

Insulation resistance

– testing – measuring – monitoring

The insulation resistance is particularly important for the prevention of damage and injury, and for the reliability of electrical systems and equipment. On the one hand it is basis for the protection of individuals and systems, on the other hand it also serves as an important indicator for the condition of an electrical installation. Depending on the life cycle of a system or an item of equipment, the insulation resistance is to be tested, to be measured or also to be monitored.

1. The life cycle

The (product) life cycle of an electrical system or an item of equipment can essentially be divided into the phases given in Table 1. Depending on the specific phase, (high) voltage testing, insulation measurement or insulation monitoring are required. In unearthed power supplies, the monitoring can be undertaken using an insulation monitoring device. In earthed power supply systems the monitoring can be undertaken indirectly using fault current monitoring. By detecting impending insulation faults at an early stage, these devices are an important tool for the timely planning of maintenance

tasks. Conversely, the insulation measurement is only an instantaneous snapshot of the insulation resistance. In principle the insulation resistance is dependent on

- The nature of the electrical installation or equipment
- The operating conditions
- The type of usage.

Here attention is to be paid to the safety risk and the protection goal.

TABLE 1: Insulation measurement/monitoring in the life cycle of an electrical system/item of equipment

Phase of the life cycle	(High) voltage test	Insulation measurement	Insulation resistance			Fault current	
			System not in operation	System in operation			
				IT system IMD	TN/TT system		RCD
Planning/installation	–	–		Including in planning / install			
Commissioning	X	X	Adjust Test	Test			Adjust Test
Operation	–	–	Signal	Shut down			Signal
Maintenance	X)*	X	Signal	Shut down			Signal
Repair	X)*	X	Signal	Shut down			Signal
Major modification	X)*	X	Check / include in planning				
Upgrade	X)*	X	Check / include in planning				
Decommissioning	–	–	–	–			–

X)* As far as required in the standards



2. (High) voltage test

To prevent the failure of the insulation, it is necessary to specify the insulation to suit the stresses to be expected. The necessary insulation co-ordination depends on the stress on the air and creepage paths due to operating voltages, overvoltage and soiling due to dust and moisture. To test the required insulation distances a high voltage test is undertaken on new equipment and systems; unlike the insulation measurement this test represents a dielectric strength test. This test is undertaken as part of a type test or routine test.

The test voltage is applied between the short-circuited main circuit (phase and neutral conductor) and the protective earth conductor. In some cases a further test is also to be undertaken between the main circuit and auxiliary circuit. The test voltage varies and is defined as a function of the standard and protection class; it can be between AC 1000 V and DC 6000 V. During the test there must not be any flashover or breakdown. Test equipment is defined in DIN EN 61180-2 (VDE 0432-11):1995-05. Such a voltage test is required, e.g., in DIN EN 60204-1 (VDE 0113-1):2007-06. The test voltage must be twice the rated voltage or 1000 V (50/60 Hz). The test duration is approx. 1 s, and the requirements are met if breakdown does not occur.

3. Insulation measurement: prior to commissioning

Prior to the initial commissioning of an electrical system, in accordance with DIN VDE 0100-600 (VDE 0100-600):2008-06 various measurements are to be undertaken. These include the measurement of the insulation resistance, which is measured between the active conductors and the protective earth conductor connected to earth. During this test the active conductors are allowed to be connected together electrically. The DC measuring voltage and the magnitude of the insulation resistance must comply with the requirements in Table 2. The insulation resistance is considered adequate if each circuit reaches the required value without electrical loads connected. During the measurement it is to be ensured that all switches in the circuit are closed. If it is not possible to close circuits, the electrical circuits not measured must be measured separately. Any connections between N and PE must be open.

The insulation measuring device must meet the requirements of DIN EN 61557-2 (VDE 0413-2):2008-02. 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 / 4). The measuring current must exceed at least 1 mA and the peak value is not allowed to exceed 15 mA.



TABLE 2: Insulation resistance and measuring voltage in accordance with DIN VDE 0100-600 (VDE 0100-600):2008-06

Nominal voltage of the electrical circuit (V)	DC measuring voltage (V)	Insulation resistance (MΩ)
SELV*, PELV**	250	≥ 0,5
Up to and including 500 V, as well as FELV***	500	≥ 1,0
Over 500 V	1000	≥ 1,0

*Sicherheitskleinspannung **Schutzkleinspannung ***Funktionskleinspannung

▶▶▶ Insulation monitoring devices (IMD) perform the task of measuring the insulation resistance in IT systems with the electrical system switched on in accordance with section 61.3.3 DIN VDE 0100-600 (VDE 0100-600):2008-06 .

4. Insulation monitoring: in operation

During the operation of an electrical system, there are several ways to monitor the insulation resistance depending on the type of system used (IT, TN or TT system).

a) Earthed power supplies (TN/TT systems)

In the case of earthed systems, the insulation resistance is determined indirectly via the magnitude of the fault current. A classic tool for this purpose is the residual current device (RCD), which shuts down the system or the loads if a certain fault current is exceeded and in this way prevents a hazard. In areas in which a shutdown could be a problem for operations, e.g. IT systems, often residual current monitors (RCM) are used. These also operate based on the residual current principle that is the difference between the current flowing in and out is measured using a measuring current transformer and a signal provided or the system shut down at a specific fault current. Depending on the related fault current, AC, pulsed DC or AC/DC sensitive devices are used. For systems in which a large number of outgoing circuits need to be monitored, multiple channel systems are also available on the market, so-called RCMSs. RCMS must meet the requirements of the product standard DIN EN 62020 VDE 0663:2005-11. These devices are also used to monitor a "clean" TN-S system, i. e. strict separation of N and PE. In accordance with DIN VDE 0100-444 (VDE 0100-444):2010-10 section 444.4.3.2 a RCM can support the effectiveness of a TN-S system.



Figure One multi-channel residual current monitoring system RCMS

b) Unearthed power supplies (IT systems)

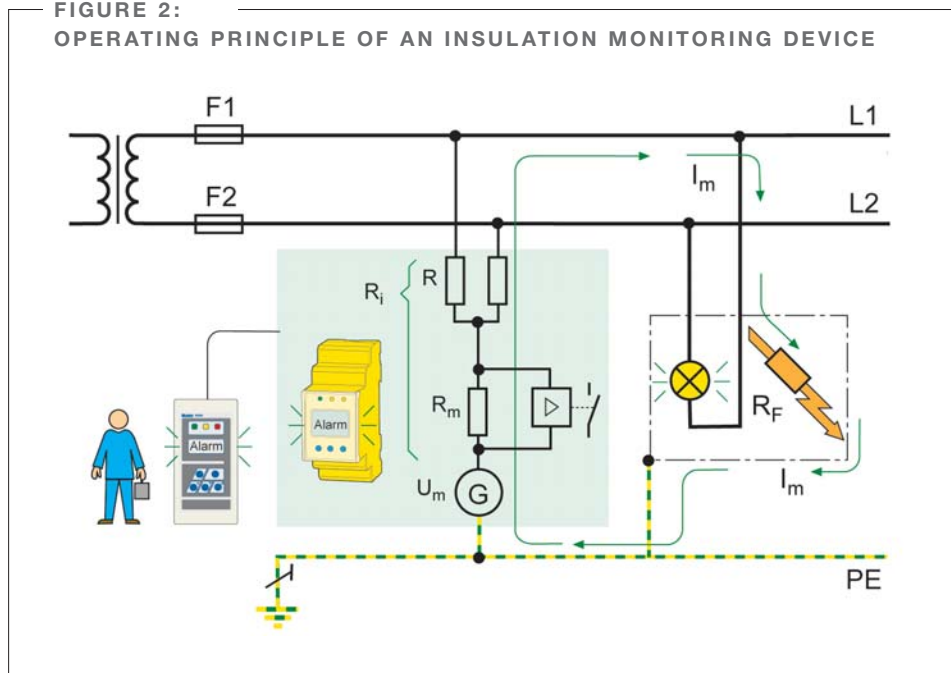
Unlike TN/TT systems, in IT systems the active conductors are insulated from earth. In these systems the insulation resistance between the active conductors and earth is continuously monitored with the aid of an insulation monitoring device (IMD). If the value measured is below a specific resistance ($k\Omega$) an alarm is output. Here a key advantage of the IT system becomes clear. In accordance with DIN VDE 0100-410 (VDE 0100-410):2007-06 shut down is not necessary on the occurrence of a first fault such that operation can continue uninterrupted. This aspect is of crucial importance in safety-related areas, e.g. in hospitals, industrial plants or electric mobility. As the IT system supplied is in operation, the insulation monitoring device measures the total insulation resistance of the system, including all loads switched on that are electrically connected to the IT system.

The insulation monitoring device superimposes a measuring voltage U_m on the system to be monitored; as per the product standard for insulation



monitoring devices DIN EN 61557-8 (VDE 0413-8):2007-12 this voltage is limited to ≤ 120 V. If an insulation fault occurs, the measuring circuit closes (see Figure 2) and the resulting measuring current I_m is a measure of the insulation resistance R_F . This resistance is indicated by an IMD, e.g. directly as a $k\Omega$ value on a display, or via interfaces as information to higher level systems. To support service, insulation fault location systems in accordance with DIN EN 61557-9 (VDE 0413-9):2009-11 are also often used; these systems precisely identify the outgoing circuit with a fault in a very short time. Both insulation monitoring devices and also equipment for insulation fault location are therefore valuable aids for service and maintenance, as weak points are clearly identified by the early alarm; maintenance measures can be planned and initiated in good time.

FIGURE 2:
OPERATING PRINCIPLE OF AN INSULATION MONITORING DEVICE



4.1 Insulation monitoring device response value

The response value required for insulation monitoring devices is given in various installation requirements. In practice a value of $100 \Omega/V$ for the main alarm and $300 \Omega/V$ for insulation monitoring devices with a pre-warning stage have been proven appropriate.



Figure 3: Insulation monitoring device ISOMETER® IRDH275 for variable-speed drives

▶▶▶ Alternatively the response value can be set to a value that is 50 % higher than the value required in the standards. The response values required in the standards are listed in Table 3. It is also possible to adjust the response value to suit the requirements of DIN VDE 0105-100 (VDE 0105-100):2009-10 (see Table 4). Here it is the responsibility of the planner or the installer of the system to draw on appropriate experience.

TABLE 3: Examples for insulation monitoring device response values

Standard	Title	Section	Insulation resistance required
DIN VDE 0100-600 (VDE 0100-600):2008-06	Low-voltage electrical installations – Part 6: Verification	61.3.6.1	100 Ω/V
DIN VDE 0100-710 (VDE 0100-710):2002-10	Erection of low-voltage installations – Requirements for special installations or locations – Part 710: Medical locations	710.531.3.1	50 kΩ
DIN VDE 0100-530 (VDE 0100-530):2011-06	Erection of low-voltage installations – Part 530: Selection and erection of electrical equipment – Switchgear and controlgear	538.3.1	50 Ω/V
DIN VDE 0100-551 (VDE 0100-551):2011-06	Low-voltage electrical installations – Part 5-55: Selection and erection of electrical equipment – Other equipment – Clause 551: Low-voltage generating sets	Annex ZB	100 Ω/V
DIN VDE 0105-100 (VDE 0105-100):2009-10	DIN VDE 0105-100 (VDE 0105-100):2009-10 Operation of electrical installations Part 100: General requirements	5.3.101.3.3	50 Ω/V



**4.2 Insulation monitoring:
for disconnected loads**

In some areas there are loads that are disconnected for a time, e.g. fire extinguishing pumps, valve drives, lift motors or emergency generators. While they are switched off, moisture or other effects can cause insulation faults in the supply cable or in the load itself and these faults go unnoticed. In this case, when switching on (from temporary disabled power consumers) either the protective device is triggered, or motor fires may occur. Ultimately, operation is no longer possible. This situation can have fatal consequences, e.g. in case of fire extinguishing pumps. To prevent this situation arising, offline monitors are used as part of the preventive maintenance; while the loads are disconnected these devices monitor the insulation resistance between all active conductors and earth (PE). The principle of operation corresponds to that of an insulation monitoring device however, with response values in the high MΩ range. If an insulation fault is detected, the operating organisation receives a message before a possibly critical operating state arises. If the system is disconnected on all poles, offline monitors can also be used in TN and TT systems.

(VDE 0105-100):2009-10. The insulation resistance is subject to a certain degree of ageing however, moisture etc. also has a significant effect such that lower values are required than on new systems. (Table 4). The method of measurement is identical to the initial measurement.

**5.1 Insulation measurement:
during periodic tests on electrical equipment
and medical electrical equipment**

Electrical equipment must be checked at regular intervals to ensure it is in correct working order. The test for electrical equipment is described in DIN VDE 0701-0702 (VDE 0701-0702):2008-06, while medical electrical equipment is to be tested in accordance with DIN EN 62353 (VDE 0751-1):2008-08. The insulation measurement forms part of the test in these standards. The insulation resistance is to be measured between the active parts and the related conductive part that can be physically touched, with the device switched on; the limits in accordance with Table 5 are to be met. The measuring voltage is DC 500 V.



**5. Insulation measurement:
during periodic tests
on electrical systems**

During periodic tests the measurement of the insulation resistance is part of the measurements to be undertaken in accordance with DIN VDE 0105-100

TABLE 4: Insulation resistances required during tests in accordance with DIN VDE 0105-100 (VDE 0105-100):2009-10

	Without equipment connected	With equipment connected and switched on	Systems outdoors or in areas in which the floors, walls and installations are sprayed for cleaning		IT systems	SELV/PELV
			Equipment connected	Without equipment connected		
Measuring voltage	typ. DC 500 V max. 1mA					DC 250 V
Insulation resistance	1000 Ω/V	300 Ω/V	150 Ω/V	500 Ω/V	50 Ω/V	0,25 MΩ

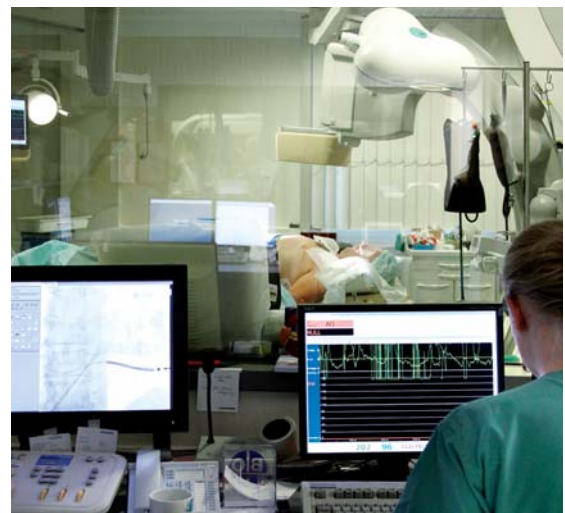
TABLE 5: Insulation resistances in accordance with DIN VDE 0701-702 (VDE 0701-0702):2008-06 for electrical equipment

Test object)*		Limit value
Between the active parts and each accessible conductive part, including the protective earth conductor (except PELV)	Devices with protective earth conductor	1 MΩ
	Devices with protective earth conductor and heating elements	0,3 MΩ
	Devices without protective earth conductor	2 MΩ
	Devices with SELV, PELV	0,25 MΩ, against accessible conductive parts

) * Note: The measurement is not necessary on information technology devices and SELV if the devices may be damaged by the measurement.

▶▶▶ In the case of medical electrical devices there is also the requirement that the power supply unit switch should be switched on. The measuring voltage is defined as DC 500 V. The measurement is made between

- Power supply unit and (unearthed) accessible conductive parts (protection class I / II)
- Power supply unit and all patient connections on the applied parts
- All patient connections on the applied parts of type F and protective earth (protection class I)
- All patient connections on the applied parts of type F and (unearthed) accessible conductive parts (protection class II)



As DIN EN 62353 (VDE 0751-1):2008-08 does not contain any limit, the limits in the previous standard VDE 0751-1 are used. Devices in protection class I $\geq 2 \text{ M}\Omega$, devices in protection class II $\geq 7 \text{ M}\Omega$ and for applied parts of type CF $\geq 70 \text{ M}\Omega$.



SUMMARY

Insulation monitoring is not the same as insulation measurement and vice versa. Depending on the related phase of the life cycle of a system or an item of equipment, these two techniques are to be used differently. However, overall it is important that a failure or a hazard for individuals and property is avoided by a preventive action. Here insulation monitoring

devices and systems for insulation fault location have been proven in particular in unearthed systems (IT systems). In earthed systems (TN/TT systems) residual current monitors are a practical aid; these monitors can also be used to optimise low-interference TN-S systems in relation to EMC requirements. ■

TABLE 6: Overview of insulation measurement, insulation monitoring, (high) voltage testing

Insulation measurement	Insulation monitoring	(High) voltage test
<ul style="list-style-type: none"> • Measurement of R_F between active conductors and earth (with/without equipment) 	<ul style="list-style-type: none"> • Measurement of R_F between active conductors and earth (with all equipment) 	<ul style="list-style-type: none"> • Testing of the dielectric strength between connected active conductors and earth
<p>Timing</p> <ul style="list-style-type: none"> – Type testing/routine testing – Initial measurement – Periodic testing 	<p>Timing</p> <ul style="list-style-type: none"> – Operation <ul style="list-style-type: none"> • Insulation monitoring <ul style="list-style-type: none"> – Active measuring principle – Passive measuring principle (in accordance with IEC 61557-8 not allowed) 	<p>Timing</p> <ul style="list-style-type: none"> – Type testing/routine testing
<p>System/equipment</p> <ul style="list-style-type: none"> • not in operation <ul style="list-style-type: none"> • External DC measuring voltage (≥ 500 V) • Electrical circuits must be taken into account (electrical isolation due to contacts etc.) • Insulation measuring device in accordance with IEC 61557-2 • Measurement is only an instantaneous snapshot (measuring time ≤ 1 min). 	<p>System/equipment</p> <ul style="list-style-type: none"> • in operation <ul style="list-style-type: none"> • All electrically connected electrical circuits are monitored • Insulation monitoring device in accordance with IEC 61557-8 • Continuous measurement (Measurement in (almost) every phase of operation). 	<p>System/equipment</p> <ul style="list-style-type: none"> • not in operation <ul style="list-style-type: none"> • External DC measuring voltage (e.g. $U_N + 1000$ V) • Measurement is only an instantaneous snapshot (measuring time ≤ 1 min).

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AUTHOR:

Dipl.-Ing. Harald Sellner
 T-NOR
 Bender GmbH & Co.KG
 35305 Grünberg
 E-Mail: Harald.Sellner@bender-de.com

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Hochspannungs-Prüftechnik für Niederspannungsgeräte: Prüfgeräte

DIN EN 60204-1 VDE 0113-1:2007-06
Sicherheit von Maschinen - Elektrische Ausrüstung von Maschinen
Teil 1: Allgemeine Anforderungen (IEC 60204-1:2005, modifiziert);
Deutsche Fassung EN 60204-1:2006

DIN VDE 0100-600 VDE 0100-600:2008-06
Errichten von Niederspannungsanlagen: Teil 6: Prüfungen
(IEC 60364-6:2006, modifiziert); Deutsche Übernahme HD 60364-6:2007

DIN EN 62020 VDE 0663:2005-11
Differenzstrom-Überwachungsgeräte für Hausinstallationen und ähnliche Verwendungen (RCMs)

DIN VDE 0100-410 (VDE 0100-410):2007-06
Errichten von Niederspannungsanlagen - Teil 4-41: Schutzmaßnahmen
Schutz gegen elektrischen Schlag

DIN VDE 0100-444 (VDE 0100-444):2010-10
Errichten von Niederspannungsanlagen
Teil 4-444: Schutzmaßnahmen – Schutz bei Störspannungen und elektromagnetischen Störgrößen

DIN EN 61557-2 (VDE 0413-2):2008-02
Elektrische Sicherheit in Niederspannungsnetzen bis AC 1 000 V und DC 1 500 V
– Geräte zum Prüfen, Messen oder Überwachen von Schutzmaßnahmen – Teil 2: Isolationswiderstand

DIN EN 61557-8 (VDE 0413-8):2007-12
Elektrische Sicherheit in Niederspannungsnetzen bis AC 1 000 V und DC 1 500 V
– Geräte zum Prüfen, Messen oder Überwachen von
Schutzmaßnahmen Teil 8: Isolationsüberwachungsgeräte für IT-Systeme

DIN EN 61557-9 VDE 0413-9:2009-11 Elektrische Sicherheit in Niederspannungsnetzen
bis AC 1 000 V und DC 1 500 V – Geräte zum Prüfen, Messen oder Überwachen von Schutzmaßnahmen
Teil 9: Einrichtungen zur Isolationsfehlersuche in IT-Systemen

DIN VDE 0105-100 (VDE 0105-100):2009-10
Betrieb von elektrischen Anlagen - Teil 100: Allgemeine Festlegungen

DIN VDE 0100-710 (VDE 0100-710):2002-11
Errichten von Niederspannungsanlagen - Anforderungen für Betriebsstätten, Räume und Anlagen
besonderer Art - Medizinisch genutzte Räume

DIN VDE 0100-530 (VDE 0100-530):2011-06
Errichten von Niederspannungsanlagen
Teil 530: Auswahl und Errichtung elektrischer Betriebsmittel – Schalt- und Steuergeräte

DIN VDE 0100-551 (VDE 0100-551):2011-06
Errichten von Niederspannungsanlagen – Teil 5-55: Auswahl und Errichtung elektrischer Betriebsmittel
– Andere Betriebsmittel – Abschnitt 551: Niederspannungsstromerzeugungseinrichtungen

DIN VDE 0701-0702 (VDE 0701-0702):2008-06
Prüfung nach Instandsetzung, Änderung elektrischer Geräte – Wiederholungsprüfung elektrischer Geräte

DIN EN 62353 (VDE 0751-1):2008-08
Wiederholungsprüfungen und Prüfung nach Instandsetzung von medizinischen elektrischen Geräten

Note: The standards can be obtained from the publishers VDE-Verlag or Beuth, Berlin