µF, a suitable test resistance has to be suddenly connected between the active conductor and earth or to the equipotential bonding and the delay time until disconnection of the output circuit (e.g. socket-outlet) has to be measured.

If higher system leakage capacitances C_e exist in the IT system, the tripping of the insulation monitoring device may be delayed. The response time can be determined by a rough calculation using the formula $5\tau = R_i \times C_e$ where R_i is the internal resistance of the insulation monitoring device. Depending on the measuring principle of the IMD a much shorter period of time is also possible. When selecting the test resistance the suitability for the application in question has to be taken into consideration (dielectric strength etc.).

d) Testing the correct optical and acoustical message

The person carrying out the test has to check whether the warning indication tripped by the IMD has arrived correctly where needed and whether it can be perceived consciously. For example in a hospital the issue is to ensure that the warning indication is shown at a location that is always manned. In addition, instructions on how to best deal with the warning indication should be placed at these locations.

It also has to be checked that the permissible and required change-over and switchback functions work correctly. When insulation monitoring devices utilise an automatic self test function, the effect of this warning indication has to be checked.

Generating a test report

After finishing the test of a new installation or after extensions or modifications of an existing installation a test report about the initial verification has to be generated. This test report must include details regarding the size of the installation covered by this report, a recording about the inspection and the test results.

Before the installation contractor declares that this installation complies with the requirements of the standards DIN VDE 0100 (VDE 0100) all deficiencies identified during the test must have been remedied. The test report must be handed over to the installation owner.

The same applies to periodic verification. A test report has to be generated from the recorded scope and the results of periodic verification.

SUMMARY

Electrical installations have to be set up according to the acknowledged rules of technology. This has to be verified by tests in order to ensure that the user operates an installation in conformity with the rules and a risk for people and damage to property can be avoided. DIN VDE 0100-600 and DIN VDE 0105-100 contain the necessary specifications. However, in the end the person carrying out the test is responsible for the measurement and the selection of the suitable measuring principles. ■

FIG. 10:

Functional test of an IMD

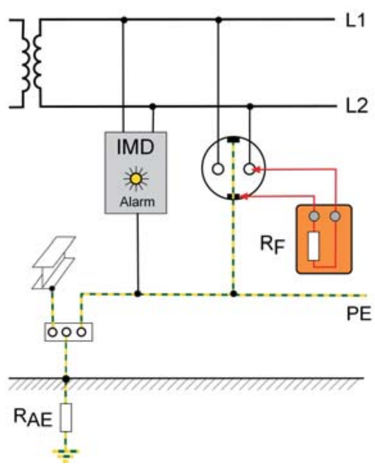
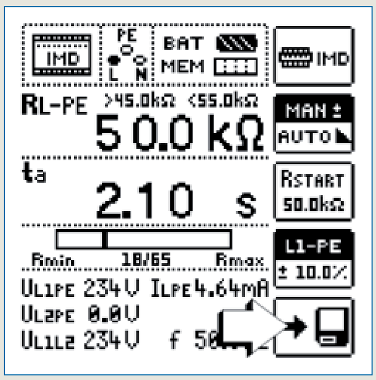


FIG. 11:

Example of an IMD test in an IT system with a test device PROFITEST MXTRA of Gossen Metrawatt

(Source: GMC-I Messtechnik GmbH)



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REFERENCES:

Wolfgang Hofheinz:
VDE series volume 114 3. Edition 2011 – Protective measures with insulation monitoring

Faber, Grapetin, Wettingfeld:
VDE series volume 114 3. Edition 2012 – Testing electrical installations and equipment – fundamental principles and methods

DIN VDE 0100-100 (VDE 0100-100):2009-06
Erection of low voltage electrical installations
Part 1: Fundamental principles, assessment of general characteristics, definitions

DIN VDE 0100-410 (VDE 0100-410):2007-06
Erection of low voltage electrical installations
Part 1: Fundamental principles, assessment of general characteristics, definitions

DIN EN 61557-2 (VDE 0413-2):2008-02
Electrical safety in low voltage distribution systems up to AC 1 000 V and DC 1 500 V
– 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 AC 1 000 V and DC 1 500 V
– 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 AC 1 000 V and DC 1 500 V
– equipment for testing, measuring or monitoring of protective measures
Part 9: Equipment for insulation fault location in IT systems

DIN VDE 0105-100 VDE 0105-100:2009-10
Operation of electrical systems
Part 100: General requirements

DIN VDE 0100-600 VDE 0100-600:2008-06
Erection of low voltage electrical installations
Part 6: Verifications

SOURCES: www.vde-verlag.de; www.beuth.de

Pictures:
Bender archive