5 Protective Measures for Persons and Installations

5.1 Electric shock protection in installations up to 1000 V as per DIN VDE 0100

5.1.1 Protection against direct contact (basic protection)

The danger of touching live parts is particularly great with this kind of switchgear, because in locked electrical premises this equipment does not require any electric shock protection by an enclosure (IP 00), or the electric shock protection can be become ineffective on opening the cubicle doors.

According to DIN VDE 0100-410 (VDE 0100 Part 410), protection against direct contact is always required regardless of the voltage. Exception: the voltage is generated in accordance with the regulations for extra low voltage SELV and does not exceed 25 V AC or 60 V DC (cf. Section 5.1.3!).

Protection against direct contact is assured by insulating, enclosing or covering the live parts and is essential for operation by electrically untrained personnel. This kind of protection should be chosen wherever possible. However, with switchgear, intervention is sometimes required to restore things to the normal conditions, e.g. actuate miniature circuit-breakers or replace indicator lamps, in areas where there is only partial protection against direct contact. Such activities may only be carried out by at least electrically instructed personnel. DIN 57106-100 (VDE 0106 Part 100) specifies the areas in which controls for restoring normal conditions may be installed (Fig. 5-1), and the clearances to bare live parts required in front of the controls (protected zone, Fig. 5-2). The rules for minimum clearance do not apply in the case of finger-proof equipment (Fig. 5-3) and for devices that cannot be contacted by the back of the hand (Fig. 5-4), within the protected zone or when mounted in substation doors.

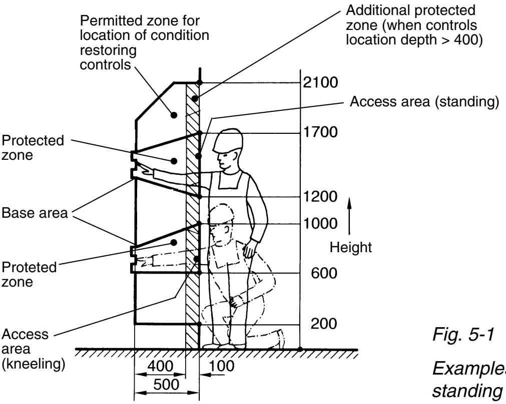


Fig. 5-1

Examples for protected zones for standing or kneeling positions

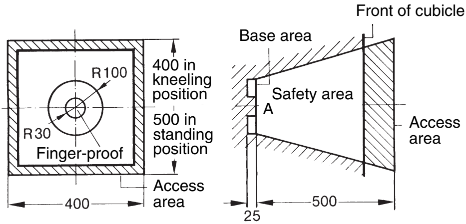
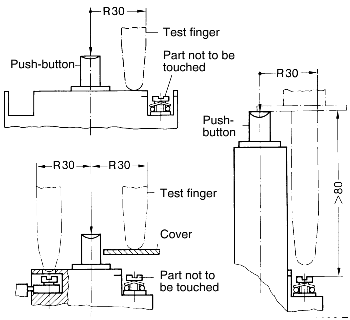


Fig. 5-2

Example for protected zone for push-button operation (A)



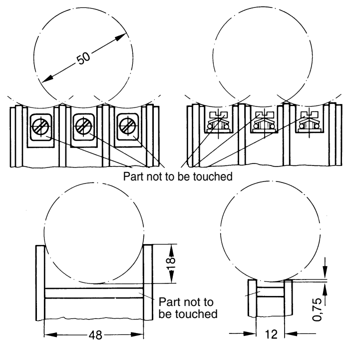


Fig. 5-3

Examples for finger-proof arrangement of shock-hazard parts

Fig. 5-4

Examples for arrangement of shock-hazard parts to prevent contact with the back of the hand

The standard VDE 0106 Part 100 applies for all switchgear, including those in locked electrical premises. It does not apply for installations that are operated at voltages of up to 50 V AC or 120 V DC, so long as these voltages are not generated by equipment such as autotransformers, potentiometers, semiconductor elements or similar.

Provisions of this standard do not apply for work on switchgear in accordance with DIN EN 50110-1 (VDE 0105 Part 1), and therefore also not to the replacement of HRC fuse links.

Additional protection in case of direct contact

The purpose of additional protection is to ensure that potentially fatal currents cannot flow through the body in the event of direct contact of live parts. The additional protection is provided by the use of highly sensitive residual current protective devices (RCDs), each with a rated fault current ≤ 30 mA. DIN VDE 0100 Part 701ff specifies which protection device is to be used in which special installations. The additional protection in case of direct contact is not permissible as the sole form of protection; the requirements for protection against direct contact must always be met.

5.1.2 Protection in case of indirect contact (fault protection)

The hazard from touch voltages in the event of a malfunction (earth fault to frame) can be avoided as per DIN VDE 0100-410 (VDE 0100 Part 410) by several different protection concepts. The two concepts that are most commonly used in switchgear installation design are discussed here.

Protection by automatic tripping of the power supply

The following are specified as limit values for the touch voltage:

50 V AC
120 V DC

Lower values are required for certain applications.

Protection by tripping ensures that in the event of faults, hazardous touch voltages are automatically prevented from persisting by protection devices. These protective measures require coordination of the earthing of the system and the protection device (Fig. 5-5), which has to trip the faulty component within the set break time (between 0.1 s and 5 s) (Table 5-1). The metallic enclosures of the equipment must be connected with a protective conductor.

Protection by tripping requires a main equipotential bonding conductor, which connects all conductive parts in the building, such as main protective conductor, main earthing conductor, lightning protection earth, main water and gas pipes and other metallic pipe and building construction systems.

If only one fault occurs in the IT system (enclosure or earth fault), tripping is not necessary if the break conditions listed in Table 5-1 are not reached. In the event of a second fault, depending on the earthing of the enclosure, the break conditions apply as in the TT system (single or group earthing) or the TN system (one common protective conductor).

Supplementary equipotential bonding may be required if the specified break conditions cannot be reached or if it is specified in the standards for special installations, e.g. rooms with a shower or bath. All metallic enclosures of equipment, which can be touched simultaneously, protective conductors, other conductive parts and the concrete-reinforcing steel rods (so far as possible) have to be included in the supplementary equipotential bonding system.

TN system

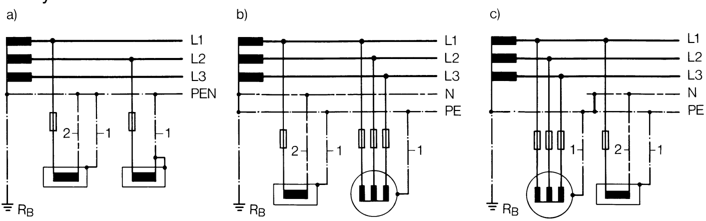


Fig. 5-5 (Part 1)

Overview of the types of earthing for systems:

a) TN-C system: Neutral conductor and protective conductor combined;
b) TN-S system: Neutral conductor and protective conductor separate;
c) TN-C-S system: Combination of layouts a) and b).
1 wire colour green/yellow, 2 wire colour light blue.

TT system

IT system

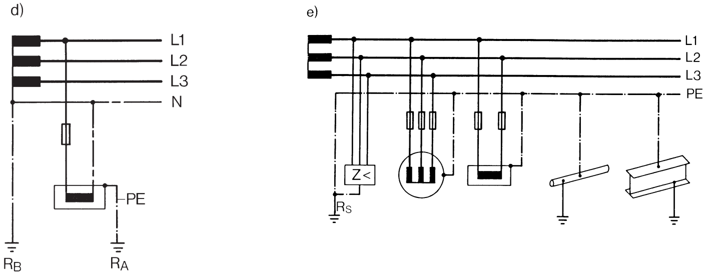


Fig. 5-5 (Part 2)

Overview of the types of earthing for systems:

d) TT system, neutral conductor and protective conductor (exposed conductive part) separately earthed, e) IT system, system not earthed or high-resistance earthed, metallic enclosures, earthed in groups or individually, Z<: insulation monitoring device.

Table 5-1

Coordination of the type of earthing of the systems and protection devices

System	Protection devices	Application	Break condition
TN-S and TN-C-S	Overcurrent Fault current		$Z_S \cdot I_a \leq U_0$
TN-C	Overcurrent		
TT	Overcurrent Fault current Insulation monitoring	not always	$R_A \cdot I_a \leq 50$ V
IT	Overcurrent Fault current Insulation monitoring	not always	$R_A \cdot I_d \leq 50$ V

Z_S Impedance of fault loop
Note: Z_S can be found by calculation, measurement or with network analyser.

R_A Earth resistance of earth of metallic enclosures

I_a Current automatically tripping the protection device within
- 0.4 s at rated alternating voltage (effective) ≤ 230 V
- 0.2 s at rated alternating voltage (effective) ≤ 400 V
- 0.1 s at rated alternating voltage (effective) > 400 V

in circuits supplying via socket-outlets or fixed connections handheld devices of safety class I or portable equipment of safety class I. In all other current circuits a break time up to a maximum of 5 s can be agreed.

When a residual current protective device is used, I_a is the rated fault current $I_{\Delta N}$.

I_d Fault current in the event of the first fault with negligible impedance between a phase and the protective conductor or a metallic enclosure connected to it. The value of I_d considers the leakage currents and the total impedance of the electrical installation against earth.

U_0 Rated voltage (r.m.s.) against earth.

The following are used as protection devices:

Overcurrent protection devices

- low-voltage fuses according to VDE 0636 Part 10 ff.
- miniature fuses according to VDE 0820 Part 1 ff.

Miniature circuit-breakers according to VDE 0641 Part 2 ff.
Circuit-breaker according to VDE 0660 Part 100 ff.
Residual current-operated circuit-breakers according to VDE 0664 Part 10 ff.
Insulation monitoring device according to VDE 0413 Part 2, Part 8, Part 9.

In TN or TT systems, the total earthing resistance of all functional earths should be as low as possible to limit the voltage rise against earth of all other conductors, particularly the protection or PEN conductor in the TN network if an earth fault occurs on a phase. A value of 2 Ω is considered sufficient in TN systems. If the value of 2 Ω cannot be reached in soils of low conductivity, the following condition must be met:

$$\frac{R_B}{R_E} \leq \frac{50\ \text{V}}{U_0 - 50\ \text{V}}$$

R_B total earthing resistance of all parallel earths of the system

R_E assumed lowest earth resistance of conductive parts not connected to a protective conductor over which an earth fault can occur

U_0 rated voltage (r.m.s.) against earth.

In the TT system, the implementation of overcurrent protection devices is problematic because of the required very low continuous earth resistance. In the IT system an earth resistance of ≤ 15 Ω is generally sufficient when all metallic enclosures of equipment are connected to a common earthing system.

If a supplementary equipotential bonding is required in an electrical installation, its effectiveness must be verified by the following condition:

$$R \leq \frac{50\ \text{V}}{I_a}$$

R Resistance between metallic enclosures and other conductive parts that can be touched at the same time.

I_a Current that effects the automatic tripping of the protection device within the set time.

When a residual current-operated device is used, I_a is the rated fault current $I_{\Delta N}$.

Protection by equipment of safety class II

Another common measure, against the occurrence of hazardous touch voltages that is also used in switchgear installation design is protection by equipment of safety class II (equipment of safety class II as per DIN VDE 0106 Part 1) or by type-tested assemblies with total insulation (type-tested assemblies with total insulation as per DIN EN 60439-1 (VDE 0660 Part 500)) or by application of an equivalent insulation.

Equipment of safety class II and type-tested assemblies with total insulation are identified with the symbol ⧈ as per DIN 40014.

Conductive parts within the enclosure must not be connected to the protective conductor, otherwise it will be a device in safety class I. If protective conductors must be routed through insulated equipment, they must be insulated like live conductors.

Exceptions

Measures for protection in case of indirect contact are not required for the following equipment:
– lower parts of overhead line insulators (except when they are within reach)
– steel towers, steel-concrete towers, packing stands
– equipment that is not likely to come into contact by any part of the human body because of its small dimensions (e.g. 50 mm x 50 mm) or because of its configuration,
– metal enclosures for protection of equipment of safety class II or equivalent.

5.1.3 Protection by extra low voltage

As per DIN VDE 0100-410 (VDE 0100 Part 410) the use of the SELV and PELV extra low-voltage systems (Fig. 5-6) can offer protection in case of direct and indirect contact. Extra low voltages in accordance with these specifications are AC voltages ≤ 50 V and DC voltages ≤ 120 V. Corresponding specifications for current circuits with limited discharge energy (≤ 350 m J) are in preparation.
Current sources for supplying extra low-voltage systems of the SELV and PELV types must be safely separated from the infeed system, e.g. as isolating transformer with shielding (DIN EN 60742 (VDE 0551) or as motor generators (DIN VDE 0530), but not as autotransformer, potentiometer and the like.
The SELV extra low voltage, apart from secure separation of the current circuits, requires that neither live parts nor metallic enclosures must be earthed. Protective measures to prevent direct contact, such as barriers, enclosures or insulation are not necessary here if the rated voltage does not exceed AC 25 V and DC 60 V.
Live parts and metallic enclosures may be earthed with the PELV extra low voltage. Protective measures against direct contact are also not necessary here with rated voltages below AC 25 V and DC 60 V, if metallic enclosures, which can be touched simultaneously, and other conductive parts are connected to the same earthing system.
The FELV extra low voltage is supplied by a power source without a safe isolation. Earthing the current circuits is permitted. Metallic enclosures must be connected to the protective conductor on the primary side of the power source. Protection against direct contact and in case of indirect contact is generally required (DIN VDE 0100-470 (VDE 0100 Part 470).
Auxiliary circuits in switchgear installations are often operated with extra low voltage. With reference to protection in case of indirect contact, the systems with safe isolation (SELV, PELV) are to be recommended, particularly with small direct cross sections, because in contrast to the FELV system, no additional measures are required. Consistent safe isolation from the supply network must be assured by the selection of the equipment in the entire current circuit.

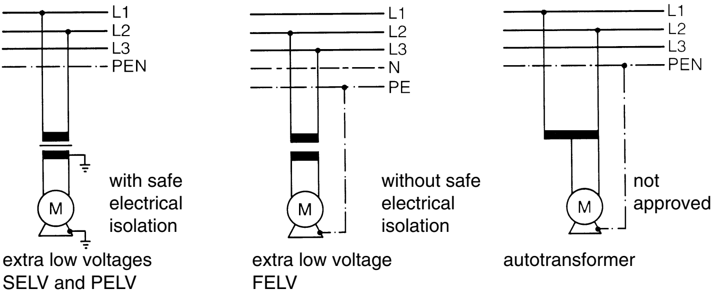


Fig. 5-6 Power sources for extra low voltages

5.1.4 Protective conductors, PEN conductors and equipotential bonding conductors

Requirements as specified by VDE 0100 Part 540

The following may be used as protective conductors:
- conductors in multicore cables and wires,
- insulated or bare conductors in the same covering together with phase conductors and the neutral conductor, e.g. in pipes or electrical conduits,
- permanently installed bare or insulated conductors,
- metallic enclosures, such as sheaths, shields and concentric conductors of cables and wires,
- metal pipes or other metallic coverings, such as electrical conduits, housings for busbar systems,
- external conductive parts,
- mounting channels, also when carrying terminals and/or devices.

If structural components or external conductive parts are used as protective conductors, their conductivity must correspond to the specified minimum cross section, and their continuous electrical connection must not be interrupted by temporary structures or affected by mechanical, chemical or electrochemical influences. Guy wires, suspension wires, metal hoses and similar must not be used as protective conductors.

The cross sections for protective conductors must be selected from Table 5-2 or calculated by the following formula for break times up to max. 5 s

$$S = \frac{\sqrt{I^2 t}}{k}$$

Here:

S minimum cross section in mm^2,

I r.m.s. value of the fault current in A, which can flow through the protective device in the event of a dead short circuit,

t response time in s for the tripping device,

k material coefficient, which depends on
- the conductor material of the protective conductor,
- the material of the insulation,
- the material of other parts,
- the initial and final temperature of the protective conductor, see Tables 5-3 and 5-4.

PEN conductors, a combination of protective and neutral conductors, are permitted in TN networks if they are permanently laid and have a minimum conductor cross section of 10 mm² Cu. The protective conductor function has priority with PEN conductors. If the concentric conductor of cables or wires is used as a PEN conductor, the minimum cross section can be 4 mm² Cu if all connections and joints are duplicated for the course of the concentric conductor. PEN conductors must be insulated for the highest expected voltage; except within switchgear installations.

Table 5-2

Minimum cross sections of protective conductors to the cross section of the phase conductors (as per DIN VDE 0100-540/05.86 – superseded by edition 11.91)

1	2	3	4		5
Nominal cross sections					
Phase conductor[4) 5)]	protective conductor or PEN conductor[1)]		protective conductor[3)] laid separately		
	Insulated power cables	0.6/1-kV cable with 4 conductors	protected mm²		unprotected[2)] mm²
mm²	mm²	mm²	Cu	Al	Cu
to 0.5	0.5	–	2.5	–	4
0.75	0.75	–	2.5	–	4
1	1	–	2.5	–	4
1.5	1.5	1.5	2.5	–	4
2.5	2.5	2.5	2.5	–	4
4	4	4	4	–	4
6	6	6	6	–	6
10	10	10	10	–	10
16	16	16	16	16	16
25	16	16	16	16	16
35	16	16	16	16	16
50	25	25	25	25	25
70	35	35	35	35	35
95	50	50	50	50	50
120	70	70	70	70	70
150	95	95	95	95	95
185	95	95	95	95	95
240	–	120	120	120	120
300	–	150	150	150	150
400	–	240	240	240	240

1) PEN conductor ≥ 10 mm² Cu or ≥ 16 mm² Al.
2) Unprotected aluminium conductors may not be laid.
3) From an outside conductor cross section of ≥ 95 mm², bare conductors are preferred.
4) Minimum cross section for aluminium conductors: 16 mm².
5) For minimum conductor cross sections for phase conductors and other conductors, see also DIN VDE 0100 Part 520.

After a PEN conductor has been split into protective and neutral conductor, they must not be joined again and the neutral conductor must not be earthed. The PEN conductor must be connected to the protective conductor terminal.

The conductor cross sections for equipotential bonding conductors can be found in Table 5-5.

When insulated conductors are used as protective or PEN conductors they must be coloured green-yellow throughout their length. The insulated conductors of single-core cables and sheathed cables are an exception. They must have durable green-yellow markings at the ends.

Equipotential bonding conductors may be marked green-yellow.

Non-insulated conductors do not require the green-yellow marking.

Green-yellow markings are not approved for anything other than the above conductors.

Table 5-3

Material coefficients k

	Protective conductor							
	Group 1				Group 2			
	G	PVC	VPE, EPR	IIK	G	PVC	VPE, EPR	IIK
ϑ_i in °C	30	30	30	30	60	70	90	85
ϑ_f in °C	200	160	250	220	200	160	250	220
	k in $A\sqrt{s}/mm^2$				k in $A\sqrt{s}/mm^2$			
Cu	159	143	176	166	141	115	143	134
Al	—	95	116	110	87	76	94	89
Fe	—	52	64	60	—	—	—	—
Pb	—	—	—	—	—	—	—	—

	Group 3			
	G	PVC	XLPE, EPR	IIK
ϑ_i in °C	50	60	80	75
ϑ_f in °C	200	160	250	220
	k in $A\sqrt{s}/mm^2$			
Cu	—	—	—	—
Al	97	81	98	93
Fe	53	44	54	51
Pb	27	22	27	26

Group 1: insulated protective conductors outside cables, bare protective conductors in contact with cable sheaths

Group 2 insulated protective conductors in cables

Group 3: protective conductors as sheath or armouring of cables

See notes to Table 5-4!

Table 5-4

Material coefficients *k* for bare conductors in cases where there is no danger to the materials of adjacent parts from the temperatures given in the table

Conductor material	Conditions	Visible and in delimited areas*)	Normal conditions	If fire hazard
Cu	ϑ_f in °C	500	200	150
	k in A $\sqrt{s}$/mm²	228	159	138
Al	ϑ_f in °C	300	200	150
	k in A $\sqrt{s}$/mm²	125	105	91
Fe	ϑ_f in °C	500	200	150
	k in A $\sqrt{s}$/mm²	82	58	50

Note: The initial temperature ϑ_i on the conductor is assumed to be 30 °C.

*) The given temperatures only apply if the temperature of the joint does not impair the quality of the connection.

Symbols used in Tables 5-3 and 5-4:

ϑ_i	Initial temperature at conductor
ϑ_f	Max. permitted temperature at conductor
G	Rubber insulation
PVC	Insulation of polyvinyl chloride
VPE	Insulation of cross-linked polyethylene
EPR	Insulation of ethylene propylene rubber
IIK	Insulation of butyl rubber

Table 5-5

Cross-sections for equipotential bonding conductors

	Main equipotential bonding	Additional equipotential bonding	
normal	≥ 0.5 × cross-section of the largest protective conductor of the installation	between two exposed conductive parts	≥ 1 × cross-section of the smaller protective conductor
		between a metallic enclosure and an external conductive part	≥ 0.5 × cross-section of the protective conductor
at least	6 mm² Cu or equivalent conductivity[1)]	with mechanical protection	2.5 mm² Cu 4 mm² Al
		without mechanical protection	4 mm² Cu
possible limitation	25 mm² or equivalent conductivity[1)]	—	—

1) Unprotected aluminium conductors may not be laid.

5.2 Protection against contact in installations above 1000 V as per DIN VDE 0101

5.2.1 Protection against direct contact

To provide protection against direct contact, measures are required to prevent people from coming dangerously close, indirectly or directly with tools or objects to the following system components:

- live parts
- conductor insulation of cables and wires from whose ends the conductive covering has been removed
- termination parts and conductive coverings on the ends of single-core cables if hazardous touch voltages are possible
- insulating bodies of insulators and other equipment
- windings of electrical machines
- converters, converter transformers and capacitors having live enclosures in fault-free operation
- installations with insulated enclosures and electric shock protection A as per IEC 60466 (formerly DIN VDE 0670 Part 7)

Depending on the location of the electrical installation, the following is required:

- complete protection against direct contact for installations outside locked premises,
- non-complete protection against direct contact for installations inside locked premises.

Protective measures against direct contact:

- protection by covering (complete protection)
- protection by distance (non-complete protection)
- the vertical distance between walkways and the parts to be guarded against direct contact must correspond at least to the values in the tables in Section 4.6.
- protection by partition (non-complete protection)
  solid walls without openings, minimum height 1800 mm,
  wire mesh, screens, minimum height 1800 mm
- protection by obstacle (non-complete protection)
  solid walls, height < 1800 mm,
  wire mesh, screens, height < 1800 mm,
  rails, chains or ropes

Protective barriers must meet the following requirements:

- mechanically robust and reliably fastened (in installations outside locked electrical premises they must be removable only with tools). Guard rails that can be removed without tools must be of non-conductive materials or wood.
- solid or wire mesh doors (40 mm mesh) may be opened only with keys, including socket-type keys. Safety locks are required for installations outside locked electrical premises.
- rails, chains or ropes must be installed at a height of 1200 to 1400 mm; in the case of chains and ropes, the clearance to the protective barrier must be greater depending on the amount of sag.
- walkways above live conductors must be of solid material and have a 50 mm high lip. They must also extend 300 mm beyond this in outside installations and 200 mm in indoor installations.

5.2.2 Protection in case of indirect contact

Measures as specified in DIN VDE 0141 must be implemented.

In the event of a short circuit in the system with earth contact, the earth carries at least part of the short-circuit current. Voltage drops that could result in potential differences are associated with this partial short-circuit current. The potential differences may be bridged by humans; they represent a danger to personnel, particularly in the form of touch voltage.

The protective earth system must be designed so that the earth fault current flows over the protective earthing in the event of an earth fault in the system.

When using protective earthing, all non-live equipment parts and installations must be earthed if they can come into contact with live parts as a result of creepage paths, arcing or direct contact. Metallic sheathing, armouring and screening of cables must be connected to one another at the joints and with the metallic joint boxes and earthed at the end seals. Earthing of sheathing at only one end is permissible if an unacceptable touch voltage cannot occur at the exposed metal parts of the cable installation under normal operation or in the event of faults. It may be desirable to earth three-core sheathed and single-conductor cables at one end only because of inductive effects in the sheaths. In this case, the end seals must be insulated. In long cable units, the touch voltage may be too high because of the induced voltage in the cable sheath, so these cables must be earthed at both ends. Low-voltage circuits of instrument transformers and surge arresters must also be connected to the protective earthing.

Certain resistance values are not required for protective earth systems in the relevant regulations. If earth voltages that are not greater than 65 V occur at a protective earth system, the approved touch voltages will be deemed to be met without verification.

In high-voltage installations with low-resistance neutral earthing, the permissible limit value for touch voltages depends on the duration of the fault current. The shorter the fault current duration, the higher the permissible limit value for the touch voltages occurring in the installation. Fig. 5-7 shows this relationship.

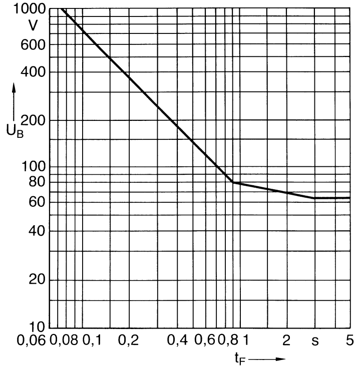


Fig. 5-7

Touch voltage U_B in relationship to the duration t_F of the fault current.

The requirement that the flow of electricity does not exceed Q = 70 mAs is met at every point on the curve in Fig. 5-7. This value is taken as the criterion, because studies have shown that no fatal accidents have occurred with this quantity of electricity. The lower value of 1000 Ω is taken as the body's resistance.

Conditions for the value of the permissible touch voltages, requirements according to which the conditions for complying with the touch voltages are met or measures to be taken [1] if the conditions are not met are described in DIN VDE 0141.

[1] Voltage grading, insulation

5.3 Earthing

5.3.1 Fundamentals, definitions and specifications

Earthing systems have the following general purpose:

Protection of life and property in the event of

– 50-Hz-faults (short circuits and earth faults)
– transient phenomena (lightning, switching operations)

The general layout of a complete earthing system with sections for low voltage, high voltage and buildings and building services is shown in Fig. 5-8.

The most important definitions related to earthing are grouped below.

Earth is the term for the earth as a location and for the earth as material, e.g. the soil types of humus, clay, sand, gravel, rock.

Reference earth (neutral earth) is that part of the earth, particularly the surface outside the area of influence of an earth electrode or an earthing system, in which there are no detectable voltages resulting from the earthing current between any two random points.

Earth electrode is a conductor embedded in the ground and electrically connected to it, or a conductor embedded in concrete that is in contact with the earth over a large area (e.g. foundation earth).

Earthing conductor is a conductor connecting a system part to be earthed to an earth electrode, so long as it is laid out of contact with the ground or is insulated in the ground.

If the connection between a neutral or phase conductor and the earth electrode includes an isolating link, a disconnector switch or an earth-fault coil, only the connection between the earth electrode and the earth-side terminal of the nearest of the above devices is deemed to be an earthing conductor.

Main earthing conductor is an earthing conductor to which a number of earthing conductors are connected.

It does not include:

a) Earthing conductors joining the earthed parts of the single units of three-phase assemblies (3 instrument transformers, 3 potheads, 3 post insulators etc.),
b) with compartment-type installations: earthing conductors that connect the earthed parts of several devices of a compartment and are connected to a (continuous) main earthing conductor within this compartment.

Earthing system is a locally limited assembly of conductively interconnected earth electrodes or metal parts operating in the same way (e.g. tower feet, armouring, metal cable sheaths) and earthing conductors.

To earth means to connect an electrically conductive part to the ground via an earthing system.

Earthing is the total of all measures used for earthing.

Specific earth resistivity ρ_E is the specific electrical resistivity of the ground. It is generally stated in Ω $m^2/m = \Omega$ m and indicates the resistance between two opposite cube faces of a cube of soil with sides of 1 m.

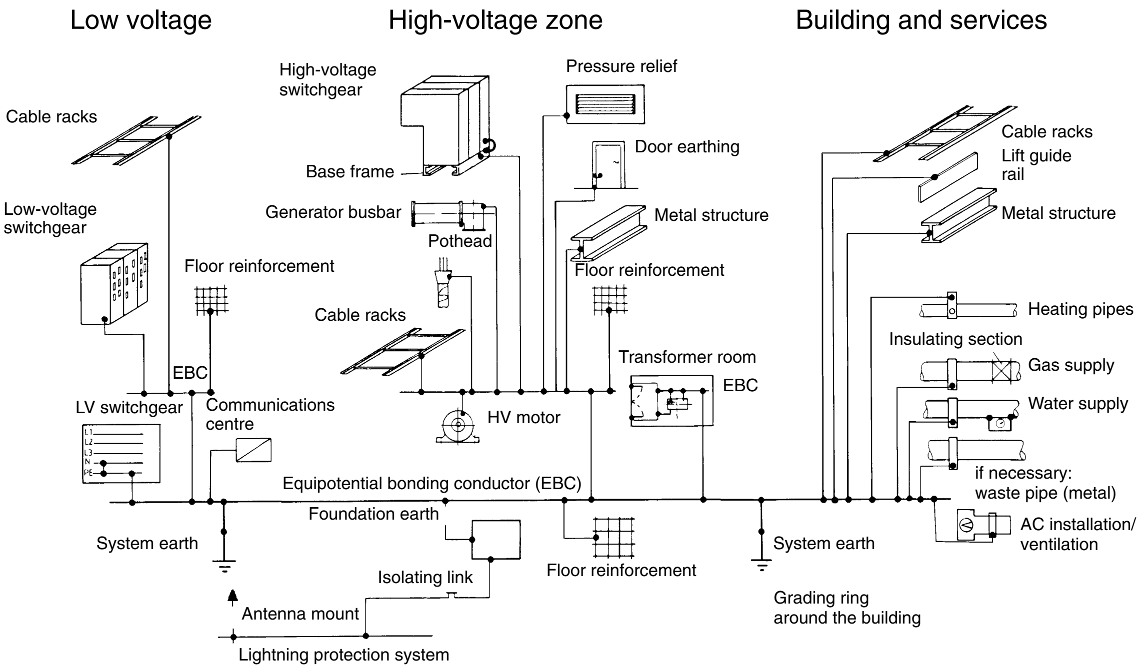


Fig. 5-8

Earthing system with equipotential bonding between HV/LV indoor switchgear and building/building services

Dissipation resistance R_A of an earth electrode is the resistance of the earth between the earth electrode and the reference earth.
R_A is in practice a real resistance.

Earthing impedance Z_E is the AC impedance between an earthing system and the reference earth at operating frequency. The value of the earthing impedance is derived from parallelling the dissipation resistances of the earth electrodes and the impedances of connected conductor strings, e.g. the overhead earth wire and cables acting as earth electrodes.

Impulse earthing resistance R_{st} is the resistance presented to the passage of lightning currents between a point of an earthing system and the reference earth.

Protective earthing is *the* earthing of a conductive component that is not part of the main circuit for the protection of persons against unacceptable touch voltages.

System earthing is the earthing of a point of the main circuit necessary for proper operation of devices or installations.

It is termed:

a) direct, if it includes no resistances other than the earthing impedance.
b) indirect, if it is established via additional resistive, inductive or capacitive resistances.

Lightning protection earthing is the earthing of a conductive component that is not part of the main circuit to avoid flashovers to the operational live conductors resulting from lightning as much as possible (back flashovers).

Earthing voltage U_E is the voltage occurring between an earthing system and the reference earth.

Earth surface potential φ is the voltage between a point on the surface of the earth and the reference earth.

Touch voltage U_B is the part of the earthing voltage that can be shunted through the human body, the current path being through the human body from hand to foot (horizontal distance from exposed part about 1 m) or from hand to hand.

Step voltage U_S is that part of the earthing voltage that can be shunted by a person with a stride of 1 m, with the current path being through the human body from foot to foot.

In contrast to the IEEE, DIN VDE 0101 does not set any limit values for the size of the step voltage.

Potential control consists in influencing the earth potential, particularly the earth surface potential, by earth electrodes to reduce the step and touch voltage in the outer area of the earthing system.

Earth fault is an electrical connection between a conductor of the main circuit with earth or an earthed part caused by a defect. The electrical connection can also be caused by an arc.

Earth fault current I_F is the current passing to earth or earthed parts when an earth fault exists at only one point at the site of the fault (earth fault location).

This is

a) the capacitive earth-fault current I_C in networks with isolated neutral

b) the earth-fault residual current I_{Rest} in networks with earth-fault compensation

c) the zero-sequence current I''_{k1} in networks with low-resistance neutral earthing.

c) also includes networks with isolated neutral point or earth-fault compensators in which the neutral point is briefly earthed at the start of the fault.

Earthing current I_E is the total current flowing to earth via the earthing impedance.

The earthing current is the component of the earth-ault current I_F *which causes the rise in potential of an earthing system.*

Types of earth electrodes

Classification by location

The following examples are distinguished:

a) *surface earth electrodes* are earth electrodes that are generally positioned at shallow depths to about 1 m. They can be of strip, bar or stranded wire and be laid out as radial, ring or meshed earth electrodes or as a combination of these.

b) *deep earth electrodes* are earth electrodes that are generally positioned vertically at greater depths. They can be of tubular, round or sectional material.

Classification by shape and cross section

The following examples are distinguished:

Strip, stranded wire and tube earth electrodes.

Natural earth electrodes are metal parts in contact with the ground or water, directly or via concrete, whose original purpose is not earthing but they act as an earth electrode. They include pipes, caisson walls, concrete pile reinforcement, steel parts of buildings etc.

Cables with earthing effect are cables whose metal sheathing, shield or armouring provides a leakage to earth similar to that of strip earth electrodes.

Foundation earths are conductors embedded in concrete that is in contact with the ground over a large area . Foundation earths may be treated as if the conductor were laid in the surrounding soil.

Control earth electrodes are earth electrodes that by their shape and arrangement are more for potential control than for retaining a specific dissipation resistance.

Rod earth electrodes of any significant length generally pass through soil horizons of varying conductivity. They are particularly useful where more conductive lower soil horizons are available and the rod earth electrodes can penetrate these horizons sufficiently (approximately 3 m). To determine whether more conductive lower soil horizons are available, the specific resistance of the soil at the site is measured (see Section 5.3.4).

Relevant standards on earthing

DIN VDE 0100-410 (VDE 0100 Part 410)
Installation of power systems with nominal voltages to 1000 V; protective measures; protection against electric shock.

DIN VDE 0100, Part 540.
Installation of power systems with nominal voltages to 1000 V; selection and installation of electrical equipment, earthing; protective conductors; equipotential bonding conductors.

DIN VDE 0151 Materials and minimum dimensions of earth electrodes with reference to corrosion.

DIN VDE 0101: 2000-01
Power installations exceeding AC 1kV

DIN VDE 0800 Part 2.
Telecommunications; earthing and equipotential bonding

IEC 60621-2
Electrical installations for outdoor sites under heavy-duty conditions (including open-cast mines and quarries). Part 2: General protection requirements.

IEC/TR 2 60479-1

Effects of currents passing on human beings and livestock.
Part 1: General aspects.

IEEE Std 80-1986 IEEE Guide for Safety in AC Substation Earthing.

5.3.2 Earthing material

Earth electrodes (under ground) and earthing conductors (above ground) must conform to specific minimum dimensions regarding mechanical stability and possible corrosion resistance as listed in Table 5-6.

Selection of material for earth electrodes with respect to corrosion (no connection to other materials) may be made in accordance wtih the following points (DIN VDE 0151):

Hot-dip galvanized steel is very durable in almost all soil types. Hot-galvanized steel is also suitable for embedding in concrete. Contrary to DIN 1045, foundation earths, earthing conductors embedded in concrete, equipotential bonding conductors and lightning conductor leads of galvanized steel can be connected to reinforcing steel if the joints are not subjected to prolonged temperatures higher than 40 °C.

Copper is suitable as an earth electrode material in power systems with high fault currents because of its significantly greater electrical conductivity compared to steel.

Bare copper is generally very durable in the soil.

Copper coated with tin or zinc is, like bare copper, generally very durable in the soil. Tin-plated copper has no electrochemical advantage over bare copper.

Copper with lead sheath. Lead tends to form a good protective layer underground and is therefore durable in many soil types. However, it may be subject to corrosion in a strongly alkaline environment (pH values ≥ 10). For this reason, lead should not be directly embedded in concrete. The sheath may corrode under ground if it is damaged.

Table 5-6

Minimum dimensions for earth electrodes and earthing conductors

Material	Form	DIN VDE 0101 DIN VDE 0151		IEC 60621-2	
Copper	Strip	50 mm^2	1)	25 mm^2	
		16 mm^2	2)	16 mm^2	3)
	Stranded wire, copper bar	25 mm^2			
		16 mm^2	2)		
Steel[4)]	Strip	90 mm^2	5)	50 mm^2	
		50 mm^2	2)	16 mm^2	3)
	Steel bar	78 mm^2	6) 7)		
		50 mm^2	2)		
	Tube	25 mm Ø	8)		
	Steel sections	90 mm^2	9)		
Steel coated with copper	Steel bar	50 mm^2	10)	no data	
Aluminium[2)]		35 mm^2		no data	

1) Minimum thickness 2 mm
2) For above-ground earthing conductors only
3) For conductors protected against corrosion
4) When laid in the soil: hot-dip galvanized (minimum coating 70 µm)
5) Minimum thickness 3 mm (3.5 mm as per DIN 48801 and DIN VDE 0185)
6) Equivalent to 10 mm diameter
7) With composite deep ground electrodes: at least 16 mm diameter.
8) Minimum wall thickness 2 mm
9) Minimum thickness 3 mm
10) For steel wire, copper coating: 20 % of the steel cross section (min. 35 mm^2), for composite deep ground electrodes: minimum 15 mm diameter

Refer to Table 5-7 for the combination of different materials for earth electrodes underground (DIN VDE 0151).

The area rule means that the ratio of the anode area F_A (e.g. steel) to the cathode area F_K (e.g. copper) is crucial for the formation of corrosion elements. As the area ratio F_A/F_K decreases, the rate of corrosion of the anode area increases. This is why coated steel pipe conductors are in danger when connected to a copper earthing system, because the surface ratio of steel to copper at fault positions in the pipe coating is unfavorable and causes fast corrosion (breakthrough). Connecting such pipe conductors to earth electrodes of copper is not approved as per DIN VDE 0151.

Table 5-7

Connections for different earth electrode materials
Ratio of large area : small area ≥ 100:1

Material with small surface area	Material with large surface area							
	Steel, hot-dip galvanized	Steel	Steel in concrete	Steel, hot-dip galvanized in concrete	Copper	Copper tin-plated	Copper, hot-dip galvanized	Copper with lead sheath
Steel, hot-dip galvanized	+	+ Zinc loss	—	+ Zinc loss	—	—	+	+ Zinc loss
Steel	+	+	—	+	—	—	+	+
Steel in concrete	+	+	+	+	+	+	+	+
Steel with lead sheath	+	+	○ Lead loss	+	—	+	+	+
Steel with Cu sheath	+	+	+	+	+	+	+	+
Copper	+	+	+	+	+	+	+	+
Copper tin-plated	+	+	+	+	+	+	+	+
Copper galvanized	+	+ Zinc loss	+ Zinc loss	+ Zinc loss	+ Zinc loss	+ Zinc loss	+	+ Zinc loss
Copper with lead sheath	+	+	+ Lead loss	+	+ Lead loss	+	+	+

\+ Good for joining
○ Can be joined
— must not be joined

5.3.3 Dimensioning of earthing systems

The cross-section of earth electrodes and earthing conductors must be measured so that in the event of a fault current I_F (I''_{K1} in networks with low-resistance neutral earthing), the strength of the material is not reduced. The required cross-section may be determined as follows:

$$A = I_F \cdot \frac{\sqrt{t_F}}{k}$$

Where

I_F : fault current
t_f : duration of fault current
k : material coefficient

The material coefficient for copper is (see Sec. 5.1.3 for other materials)

$$k = 226 \sqrt{\ln \left(1 + \frac{\vartheta_f - \vartheta_i}{234.5\ °C + \vartheta_i}\right)}\ A \cdot \sqrt{s}/mm^2$$

Where

ϑ_i : initial temperature in °C (maximum ambient temperature)
ϑ_f: permitted final temperature

For the permissible final temperature see Table 5-8, (see also Sec. 13.1.1). Where earthing conductors and PVC cables are laid on cable racks together ϑ_f must not exceed 150 °C.

Table 5-8

Permissible final temperatures in ° C for various materials

Material	DIN VDE 0101	IEC 60621-2 DIN VDE 0100 Part 540
Cu bare	300 1)	500 2) 200 3) 150 4)
Al bare	300 1)	300 2) 200 3) 150 4)
Steel bare or galvanized	300 1)	500 2) 200 3) 150 4)
Cu tin-plated or with lead sheath	150	no data

1) If there is no risk of fire
2) For visible conductors in locations that are not generally accessible
3) For non-visible conductors in locations that are generally accessible
4) Where hazards are greater
– for non-visible conductors in locations with increased fire risk
– for earthing conductors laid together with PVC cables

The required standard cross-sections for bare copper depending on the single-line fault current and fault current duration are given in Table 5-9.

Personnel safety in the event of malfunction is ensured when the step and touch voltages do not exceed the limit values set in the standards (e.g. DIN VDE 0101). Step and touch voltages can only be calculated with the aid of computer programs in a very complex process.

As per DIN VDE 0101, the touch voltages in outdoor installations are in compliance when the following three conditions are met simultaneously:

1) Presence of a surface earth electrode surrounding the earthing system in the form of a closed ring. Inside this ring there is an earthing grid (grid size ≤ 50 m × 10 m). Any station components outside the ring and connected to the earthing system are provided with control earth electrodes.
2) Fault current duration ≤ 0.5 s
3) Earthing voltage U_E ≤ 3000 v.

The earthing voltage U_E is the voltage that the entire earthing system has in the event of malfunction compared to reference earth (∞ removed).

Table 5-9 Standard cross-sections

$I''_{k1} = I''_{k3} \dfrac{3}{2 + x_0/x_1}$			Standard cross-sections for earthing material of copper in mm²					
I''_{k3}	x_0/x_1	I''_{k1}	ϑ_i = 30 °C, ϑ_f = 300 °C			ϑ_i = 30 °C, ϑ_f = 150 °C		
in *kA*		in *kA*	1.0 s	0.5 s	0.2 s	1.0 s	0.5 s	0.2 s
	1	80	—	4 × 95	2 × 95	—	4 × 120	4 × 70
80	2	60	—	2 × 120	2 × 95	—	4 × 95	2 × 120
	3	48	—	2 × 95	120	—	4 × 70	2 × 95
	1	63	—	2 × 120	2 × 95	—	4 × 95	2 × 120
63	2	47.3	—	2 × 95	120	—	4 × 70	2 × 95
	3	37.8	—	2 × 95	95	—	2 × 120	2 × 70
	1	50	—	2 × 95	120	—	4 × 70	2 × 95
50	2	37.5	—	2 × 70	95	—	2 × 120	2 × 70
	3	30	—	120	95	—	2 × 95	120
	1	40	2 × 120	2 × 95	95	4 × 95	2 × 120	2 × 70
40	2	30	2 × 95	120	95	2 × 120	2 × 95	120
	3	24	2 × 70	95	70	2 × 95	2 × 70	95
	1	31.5	2 × 95	120	95	2 × 120	2 × 95	120
31.5	2	23.6	2 × 70	95	70	2 × 95	2 × 70	95
	3	18.9	120	70	50	2 × 70	120	70
	1	25	2 × 70	95	70	2 × 95	2 × 70	95
25	2	18.8	120	70	50	2 × 70	120	70
	3	15	95	70	35	120	95	50
	1	20	120	95	50	2 × 95	120	70
20	2	15	95	70	35	120	95	50
	3	12	70	50	35	95	70	50
	1	16	95	70	50	120	95	70
16	2	12	70	50	35	95	70	50
	3	9.6	70	50	35	70	50	35

(continued)

Table 5-9 (continued)

Standard cross-sections

$I''_{k1} = I''_{k3} \frac{3}{2 + x_0/x_1}$			standard cross-sections for earthing material of copper in mm²					
I''_{k3} in kA	x_0/x_1	I''_{k1} in kA	ϑ_i = 30 °C, ϑ_f = 300 °C 1.0 s	0.5 s	0.2 s	ϑ_i = 30°C, ϑ_f = 150 °C 1.0 s	0.5 s	0.2 s
	1	12.5	70	50	35	95	70	50
12.5	2	9.4	50	35	35	70	50	35
	3	7.5	50	35	35	70	50	35
	1	10	70	50	35	95	70	35
≤ 10	2	7.5	50	35	35	70	50	35
	3	6	35	35	35	50	35	35

x_0/x_1: Ratio of zero-sequence reactance to positive-sequence reactance of the network from the point of view of the fault location; 1 for faults near the generator, heavily loaded networks and in case of doubt; 2 for all other installations; 3 for faults far from the generator.

The earthing voltage U_E in low-resistance earthed networks given approximately by:

$$U_E = r \cdot I''_{K1} \cdot Z_E$$

Where
r : reduction factor
Z_E : earthing impedance
I''_{K1} : single-line initial symmetrical short-circuit current

Overhead earth wires or cable sheaths connected to the earthing system carry some of the fault current in the event of malfunction as a result of magnetic coupling. This effect is expressed by the reduction factor *r*. If overhead earth wires or cable sheaths are not connected, $r = 1$. In the case of overhead earth wires of overhead lines, the typical values given in Table 5-10 apply.

Table 5-10

Typical values for earth wire reduction factors *r*

Earth wire type	r
1 x St 70	0.97
1 x Al/St 120/20	0.80
1 x Al/St 240/40	0.70
2 x Al/St 240/40	0.60

The earthing impedance Z_E is derived from the parallel switching of the dissipation resistance R_A of the installation and the impedance Z_P of parallel earth electrodes (cable, overhead cables, water pipes, railway tracks etc.). The following is approximate:

$$Z_E = \left(\frac{1}{R_A} + \frac{1}{Z_P}\right)^{-1}$$

The dissipation resistance of the mesh earth electrodes of a switchgear installation can be calculated as follows:

$$R_A = \frac{\rho}{4}\sqrt{\frac{\pi}{A}}$$

Where:
ρ : specific resistance of the soil [Ωm]
A: area of mesh earth electrode [m^2]

The guidance values given in Table 5-11 (DIN VDE 0228) apply for the specific resistance of various soil types.

Table 5-12 shows guidance values for the parallel resistances Z_P of various earth electrodes. The values listed there only apply from a specific minimum length. The values for overhead lines only apply for steel towers.

The dissipation resistances of surface and deep earth electrodes can be seen in Figs. 5-9 and 5-10. The broken curve in Fig. 5-10 shows the results of a measurement for comparison.

Table 5-11

Specific resistivity of different soils

Type of soil	Climate normal, Precipitation ≈ 500 mm/year		Desert climate, Precipitation ≈ 250 mm/year	Under-ground saline water
	Typical value Ωm	Range of measured values Ωm		
Alluvium and light alumina	5	2 to 10[1)]		
Non-alluvial clay	10	5 to 20	10 to 1000	3 to 10
Marl, e.g. Keuper marl	20	10 to 30	50 to 300	3 to 10
Porous limestone, e.g. chalk	50	30 to 100	50 to 300	3 to 10
Sandstone, e.g. Keuper sandstone and shale	100	30 to 300	> 1000	10 to 30
Quartz, chalk, solid and crystalline, e.g. marble, carbonaceous limestone	300	100 to 1000	> 1000	10 to 30
Argillaceous slate and shale	1000	300 to 3000	> 1000	30 to 100
Granite	1000	> 1000		
Slate, petrifaction, gneiss, rock of volcanic origin	2000			

1) depending on the groundwater level

Table 5-12

Parallel resistances of earth electrodes

earth electrode type	Zp [Ω]	Minimum length [km]
overhead line with 1 earth wire St 70	3.2	1.8
overhead line with 1 earth wire Al/St 120/20	1.3	4.2
overhead line with 1 earth wire Al/St 240/40	1.2	5.4
overhead line with 2 earth wires Al/St 240/40	1.1	6.8
10-kV cable NKBA 3 × 120	1.2	0.9
Water pipe NW 150	2.3	1.5
Water pipe NW 700	0.4	3.0
Electric rail 1 track	0.6	8.0
Electric rail 2 tracks	0.4	6.9

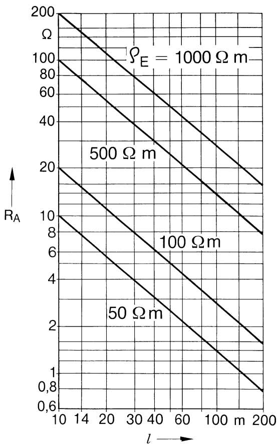


Fig. 5-9

Dissipation resistance R_A of surface earth electrodes (strip, bar or stranded wire) laid straight in homogenous soil in relationship to the length l with different specific resistivities ρ_E

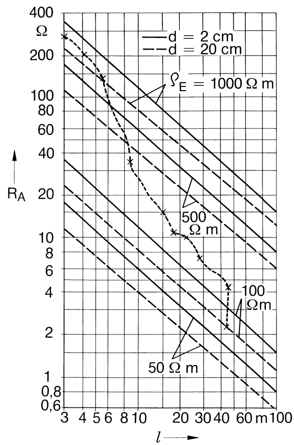


Fig. 5-10

Dissipation resistance R_A of deep earth electrodes placed vertically in homogenous soil in relationship to the electrode length l with various diameters and specific resistivities ρ_E, curve x ... x: Measured values

5.3.4 Earthing measurements

The specific resistivity ρ_E of the soil is important for calculating earthing systems. For this reason, ρ_E should be measured before beginning construction work for a switchgear installation; the measurements are made using the "Wenner Method" (F. Wenner: A Method of Measuring Earth Resistivity, Scientific papers of the Bureau of Standards, No. 248, S. 469-478, Washington 1917).

Measuring the step and touch voltages after setup of a switchgear installation is one way to confirm the safety of the system; the measurements are conducted in accordance with the current and voltage method in DIN VDE 0101.

The current and voltage method also allows the earthing impedance (dissipation resistance) of the installation to be calculated by measuring the potential gradient.

Use of earth testers (e.g. Metraterr II) to measure dissipation resistance should be restricted to single earth electrodes or earthing systems of small extent (e.g. rod earth electrode, strip earth electrode, tower earth electrode, earthing for small switchgear installations).

5.4 Lightning protection

Damage caused by lightning strikes cannot be completely prevented either technically or economically. For this reason, lightning protection facilities cannot be specified as obligatory.

The probability of direct lightning strikes can be greatly reduced on the basis of model experiments, measurements and years of observation with the methods described below.

5.4.1 General

A distinction is made between external and internal lightning protection.

External lightning protection is all devices provided and installed outside and in the protected installation provided to intercept and divert the lightning strike to the earthing system.

Internal lightning protection is total of the measures taken to counteract the effects of lightning strike and its electrical and magnetic fields on metal installations and electrical systems in the area of the structure.

The earthing systems required for lightning protection must comply with DIN VDE 0101, with particular attention paid to the requirements for lightning protection in outdoor switchgear (e.g. back flashover).

Key to symbols used

A		live part
B		overhead earth wire lightning rod
C	(m)	distance between lightning rods
H	(m)	height of earth wire height of lightning rod (height of interception device)
2H	(m)	twice the height of the earth wire
3H	(m)	three times the height of the lightning rod
h	(m)	height of live part over ground level (object height)
h_B	(m)	radius of lightning sphere, flashover distance to earth
h_x	(m)	lowest height of protected zone at midpoint between two lightning rods
L	(m)	distance overhead earth wire to equipment distance lightning rod to equipment
L_x	(m)	distance live part from axis of lightning rod (protected distance)
M		centre of arc for limitation of outer protective zone
M_1		centre of arc for limitation of inner protective zone
R	(m)	radius for M_1-B
r_x	(m)	radius for limitation of protected zone at height h
α		*shielding angle (with universal method)*

5

5.4.2 Methods of lightning protection

There are currently four methods of designing lightning protection systems:

- Lightning sphere method
- Method as per DIN VDE 0185
- Linck's universal method
- Method as per DIN VDE 0101

Lightning sphere method

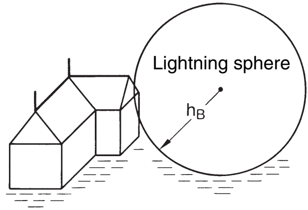
The lightning sphere method ensures complete lightning protection. It is used for residential buildings or high-hazard locations (warehouses with highly flammable materials such as oil, gas, cotton etc.). It is not used for electrical power systems.

The contours of the objects that are to be protected and the planned interception devices are modeled – e.g. at a scale of 1:100 to 1:500. Then a sphere is made with a scale radius of 10, 20 or 40 m depending on the requirements, which corresponds to the flashover distance to earth h_B. The lightning sphere is then rolled around the model on a flat surface. If the lightning sphere only touches the interception devices, the protected objects are completely in the protected area. However, if the lightning sphere does touch parts of the protected objects, the protection is not complete at these sections (see Fig. 5-11).

If the configurations of the air terminals are simple, it will generally be unnecessary to produce a model. The effectiveness of the protection system can be assessed by examinations based on the projection of the lightning sphere.

Fig. 5-11

Determining the effectiveness of lightning rods and conductors for protecting the building



Method as per DIN VDE 0185

The lightning protection method as per DIN VDE 0185 ensures that buildings are almost fully protected. The structural features for the protected area are determined by the above method and are generally the same as the method as per DIN VDE 0101.

Linck's universal method

Linck's universal method (see Fig. 5-12) provides the following data for the external lightning protection system (interception devices):

– number and height of lightning rods and overhead earth wires,
– theoretical location layout for interception devices.

Linck's lightning protection method is based on the statistical data of the disconnection frequency in overhead cables.

Disconnecting of overhead lines caused by a direct lightning strike is based on two effects:

– incomplete shielding by the earth wire,
– back flashover.

Depending on the nominal voltage and the shielding angle of the building and overhead line, the back flashover is involved in the following percentages of all disconnections:

min.	0 %
mean	25 %
max.	50 %

When using Linck's method to specify the permissible disconnection frequency for switchgear installations, note that back flashover cannot occur in switchgear installations and the assumed disconnection frequency Y is conservative.

It is calculated as follows:

– defining the required data,
– preparing the input data,
– calculation,
– preparing design data.

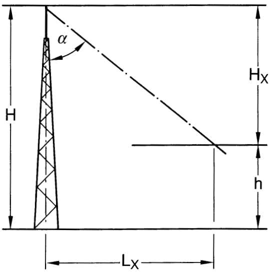


Fig. 5-12

Determining the protected zone by the universal method (Linck)

Method as per DIN VDE 0101

This method ensures almost complete lightning protection and is used exclusively for designing outdoor switchgear installations.

The method described below for determining the protected zone of a high-voltage switchgear installation corresponds to the recommendations of DIN VDE 0101. It has the advantage of being simple for the designer to set the dimensions of the lightning protection facilities. It is suitable for installations of up to approximately 245 kV and protected zone heights of up to approximately 25 metres. Linck's universal method is suited for installations with higher voltage levels and greater protected zone heights or for more precise calculations.

Lightning arresters installed in an installation generally only protect the installation against incoming atmospheric overvoltages (see Sec. 10.6). Overhead earth wires or lightning rods may be installed on the strain portals of the busbars and overhead lines as lightning protection for an outdoor installation. Separate support structures may sometimes be required for this purpose. The overhead earth wires of the incoming overhead lines end at the strain structures of the outdoor installation.

Overhead earth wires and lightning rods must be corrosion-resistant (e.g. Al/St stranded wire, or hot-dip galvanized steel pipes, or bars for rods).

5.4.3 Overhead earth wires

The protected zone, which should enclose all equipment and also the transformers, is determined as shown in Fig. 5-13 or from a diagram (Fig. 5-14).

The sectional plane of the protected zone is bounded by an arc along an overhead earth wire as shown in Fig. 5-13, whose midpoint M is equal to twice the height H of the earth wire both from ground level and from the overhead earth wire B. The arc touches the ground at a distance $\sqrt{3} \cdot H$ from the footing point of the overhead earth wire.

The sectional plane of the protected zone for two overhead earth wires, whose distance from each other is $C \leqq 2 \cdot H$, is shown in Fig. 5-13b. The outer boundary lines are the same as with an overhead earth wire. The sectional plane of the protected zone between the two overhead earth wires B is bounded by an arc whose midpoint M_1 is equal to twice the height 2H of the earth wire from ground level and is in the middle of the two overhead earth wires. The radius R is the distance between the overhead earth wire B and the midpoint M_1.

The angle between the tangents to the two bounding lines is 2 × 30° at their point of intersection. If an angle of around 2 × 20° is required in extreme cases, the distance 1.5H must be selected instead of the distance 2H.

The arrangement of the overhead earth wires for a 245 kV outdoor installation is shown in Fig. 5-13 c. The bounding line of the protected zone must be above the live station components.

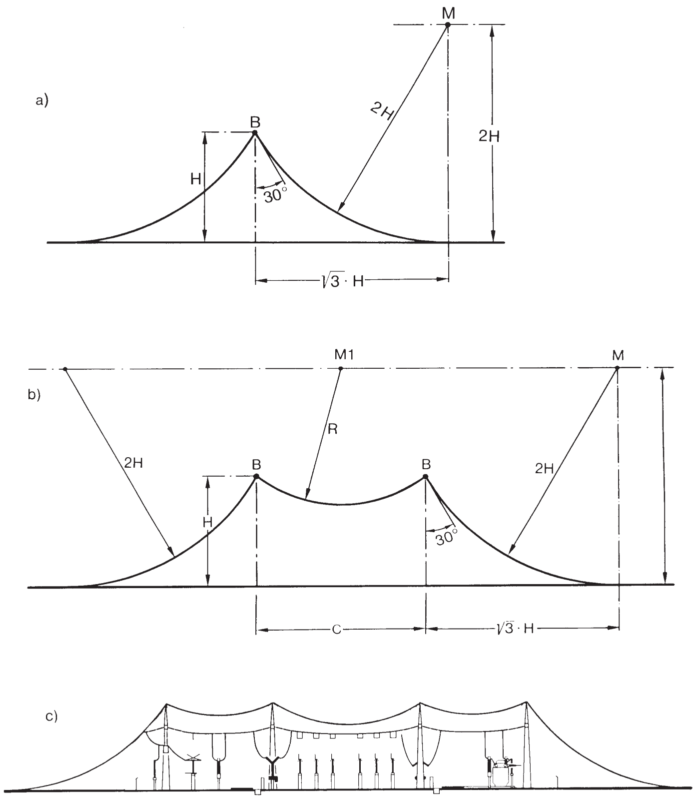


Fig. 5-13

Sectional plane of the protected zone provided by overhead earth wires as per the FGH recommendations:

a) sectional plane of the protected zone with one overhead earth wire,
a) sectional plane of the protected zone with two overhead earth wires,
c) arrangement of the overhead earth wires and protected zone of an outdoor switchgear installation.

The height H of the overhead earth wire can be calculated from Fig. 5-14. The curves show the sectional plane of the protected zone one overhead earth wire.

Example: equipment is installed at a distance of L = 12.5 m from the overhead earth wire, with the live part at height h = 9.0 m above ground level: The overhead earth wire must be placed at height H = 23.0 m (Fig. 5-14).

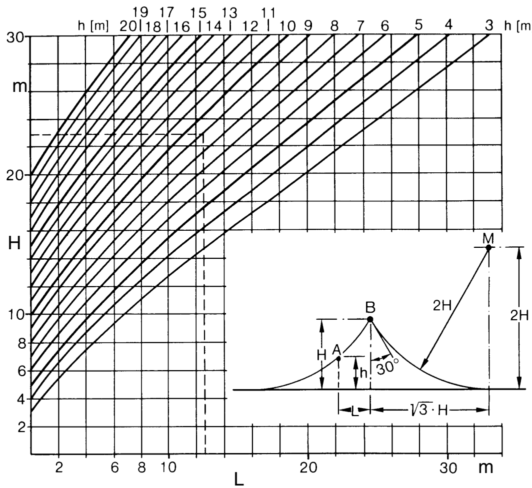


Fig. 5-14

Sectional plane of the protected zone for one overhead earth wire

5.4.4 Lightning rods

Experience and observation have shown that the protected zone formed by rods is larger than that formed by wires at the same height.

A lightning rod forms a roughly conical protected zone, which in the sectional plane shown in Fig. 5-15 a) is bounded by the arc whose midpoint M is three times the height H of the rod both from ground level and the tip of the lightning rod. This arc touches the ground at distance $\sqrt{5} \cdot H$ from the footing point of the lightning rod.

The area between two lightning rods whose distance from each other is $\leqq 3 \cdot H$ forms another protected zone, which in the sectional plane shown in Fig. 5-15 b) is bounded by an arc with radius R and midpoint M_1 at $3 \cdot H$, beginning at the tips of the lightning rods.

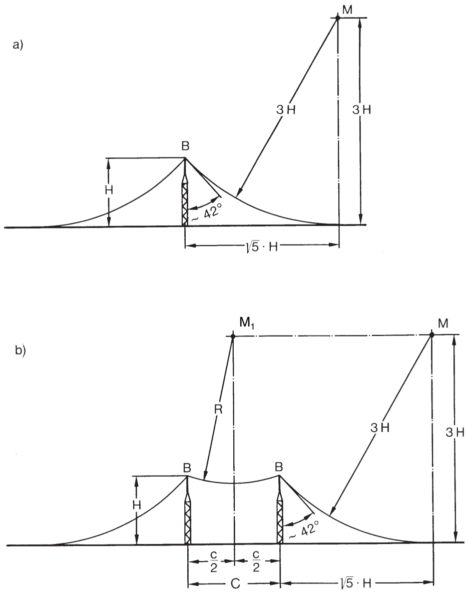


Fig. 5-15

Sectional plane of the zone protected by lightning rods: a) sectional plane of the protected zone with one lightning rod, b) sectional plane of the protected zone with two lightning rods.

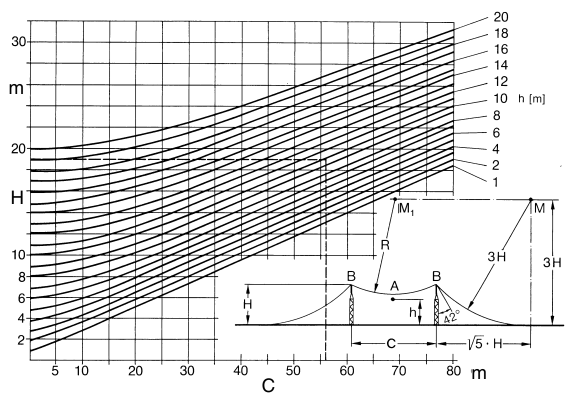


Fig. 5-16

Sectional plane of the protected zone for two lightning rods

The height H of the lightning rod can be calculated from Fig. 5-16. The curves show the protected zone for two lightning rods.

Example: equipment is centrally placed between two lightning rods, which are at distance C = 560 m from each other; the live part is at height h = 10.0 m above ground level: the lightning rods must be at a height of H = 19.0 m (Fig. 5-16).

The width of the protected zone L_x – at a specific height h – in the middle between two lightning rods can be roughly determined from Figs. 5-17 a) and 5-17 b) and from the curves in Fig. 5-17 c).

Example: equipment is centrally placed between two lightning rods at distance L_x = 6.0 m from the axis of the lightning rods; the live part is at height h = 8.0 m above ground level: When the lightning rods are at a distance of C = 40.0 m the height of the lightning rods must be H = 18.5 m (Fig. 5-17).

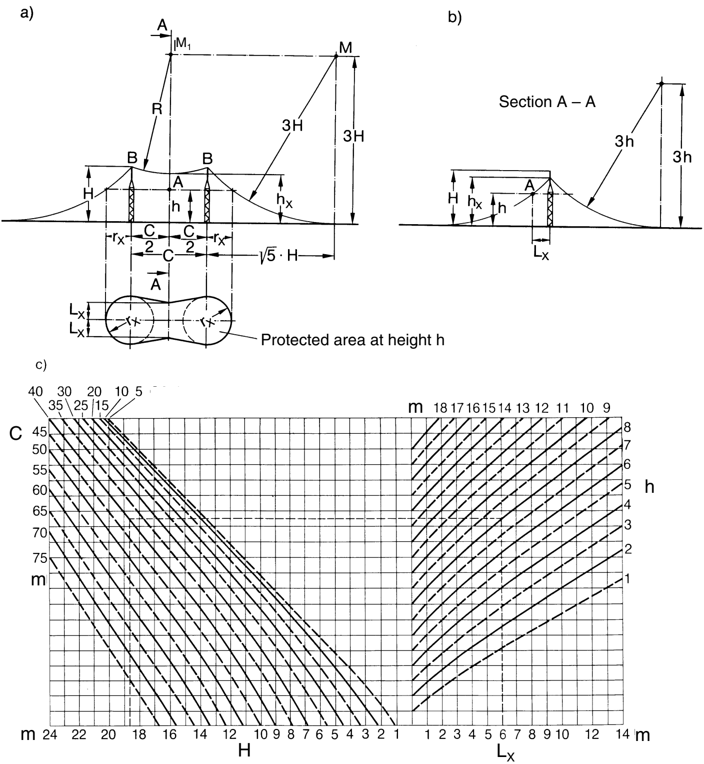


Fig. 5-17

Protected zone outside the axis of 2 lightning rods

5.5 Electromagnetic compatibility

The subject of electromagnetic compatibility (EMC) includes two fundamentally different aspects of the effects of electromagnetic fields, i.e.

– electromagnetic compatibility between electrical equipment and
– the effects of electromagnetic fields on biological systems, particularly on humans.

Effects of electromagnetic fields on humans

Treatment of this part of the subject in the media has resulted in increased worry among the public, although there is no foundation for this, based on events in practice or any relevant research results.

The effects of electromagnetic fields on humans are divided into a low-frequency range (0 Hz to 30 kHz) and a high-frequency range (30 kHz to 300 GHz).

"Approved values" have already been established for both ranges. The low-frequency range is of primary interest for the operation of switchgear installations. The work of standardization in this area is still not complete. Currently there are:

– the 26th federal regulations for the Federal Immission Control Act (26th BImSchV), in force since 1 January 1997 for generally accessible areas without limitation on time of exposure for fixed installations with voltages of 1000 V and above,
– DIN VDE V 0848-4/A3, published in July 1995 as a draft standard and
– ENV 50166-1, a European draft standard from January 1995.

In the low-frequency range, the current density occurring in the human body is the decisive criterion for setting the limit values. According to a study by the World Health Organisation (WHO), interaction between current and muscle and nerve cells occurs above a body current density of 1000 mA/m^2, with proven acute danger to health in the form of interference with the functioning of the nerves, muscles and heart. The lowest limit for detection of biological effects is approximately 10 mA/m^2. Current densities below 1 mA/m^2 have no biological effects.

In 26th BImSchV, a body current density of 1-2 mA/m^2 was selected as the basic value for the derivation of approved field quantities. At 50 Hz this yields permissible values of 5 kV/m for the electrical field and 100 μT for the magnetic flux density.

Short-term higher values to double the permissible value are approved for both values. Higher values in a small space in the same dimensions are approved for the electrical field outside buildings.

DIN VDE V 0848-4 and ENV 50166-1 specify a body current density of 10 mA/m^2 as the initial value for exposure in the workplace with limited exposure time. The associated derived field quantities vary greatly depending on the exposure time. They are significantly higher than those specified by 26th BImSchV.

The approved limit values are set with close attention to the effects detected in the body with due consideration to high safety factors (250-500) with reference to the limit of direct health hazards. The current research results give no indication that lower values should be specified as approved quantities with reference to the occurrences of cancers.

Readings in the field taken under a 380 kV line at the point of greatest sag showed a magnetic flux density of 15 to 20 µT (at half maximum load) and an electrical field intensity of 5-8 kV/m. The corresponding values were lower with 220 kV and 110 kV lines. Electrical field intensities are practically undetectable outside metal-encapsulated switchbays, and the magnetic field intensity generally remains below the limits of 26th BImSchV, even at full load.

Heart pacemakers may, but need not be influenced by electrical and magnetic fields. It is difficult to predict the general sensitivity of pacemakers. When utilizing the approved limit value for workplace exposure, a careful case-by-case analysis is recommended.

Electromagnetic compatibility between electrical equipment

This part of the subject includes terms such as secondary lightning protection, precision protection and nuclear electromagnetic pulses (EMP or NEMP) and radio interference suppression. While these subjects are not treated in detail, this section deals with the physical phenomena and the technical measures described in the following sections.

Electromagnetic compatibility is the capacity of an electrical device to function satisfactorily in its electromagnetic environment without influencing this environment, which includes other equipment, in a non-approved manner (DIN VDE 0870).

The electromagnetic environment of a device is represented by all the sources of interference and the paths to the device (Fig. 5-18). At the same time, the electromagnetic quantities generated in the device also act on the environment through the same paths.

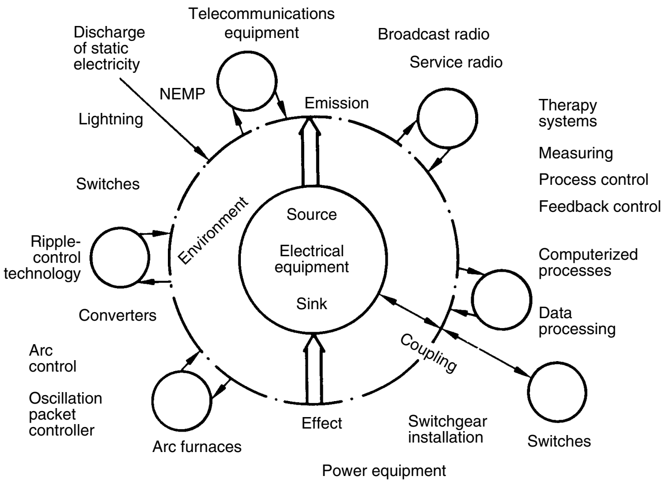


Fig. 5-18

Multilateral interference model

Electromagnetic compatibility (EMC) is essential at every phase of a switchgear installation project and extends from establishing the electromagnetic environment to specifying and checking the measures required to maintaining control over planning and changes to the installation. The EMC activities are shown in Table 5-13.

Table 5-13

Overview of EMC activities during the design of switchgear installations

EMC analysis
- identifying sources of interference
- determining interference quantities
- calculating/estimating/measuring paths
- determining the interference resistance of interference sinks (e.g. from secondary equipment)

Measures for achieving EMC
- measures at interference sources
- measures on coupling paths
- measures at interference sinks

Verification of EMC
- generating interference quantities with switching operations
- simulation of interference quantities in the laboratory

Particularly in the event of a fault, i.e. if there is non-permissible interference, the bilateral influence model as shown in Fig. 5-19 is sufficient to clarify the situation. Action must be taken to decouple the interference source and the interference sink.

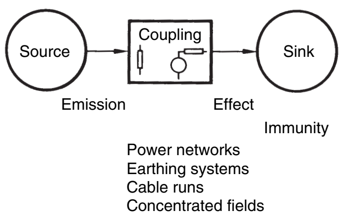


Fig. 5-19

Bilateral interference model

Good electrical conductivity in the system is an essential basis for decoupling measures between the parts of the system and its environment to ensure equipotential bonding and shielding.

Measures for equipotential bonding are combined under the term “bonding”. All electrical conductive parts of a system are connected to an earth. Conducting parts of the system can be conductively connected to this earth to enable operation of the system in accordance with regulations (bonding). If the earth is conductively connected to an earth electrode (earthing), this is considered functional earthing (telecommunications, DIN VDE 0804) or system earthing (low-voltage systems). Functional earthing can also be implemented with protective functions (in connection with low-voltage) and must then be able to meet the corresponding requirements.

Equipment housing that forms a part of the earthing system can be designed so it forms an equipotential envelope, which protects the equipment by shielding it against incoming and outgoing interference fields.

Two important points must be observed when connecting conductive parts of electrical equipment during design of electrical installations:

– protection against unacceptably high touch voltages by protective measures, as specified by DIN VDE 0100 and 0101: a protective conductor system is used for this when required.
– reduction of electromagnetic interference by creating equipotentials: this is the purpose of the bonding system.

5

5.5.1 Origin and propagation of interference quantities

An electromagnetic interference quantity is an electromagnetic quantity that can indicate undesirable interference in an electrical system.

The interference quantity is a collective term that covers the actual physical terms of interference caused by voltage, current, signals, energy etc. (DIN VDE 0870). Interference quantities are caused by otherwise useful technical quantities or parts of them and by discharge of natural and technically generated static electricity. The term “interference” expresses the intention of considering the quantity in question in terms of its possible interference effects.

Fig. 5-20 shows an overview of the most important interference sources in switchgear installations and their interference quantities and coupling paths.u

The behaviour of an interference quantity over time depends on the type of process that causes it and may be periodic or unique.

Periodic, sinusoidal interference quantities

They are referred to as ripple-control signals or carrier signals in data transmission and in general radio technology. Harmonics caused by the system voltage caused by ignition processes (fluorescent lights, power supplies, power electronics) must also be considered. The actual cause of these harmonics is individual periodic switching operations of electronic devices. Each one of these switching operations can therefore be considered as an interference quantity, which can be classified among the transient, pulse-type sources of interference described below.

Periodic, sinusoidal processes are shown in the frequency range resulting from a Fourier series transformation, in the so-called amplitude spectrum as single lines. The height of these lines represents the proportion of a characteristic frequency, which is contained in the sinusoidal interference signal. These frequency segments can also be directly measured (DIN VDE 0847 Part 1).

Transient, pulse-type interference quantities

These occur with switching operations with a more or less steep transition from one switch status to the other, in arc furnaces, in manually or electrically actuated mechanical switches of the most varied power and in the semiconductors of power-electronic and computer equipment. A discharge process can also act as a general pulse-type interference source. So both the discharge of static electricity, such as natural lightning and the exposed conductive part discharge, and partial discharges in insulation (transformers, transducers, machines) can be described as pulse processes.

Pulse-type, periodic processes, such as are generated by brush motors asynchronously to the network frequency (“brush fire”), must also be classified as transient, pulse-type interference quantities when the individual processes are considered, in spite of a periodicity of the pulse sequences.

A unified and coherent representation of pulse-type interference quantities, including their partial phenomena, is also possible in the amplitude density spectrum, which is derived from the Fourier series transformation and can also be measured (DIN VDE 0847 Part 1).

The interference quantities that originate with the very frequently occurring switching operations in the high-voltage area (primary side) of switchgear installations are listed in Table 5-14. They oscillate with high frequency.

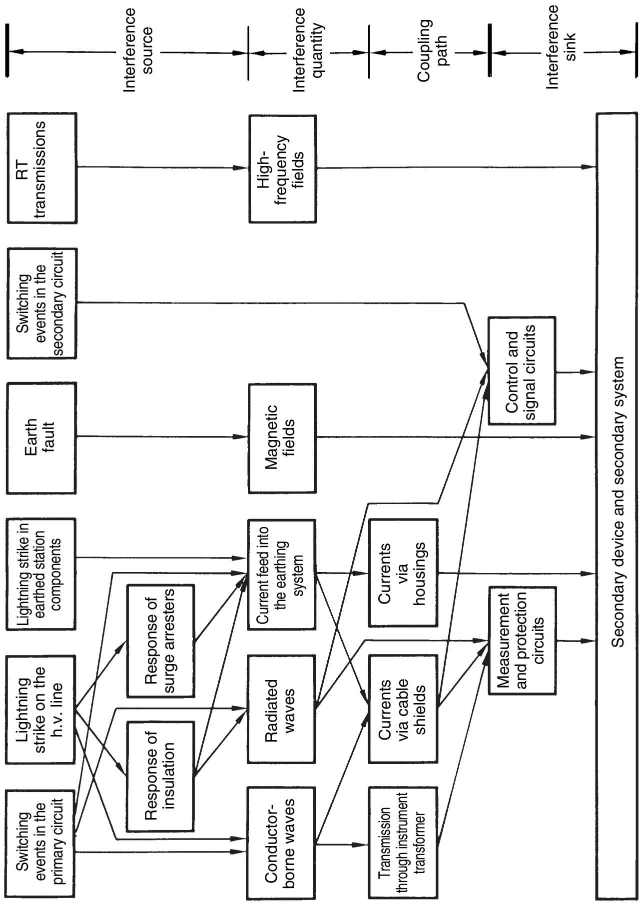
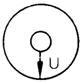
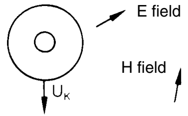
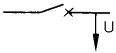
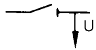
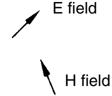


Fig. 5-20

Origin and propagation of interference quantities in switchgear installations.

Table 5-14

Characteristic parameters of interference quantities with switching operations in the primary circuit of high-voltage installations

SF_6 Gas-insulated switchgear (GIS)					Conventional outdoor switchgear installation (AIS)			
					 SF_6 Self-actuating pressure switch	 disconnector		
Quantity	Voltage U	Voltage U_K	E field	H field	Voltage U	Voltage U	E field	H field
Rise time Frequency Height Damping Geometrical distances	4 – 7 ns kHz – 10 MHz system-specific weak small	15 – 50 ns MHz system-specific strong large	 – 20 MHz $1^{1)} – 50^{2)}$ $\frac{kV}{m}$ strong	 – 20 MHz $2.5^{1)} – 125^{2)}$ $\frac{A}{m}$ strong	50 – 100 ns kHz – MHz system-specific strong large	200 ns kHz – MHz system-specific strong large	180 – 700 ns $5^{3)} – 50^{4)}$ $\frac{kV}{m}$ strong	60 – 100 ns $1^{3)} – 2^{4)}$ $\frac{A}{m}$ strong

1) GIS with building
2) GIS without building

3) 345-kV breakers
4) 500-kV breakers

Interference quantities propagate along the wires and by radiation:

- galvanically, over the apparent resistances of conductors,
- inductively coupled,
- capacitively coupled,
- as a common wave from two conductor systems,
- as a free spatial wave.

Once coupled into the bonding system, earthing system or a signal circuit, the interference quantity moves along the path of the conductor.

An interference quantity varies in time in the course of its propagation according to the coupling between interference source and interference sink:

- partial events may merge,
- an event may be split into partial events.

The spectral energy density of the interference quantity causes the entire system transmitting it to oscillate; see Fig. 5-21, Coupling mechanisms for interference quantities in a high-voltage switchgear installation.

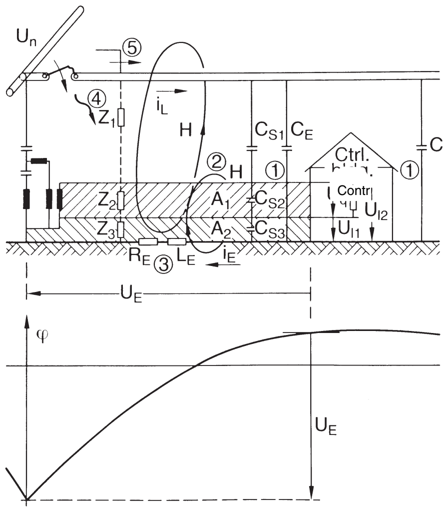


Fig. 5-21

Coupling mechanisms for interference quantities in a high-voltage switchgear installation

U_{l1}, U_{l2} components of longitudinal voltage, U_q transverse voltage

① *Capacitive coupling, C_E capacitance of high-voltage conductor to earth grid, C_{S1}, C_{S2}, C_{S3} capacitances of the secondary system conductor*

② *Inductive couplings, H influencing magnetic fields, A_1, A_2 induction areas*

③ *Galvanic coupling, R_E, L_E resistivity and inductivity of the earth grid, i_E current in earth grid resulting from coupling over C_E*

④ *Radiation coupling*

⑤ *Surge waves from transient processes, Z_1, Z_2, Z_3 wave impedances*

An interference quantity occurs in a current circuit (Fig. 5-22) whose conductors show earth impedances (primarily capacitance). This means that the interference quantity also finds current paths to earth or reference earth. This yields the following interference voltage components:

– symmetrical (differential mode, transverse voltage) between the conductors of the current circuit
– non-symmetrical between a conductor and earth or reference earth
– asymmetrical (common mode, longitudinal voltage) as resultant of non-symmetrical components

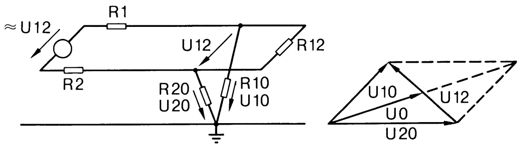


Fig. 5-22

Relationships among potentials of an interference voltage:
U12 symmetrical interference voltage component
U10, U20 non-symmetrical interference voltage components
U0 asymmetrical interference voltage component

If an interference quantity is produced in a current circuit, its asymmetrical component disappears if the current circuit is structured and operated completely symmetrically. The asymmetrical component is the interference quantity, which may cause interference in an isolated sink circuit.

If a conductor of the source current circuit is earthed, i.e. connected with reference earth, its non-symmetrical component becomes very small while the other conductor assumes the symmetrical component as non-symmetrical. In this case, the asymmetrical component is about half the symmetrical.

An asymmetrical interference voltage component coupled to a sink current circuit has a non-symmetrical and a symmetrical component corresponding to the current circuit's non-symmetry.

5.5.2 Effect of interference quantities on interference sinks

The origin of interference components at the input terminals of a device considered as an interference sink is determined by its design, the operating mode and the design of the connected line and also the device operated via the line.

a) Symmetrical operation:

Symmetrical operating mode for a current circuit occurs when its conductors have equal impedances with respect to reference earth in the frequency range of the useful quantity. Symmetrical operation is achieved by potential separation or the use of differential amplifiers.

– The asymmetrical influence of the line acts equally on both wires of the line and generates non-symmetrical components in accordance with the earth relationships of the line terminals at the equipment. The difference of the non-symmetrical components occurring at higher frequencies is a symmetrical component.

– A symmetrical interference component in the high-frequency range occurs because of non-symmetries of the connected equipment on the asymmetrical coupling path, in the low-frequency range by couplings (inductive for finite area, capacitive for non-symmetrical configuration) in the conductor loop of the line.
– Direct non-symmetrical influence does not occur with symmetrical operation.

b) Non-symmetrical operation:

Non-symmetrical operating mode occurs when the conductors of a current circuit have unequal impedances compared to the reference earth; this is always the case when multiple signal voltages have a common reference conductor.

The interference then affects each wire of the line separately. Particularly in the case of inductive impedances within the equipment, the non-symmetrical interference component on the signal reference conductor is not always zero.

– The symmetrical interference component on the low-frequency range is equal to the non-symmetrical component, and in the high-frequency range approximately equal to the non-symmetrical component.
– The asymmetrical influence has no meaning with non-symmetrical operation.

The ultimate effect of an interference quantity in equipment must be assessed in terms of voltage or current.

An interference effect in or even destruction of a semiconductor only occurs if a voltage (a current) exceeds a specific threshold value and then forms a sufficiently large pulse-time area.

Even if interference does not affect the functioning of an electronic circuit or stop it from functioning, it is essential that the semiconductors used are not overstressed by the interference quantity.

Semiconductors are destroyed by current spikes when exposed to pulsed events or they are affected by cumulative damage until they eventually no longer have the properties required for proper functioning of the device: dielectric strength, current amplification and residual current.

An interference quantity can be superimposed on the useful signal as a symmetrical component and can adversely affect the functioning in the influenced equipment depending on the interference distance (signal level – interference level) or sensitivity.

As a non-symmetrical component, the interference quantity can reach any part of the circuit and result in spurious functions or affect the actual signal processing.

5.5.3 EMC measures

EMC must be planned quantitatively. This means that the interface requirements (emission, strength) must be specified for defined zones (EMC zones). Then the compatibility level is defined, for which various types of decoupling measures are required. In this connection, the bonding system is particularly important.

It is useful to assess the hierarchical elements of a systems, such as the complete plant
equipment room
cubicle assembly
rack assembly
circuit board
circuit section
component
with respect to their multilateral compatibility in their various electromagnetic environments; see Fig. 5-23.

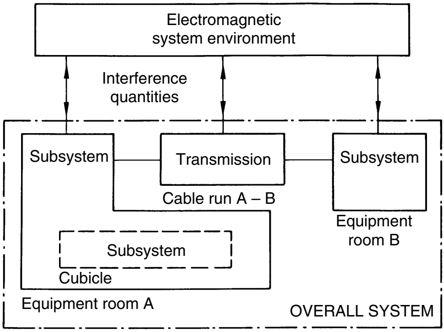


Fig. 5-23

EMC zones in their environment

The purpose of EMC measures is to reduce interference quantities at specific points between the site of origin (interference source) and the site of functional effect (interference sink), see Table 5-15.

Table 5-15

Application of EMC measures in a complete switchgear installation

Zone	Source	Coupling path	Sink
Objective	To reduce Interference emission	To reduce coupling	To enhance interference resistance
Technical measure	Low-inductance earthing	Layout Isolation Equipotential bonding Shielding	Filtering Limitation Optocoupler
	Wiring of relay coils	Balancing Symmetrical operation Non-electrical transmission	
Organizational measures	Separation by coordinating operation processes Fault-tolerant programs and protocols		

The effectiveness of any measures must be assessed depending on the frequency; see Table 5-16. The upper limit frequency for the effectiveness of a measure is limited by the extension of the configuration for which they are used (Lambda/10 rule). This assessment must be applied to the length of earthing conductors, cable shields and their connections, to the side lengths and openings of shielding housings and to the grid size of bonding systems.

Table 5-16

Limit frequencies for the effectiveness of measures

Zone	Upper limit frequency	Max. length
Switchgear installation	100 kHz	300 m
Building	1 MHz	30 m
Equipment room	10 MHz	3 m
Cubicle	15 MHz	2 m
Device (rack – circuit board)	100 – 1000 MHz	30 – 3 cm

EMC measures should prevent or minimize the occurrence of symmetrical and non-symmetrical components. They are generally initially based on minimizing the asymmetrical component and with that, the symmetrical component. Measures against the asymmetrical component are bonding or ground-based. Measures for minimizing the symmetrical component must be compatible with these.

Bonding-based EMC measures are shown in Fig. 5-24 with the example of an outdoor switchgear installation. The following is assumed:

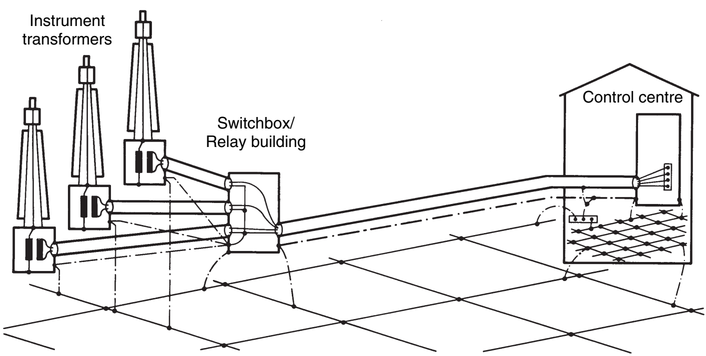


Fig. 5-24

Meshed bonding system and treatment of shielding of secondary wiring in a high-voltage switchgear installation[1)]

[1)] ABB publication DSI 1290 88 D, reprint from “Elektrotechnik und Informationstechnik” 105 (1988): p. 357-370: Remde, Meppelink, Brand “Electromagnetic compatibility in high-voltage switchgear installations”.

– secondary lines laid parallel to earth conductors
– screening connected to ground at both ends by coaxial connection wherever possible
– additional equipotential bonding conductor over full length of line
– multiple connection of building earth with the switchgear installation earth
– multiple shield earth connection with increasing density in the direction of the electronics, in accordance with the Lambda/10 rule
– instrument transformer secondary circuit earthed only once per 3-phase group (in local cubicle)

Decoupling measures

The interference level of an interference source acting on an interference sink can be reduced by a number of measures. In most cases, a single type of decoupling measure is not sufficient to achieve the required decoupling damping; several types of measure must be applied in combination. Depending on the design in practice, the following list of options should be considered:

– Routing:
  lines of different interference sensitivity laid separately; minimum clearance, restriction of common lengths.
– Conductors:
  two-wire lines instead of common returns; symmetrical signal transmission with symmetrical source and sink impedances.
– Potential isolation:
  galvanic isolation of the signal circuits at the system boundary; attention to parasitic coupling properties of the isolating components.
– Shielding:
  for extensive compensation of galvanically coupled high-frequency potential differences in the earthing system, generating a negative-sequence field with inductive influence and diversion of displacement currents with capacitive influence.
– Filtering:
  generally low-pass filter with concentrated components.
– Limitation:
  voltage-limiting components (surge arresters) to limit the voltage, but less influence on steepness, source of new interference quantities because of non-linearity; more for protection against destruction than to avoid functional deterioration.
– Equipotential bonding:
  for low-impedance connection of system or circuit sections between which the potential difference should be as low as possible; basic requirement for effectiveness of shielding, filtering and limitation.

Decoupling measures are only effective in restricted frequency ranges (see Fig. 5-25). This makes it all the more important to know what frequency range requires the greatest decoupling damping. The greater the bandwidth of the decoupling is required, the more measures are required in the chain. The basic rule with the application of decoupling measures in the direction of propagation of the interference quantity is to begin with the following:

– from the interference source to the environment with the decoupling of high frequencies,
– from the environment to the interference sink with the decoupling of low frequencies.

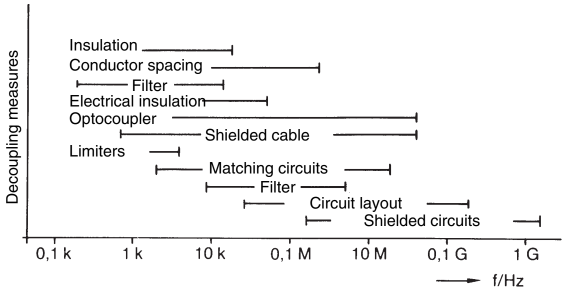


Fig. 5-25

Effectiveness trend of decoupling measures with respect to preferred frequency ranges

Bonding system

The bonding system includes all equipment for electrically connecting the
housing grounds,
shield conductors,
reference conductors where ever they are to be connected to the earth.

DIN VDE 0870 defines the terms for bonding and earthing. Bonding is most important for the requirements of EMC. It is the total of all electrically conductive metallic parts of an electrical system, which equalizes different potentials for the relevant frequency range and forms a reference potential.

Note: The relevant frequency range covers both the functional and the environmental frequencies. This frequency range and the spatial extent of the electrical equipment determine the achievable equipotential bonding and therefore the effectiveness of the bonding system. The bonding does not always cover the safety requirements of the potential equalization.

The bonding can be connected with the earth (protective measures); this is the general rule in switchgear installations.

Telecommunications equipment in particular can be operated with functional earthing. In this case, the earthing has the purpose of enabling the required function of an electrical system. The functional earthing also includes operating currents of those electrical systems that use the earth as a return.

An equipotential bonding between system parts intended for protection against unacceptably high touch voltages and also for electromagnetic compatibility must have sufficiently low resistivity even in the high frequency range in which the line inductance is dominant. This can be done by designing the bonding system as a mesh configuration, which reduces the inductance by up to 5 times more than linear systems. The effectiveness of this measure is limited by the grid size for high frequencies (see Table 5-16).

The leakage currents from limiters, filters and shielding must be considered in the design of a bonding system and coupling in signal circuits must be avoided.

Extended conductors, which of course include conductors for equipotential bonding, are also subject to electromagnetic interference quantities. Coupling an electromagnetic wave carried by a line is reduced as the effective area of the conductor picking up the interference increases. The inductive coupling with meshed conductors is reduced by generating opposing fields around the conductors of the mesh. Therefore, meshed systems, combined with their effective capacitance, particularly with the influence of the housing grounds installed over them, have an excellent stable potential in whose vicinity the influence on the signal lines is low, similar to laying them in natural soil with its natural electrical properties.

The more extensive the design of a system, the more difficult is it to implement a continuous ground plane. For this reason, such grounds are only hierarchical, correspondingly limit the EMC areas and must be consistently linked to the entire bonding system with consideration of their limit frequency. Potential differences between the earths of subsystems distant from one another must be accepted. This means that a non-symmetrical transmission of small signals of high bandwidth between these subsystems may be subject to interference.

The bonding system set up with reference to EMC must be assessed according to the following regulations:

– DIN VDE 0160 for heavy-current installations with electronic equipment
– DIN VDE 0800 for the installation and operation of telecommunications systems including data-processing systems
– DIN VDE 0804 for telecommunications devices including data-processing devices

DIN VDE 0160 deals with the properties of the operational leakage currents (from all practical busbar systems) that can occur in industrial power systems in the data processing and heavy current subsystems.

In this case, a hierarchical, radial earthing design offers advantages for decoupling the subsystems and systems with respect to interference.

DIN VDE 0800 and 0804 deal with the requirements of more extended data-processing systems where the levels handled are generally of the same order of magnitude and interference by common busbars is not anticipated, making it unnecessary to decouple the busbars. This is advantageous for the treatment of the signal interfaces.

Systems and subsystems complying with the above regulations can be integrated into an earthing/bonding concept if a bonding system with a superimposed protective conductor system is designed. The interface between the subsystems and their environment is defined as follows:

– protective conductor connection
– bonding system connection.

For more general reasons, structures intended for installation in systems (radial or mesh) may be specified for the bonding system. It is possible to use radial substructures in a meshed bonding system with no particular measures.

If a radial bonding system is specified (Fig. 5-26), the earths of the subsystems must only be connected together over the common equipotential bonding. This means that the following configurations are not permitted when signals are exchanged between subsystems:

– shielding connected at both ends,
– signal exchange with reference to a common signal reference conductor connected to the earth at both ends
– signal exchange over coaxial cable connected to earth at both ends.

This means that signal connections between subsystems must be configured in a radial bonding system to be always isolated.

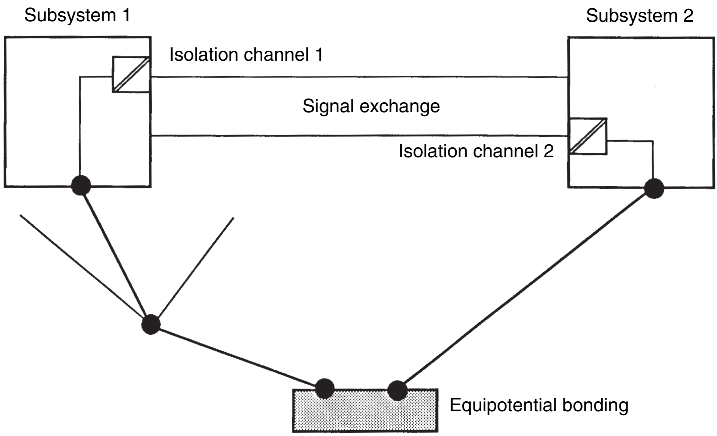


Fig. 5-26

Two subsystems in a radial bonding system

Shielding

Cables are shielded to protect the internal conductors of the cable against interference, which can be coupled capacitively and inductively or galvanically (alternating values). With respect to the effect, the shielding must initially be considered as the influenced conductor. Coupling interference quantities in this conductor yields a current that generates a voltage between the inner conductor and shield as a product of the shielding current and the complex shield resistance. The complex shield resistance is identical to the shield-coupling resistance. The lower the shield resistance, the greater the decoupling effect of the shield. In practice, it is essential to include the resistance of the entire shield circuit, i.e. the shield connection, in the calculation.

A shield that is connected to reference earth at just one end only acts against the capacitive interference. It then forms a distributed low-pass filter whose full capacitance acts at the end of the line to which the shield is connected. The interference coupling tends to increase at the open end of the shield, which becomes particularly evident at high interference frequencies.

If a shield can only be earthed at one end, this should always be the point of lower interference resistance. This is often the receiver, amplifier or signal processor side.

A shield earthed at both ends, closes the current circuit around the area carrying a magnetic flux. A current that acts against the interference field according to the Lentz rule flows and so has a decoupling effect on the conductors of the shielded cable. This effect can also be induced with non-shielded lines by using free wires or closely parallel earth conductors as substitute shields.

The assumption here is that the shielded line is not influenced by low frequency shield currents resulting from equipotential bonding. This requirement is met by a bonding system that has sufficiently low impedances with the relevant frequencies. For frequencies where the external inductive component of the shield resistance is sufficiently large compared to its real component, i.e. at high frequencies, a coupling caused by potential difference is reduced to a value only induced by the transfer impedance.

The higher limit frequency of the shield effect depends on the length of the shield between its connections to earth. Therefore, a shield must be connected to earth at shorter intervals, the higher the limit frequency of its effectiveness should be. Fig. 5-27 shows typical methods of connecting shields for control cables.

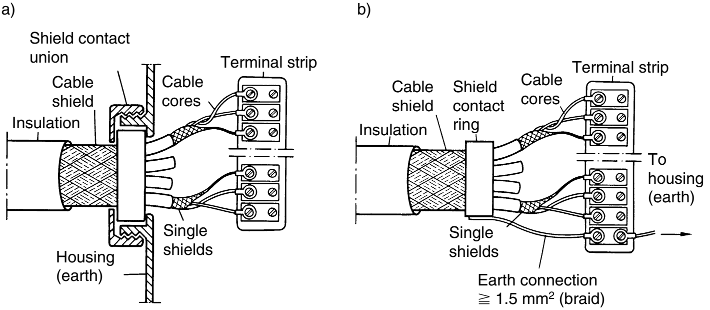


Fig. 5-27

Methods of connecting shielded control cables:
a) coaxial (preferred) b) braided (less effective)

There are (fully insulated) devices with no connection to a protective conductor system. However, they have an inner shield for connection to the shield of the signal lines. This shield may carry interference voltages relative to its environment (“remote earth”).

The manufacturer’s directions for installation of all types of devices must be observed, without affecting the structure of the bonding system (DIN VDE 0160 or DIN VDE 0800/0804).

Cable shields should always be connected at both ends. The ground connection between the subsystems to be connected with the shielded cable should have a lower resistance than the shield circuit. This is sufficient to prevent interference from bonding currents on the shield.

The relevant equipment can have a shield conductor rail (as per DIN VDE 0160) or special shield conductor terminals (as per DIN VDE 0800). Design in accordance with DIN VDE 0800 should be preferred for data-processing systems when considering the possibility of interference. Where several systems interact, both bonding principles can be applied independently with reference to their shield connections, as shown in Fig. 5-28.

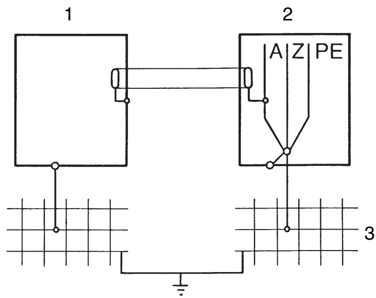


Fig. 5-28

Shielding of systems as per DIN VDE 0160 and 0800:

1 shielding as per DIN VDE 0800, 2 shielding as per DIN VDE 0160 with busbars A to connection of shield conductor, Z to connection of the signal reference conductor, PE to connection of protective conductor, 3 spatial bonding system(s)

Cable routing

Signal cables of control systems must always be laid separately from the general installation network. However, power supply cables leading from a central distribution point to subsystems (e.g. peripheral devices) should be laid with the signal cables. – A clearance of more than 0.3 m between the cables is sufficient for separate cable laying.

In the control rooms, the power supply lines are laid in a radial pattern from the low-voltage distributors to the various devices or subsystems. They are laid along the conductors of a bonding system that is meshed wherever possible.

Switch cabinets

The following information applies for proper design of switchbays with respect to EMC:

- Wide-area, metallic conductive equipotential bonding of all metallic components of the switchbox together is essential.
- Use support plates, rails and racks of galvanized sheet steel only. Note: painted, anodized or yellow-passivized components in some cases have very high resistance values above the 50 Hz frequency.
- Metallic components and parts inside the switchbay must be connected over a wide area and reliably. Ensure that appropriate contact material (screws and accessories) is selected.
- Wide-area, low-resistance earthing of interference sources (equipment) on support plates and racks prevents unwanted radiation.

- The cable layout inside the cabinet should be as close as possible to the reference potential (cabinet ground). Note: freely suspended cables act preferably as active and as passive antennas.
- Unused wires, particularly those of motor and power cables, should be placed on protective conductor potential (PE) at both ends.
- Unshielded cables and wires of a circuit – i.e. feed and return – should be twisted together because of symmetrical interference.
- Relays, contactors and magnetic valves must be switched by spark suppressor combinations or by overvoltage-limiting components. Line filters or interference suppression filters increase the interference resistance of the switchgear installation depending on the interference frequency at the network input.

5.6 Partial-discharge measurement

Partial-discharge measurement is an important tool for assessing the status of high-voltage insulation. It is a proven technique for diagnosing errors in the laboratory, for quality assurance in production and on-site for all high-voltage equipment, such as transformers, instrument transformers, cable systems, insulating bushings and gas-insulated switchgear.

Partial discharges can damage solid insulation materials in the interior and on the surface and may result in breakdown of the insulation. Partial discharges can decompose fluid and solid insulation.

Technical interpretation of the results obtained from the partial-discharge measurements enables detection of weak points at or in insulation systems and provides information on the continuing availability of the equipment.

Partial discharges (PD) are low-energy electrical discharges, which bridge only part of the insulating clearance. They occur when the electrical strength between electrodes of different potential is exceeded at a localized point and result in brief discharges of partial capacities within insulation. These fleeting phenomena result in high-frequency interference fields. In practice, the operator should be aware of possible damage to insulation, emission of electromagnetic interference fields (EMC) and the development of noise (corona).

Partial discharges may occur as follows:

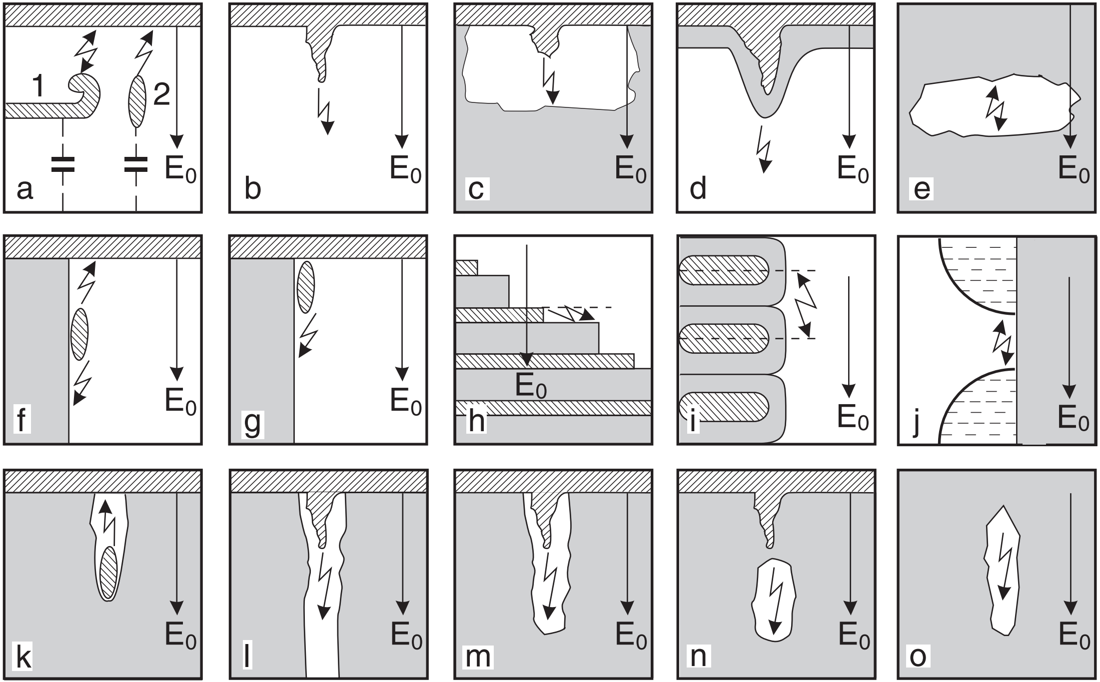
- in cavities inside solid insulation materials,
- at unhomogenous points of the electrical field in solid, fluid and gas insulation materials
- in conductors without fixed potential and stray particles in the area of electrical fields.

Some typical sources of partial discharges are shown in Fig. 5-29.

Partial discharges are verified by

- electrical partial-discharge measurement,
- acoustic partial-discharge measurement,
- optical partial-discharge measurement,
- chemical tests.

Electrical partial-discharge measurement is discussed below.



E_0=field intensity vector = Metal or conductive material = solid insulation material

Fig. 5-29 *Sources of partial discharge at electrodes, insulation and in gas*

5.6.1 Partial discharge processes

There is a basic distinction between internal and external partial discharges.

Internal partial discharges

Internal partial discharges are gas discharges that occur in the cavities of solid insulation material and in gas bubbles in fluid insulation material. This includes discharges in cavities between insulation and electrode (Fig. 5-29 c) and within an insulating body (Fig. 5-29 e).

Fig. 5-30 a shows a faulty insulating body. The non-faulty dielectric is formed by the capacitances C'_3, the gas-filled cavity by C_1 and the element capacitances above and below the fault position by C'_2. The replacement configuration of the insulating body is shown in Fig. 5-30 b. A spark gap F is placed parallel to the cavity capacitance C_1. If the disruptive discharge voltage of the gas-filled fault point is exceeded, it will break down and the capacitance C_1 will be discharged.

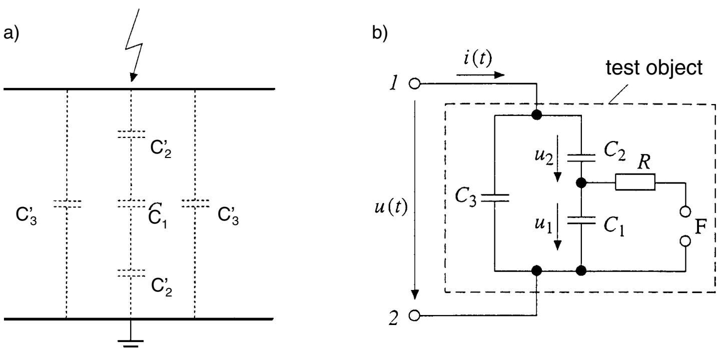


Fig. 5-30

Configuration with internal partial discharges:
a) material background b) equivalent c.t. circuit

If alternating voltage u(t) is applied at the terminals of the equivalent circuit, the voltage at the capacitance of the cavity is found

$$u_{10}(t) = \frac{C_2}{C_1 + C_2} \hat{U} \cdot \sin(\omega t)$$

Fig. 5-31 a shows the two voltage processes. If voltage $u_{10}(t)$ exceeds igniting voltage U_Z of the gas-filled cavity, the spark gap F breaks down and the capacitance C_1 discharges. The persistent voltage value on the test object is referred to as partial discharge (PD) inception voltage. If the voltage on the test object u(t) exceeds this value, the internal discharge will spark several times during a half-wave.

When C_1 is discharged via F, pulse-shaped capactive charging currents i(t) – only partially fed from C_3 but primarily from the external capacitances of the circuit – are superimposed on the network-frequency alternating current (Fig. 5-31 b). The

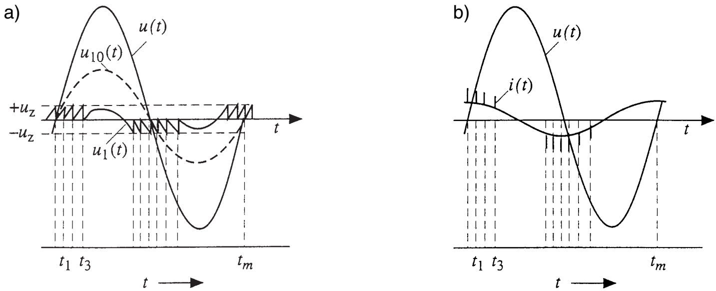


Fig. 5-31

a) voltage characteristics in the equivalent-circuit diagram for pulse-type internal partial discharges
b) current characteristics in the equivalent-circuit diagram for pulse-type internal partial discharges

accumulation of impulses in the area of the zero crossings of voltage u(t) – generally overwhelmingly in the area after the zero crossings – is an indicator for discharges in the cavities of solid insulation materials.

External partial discharges

If the field intensity at air-insulated electrode configurations (e.g. outdoor fittings) – such as in the area before the sharp edges – exceeds the electrical strength of air as a result of impulse ionization in the heavily loaded gas space electron avalanches and photoionization will occur, ultimately resulting in partial breakdown of this area (trichel impulses).

Figs. 5-32 a and b shows a simplified view of the processes with the associated equivalent circuit. In the diagram, C_1 represents the gas space through which the partial discharge breaks down and resistance R_2 represents the charge carriers formed before the peak, which move around in the field cavity and result in a degree of conductivity.

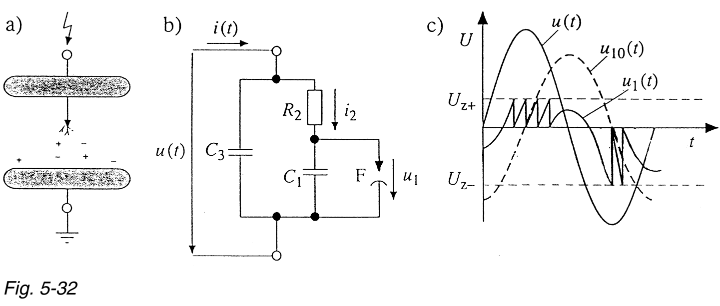


Fig. 5-32

Configuration with external partial discharges: a) peak plate configuration b) equivalent-circuit diagram c) voltage characteristics in the equivalent-circuit diagram for pulse-type external partial discharges.

The associated voltage characteristics of the configuration are shown in Fig. 5-32 c.The voltage characteristic $u_{10}(t)$ at C_1 before the beginning of the first partial discharge follows the equation

$$u_{10}(t) = \frac{\hat{U}}{\omega C_1 R_2} \sin(\omega t - \frac{\pi}{2})$$

The response of the spark gap F in the equivalent-circuit diagram shows the pulse-shaped partial breakdown. If the voltage at the test object is sufficiently high over a time range, the result is a number of PD impulses per half-wave. An indication of external partial discharges on sharp-edged electrodes is the accumulation of impulses in the range of the peak values of the external voltage u(t) applied at the fittings.

5

5.6.2 Electrical partial-discharge measurement procedures

Electrical partial-discharge measurement according to IEC 60270 (DIN VDE 0434)

In the course of almost 40 years of use with simultaneous intensive development of the procedures, this procedure, which is based on the measurement of the apparent charge of the PD impulses at the test object terminals, has become very widespread in the area of high-voltage installations and devices.

Three different test circuits can be used (Fig. 5-33). The coupling capacitor C_K and the four-terminal coupling circuit Z_m (and Z_{m1}) are required for partial-discharge measurement. Impedance Z protects the high-voltage test source and acts as a filter against interference coupled from the network.

The high-frequency high-capacity charging current resulting from the partial discharges in the test object feeds the test object capacitance C_a from the coupling capacitance C_K. Therefore, ratio C_K/C_a determines which charge component at four-terminal coupling circuit Z_m can be measured, i.e., C_K determines the sensitivity of the PD measurement. The quantitative evaluation of the partial-discharge measurement is based on the integration of the high-capacity charging current. This is integrated in the partial discharge instrument within a fixed frequency band.

With respect to the strong influence of the test object and the instrumentation on the result, the test circuit must be calibrated before every test cycle with the test object connected. During this process, a calibration pulse generator feeds defined charge impulses to the terminals of the test object.

The partial discharge instrument gives the apparent charge as a numerical value with the dimension pC (pico-coulomb) as the result of the measurement. The phase angle of the partial charge impulses based on the applied test voltage is also significant. Different displays are shown on monitors for this purpose. Modern devices show the amplitude, rate of occurrence, frequency and phase angle at a specific voltage in a colour image (Fig. 5-34).

The test circuit as shown in Fig. 5-33a is preferred for measurements in practice. In the case of laboratory measurements where the test object is isolated from ground, the test circuit as shown in Fig. 5-33b is suitable.

The partial-discharge measurement technology distinguishes between narrow-band and broad-band partial-discharge measurement. This classification is based on the frequency segment in which the partial discharges are recorded. While measurement with the narrow-band measurement in an adjustable frequency band is done with selected mid-frequency, the broad-band method covers a frequency range of 40 kHz to

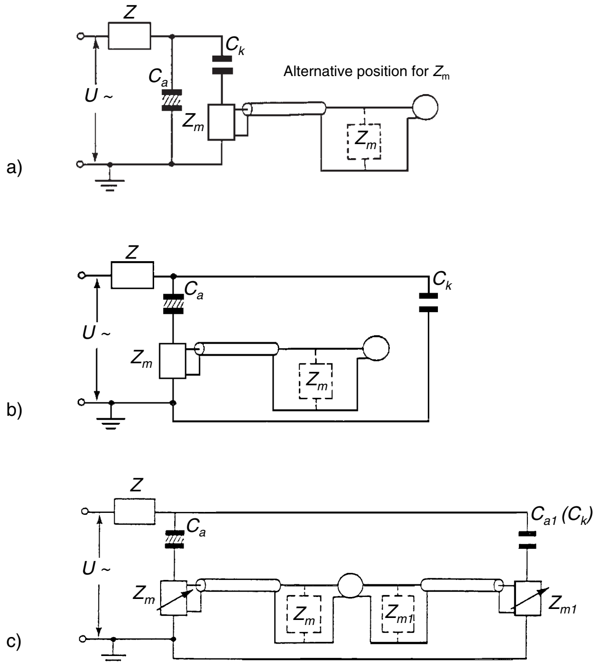


Fig. 5-33

Basic circuit from IEC Publication 60270:
a) + b) direct measurement c) bridge measurement

800 kHz. Interference couplings are a particular problem, as they tend to occur in measurements on site as a result of a lack of shielding. There are now a number of countermeasures for this, such as narrow band measurements and active gate circuits. Another method is to use the bridge test circuit shown in Fig. 5-33 c.

Partial discharges within encapsulated switchgear installations are frequently located by acoustic partial-discharge measurement in addition to electrical partial-discharge measurement. It reacts to the sound energy that is generated by partial-discharge activity. Sensitive sensors, such as parabolic mirrors and structural sound pickups, detect these sounds in the frequency range between 20 kHz and 100 kHz.

UHF measurement

The PD impulse in SF_6-isolated high-voltage installations has a wide frequency

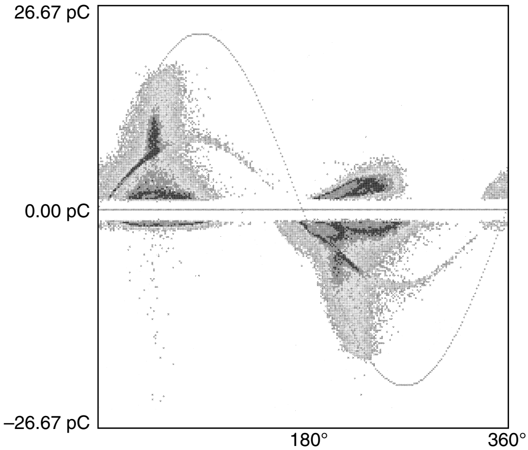


Fig. 5-34

Characteristic partial-discharge image

spectrum up to the GHz range. The electromagnetic waves generated in this process spread inside the encapsulation in the form of travelling waves. They can be detected using capacitive probes integrated into the encapsulation (Fig. 5-35) and used to locate the fault positíon.

However, this requires several probes in one installation, and also the laws of travelling wave propagation, including the effects of joints (such as supports) and branching must be taken into account in the interpretation.

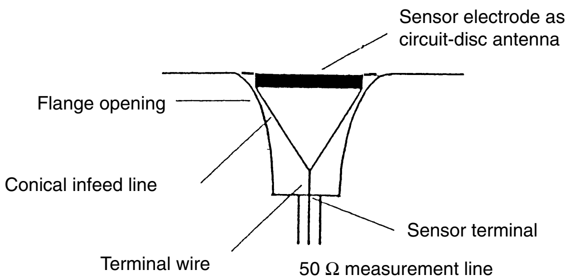


Fig. 5-35

Cone sensor in the flange of a GIS

The characteristic partial-discharge images formed with UHF measurement are similar to those formed by conventional measurement. The measurement sensitivity is not determined with a calibration pulse generator but by applying a voltage to one of the UHF PD probes to determine the transmission function of the installation, including the other PD probes.

One great advantage of the UHF measurement (Ultra High Frequency, 300 MHz to 3 GHz) is the significant decrease of external interference in this frequency range.

UHF measurement by permanently installed probes is particularly suited for monitoring high-voltage installations during operation. Measurements can be made continuously while storing the measured values or at regular intervals (monitoring).

5.7 Effects of climate and corrosion protection

The operational dependability and durability of switchgear installations and their components are strongly influenced by the climatic conditions at their place of installation.

There are two aspects to the demand for precise and binding specifications for these problems:

- The description of the climatic conditions to be expected in service and also during storage, transport and assembly.
- The specification of the test conditions or design requirements that ensure reliable functioning under defined climatic conditions.

5.7.1 Climates

The standard DIN EN 60721-3, “Classes of environmental influence quantities and their limit values”, is a comprehensive catalogue of classes of interconnected environmental factors. Every class is identified with a three-character designation as follows:

1st place: type of product use
(1 = storage, 2 = transport, 3 = indoor application, 4 = outdoor application etc.)

2nd place: type of environmental influence

(K = climatic conditions, B = biological conditions, C = chemically active substances etc.)

3rd place: assessment of the severeness of the environmental influences (higher figures = more difficult conditions)

For example, class 3K5 can be considered for applications of indoor switchgear installations in moderate climate zones. It indicates a total of 16 parameters of different climatic conditions. The most important are summarized in Fig. 5-36 in the form of a climatic diagram.

It must not be assumed that one or even more of the given limit values will occur in service continuously; on the other hand it is also assumed that they will be exceeded for a short period or in rare cases, but with a probability of < 0.01.

The classification of environmental conditions only provides manufacturers and users of electrotechnical products with an orientation and a basis for dialogue. The IEC committees responsible for the product groups are expected to use them as a basis

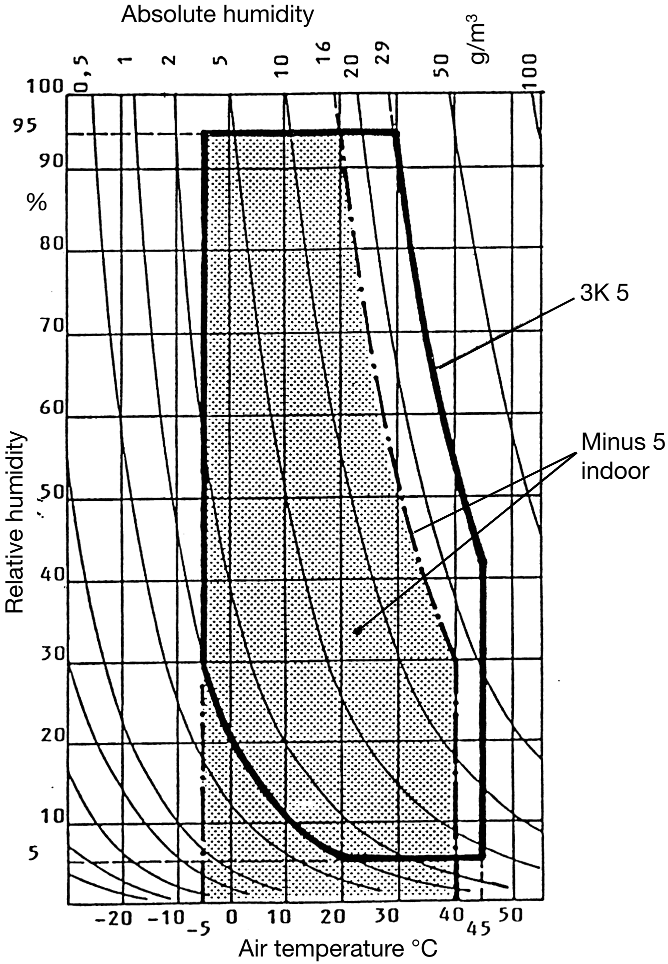


Fig. 5-36

Climatic service conditions for indoor switchgear
Climate diagrams as per DIN EN 60721-3 for class 3K5
and as per DIN EN 60694 for class “Minus 5 indoor”

Table 5-17

Normal and special climatic service conditions for indoor application
N = normal service conditions (with variations N_1, N_2 etc.)
S = special service conditions

Environmental influence	High-voltage switchgear and controlgear DIN EN 60694 (VDE 0670 Part 1000)	Low-voltage switchgear assemblies DIN EN 60439-1 (VDE 0660 Part 500)
Minimum temperature	N_1: – 5°C N_2: – 15°C N_3: – 25°C S: – 50°C/+ 40°C	N: – 5°C
Maximum temperature	N_1: + 40°C N_2: + 35°C (24h average) S: + 50°C/– 5°C	N: + 40°C
Relative humidity	N: 95% (24h average) N: 90% (monthly average) S: 98% (24h average)	N: 50% at 40°C N: 90% at 20°C
Water vapour partial pressure[1]	N: 2.2 kPa (24h average) N: 1.8 kPa (monthly average)	
Condensation	occasional	occasional
Solar radiation	negligible	N: none S: present, caution!
Installation height	N: ≤ 1000 m S: > 1000 m (with dielectric correction)	≤ 2000 m[2]

[1] 2.2 kPa = 22 mbar = 16 g/m3
1.8 kPa = 18 mbar = 12 g/m3
[2] > 1000 m special agreement for electronic equipment

for unified specifications for normal and special service conditions. Tables 5-17 and 5-18 show the corresponding specifications in the product standards DIN EN 60694 (VDE 0670 Part 1000) – High-voltage switchgear and controlgear[3] – and DIN EN 60439-1 (VDE 0660 Part 500) – Low-voltage switchgear assemblies.

These standards also include specifications regarding additional environmental conditions such as contamination, oscillations caused by earthquakes, technically originated external heat, electromagnetic influence etc.

[3] Compare the climatic diagram (Fig. 5-36).

Table 5-18

Normal and special climatic service conditions for outdoor application
N = normal service conditions (with variations N_1, N_2 etc.)
S = special service conditions

Environmental influence	High-voltage switchgear and controlgear DIN EN 60694 (VDE 0670 Part 1000)	Low-voltage switchgear assemblies DIN EN 60439-1 (VDE 0660 Part 500)
Minimum temperature	N_1: –10 °C N_2: –25 °C N_3: –40 °C S: –50 °C/+ 40 °C	N_1: –25 °C N_2: –50 °C
Maximum temperature	N_1: +40 °C N_2: +35 °C (24h average) S: +50 °C/–5 °C	N: +40 °C +35 °C (24h average)
Condensation and Precipitation	are to be considered	100 % rel. humidity at +25 °C
Solar radiation	1000 W/m²	N: — S: If present, caution!
Ice formation	N_1: 1 mm thickness N_2: 10 mm thickness N_3: 20 mm thickness	
Installation height	N: ≤ 1000 m S: > 1000 m (with dielectric correction)	≤ 2000 m[1)]

[1)] above 1000 m special agreement for electronic equipment

Switching devices, including their drives and auxiliary equipment, and switchgear installations must be designed for use in accordance with their ratings and the specified normal service conditions. If there are special service conditions at the installation site, specific agreements are required between manufacturer and user.

5.7.2 Effects of climate and climatic testing

Fig. 5-37 uses examples to indicate the variety of influences possible on switchgear in service resulting from climatic conditions. The development and manufacture of devices and installations that resist these influences require considerable experience. Additional security is provided by conducting appropriate tests based on the relevant product standards. The following are some examples:

– Wet-test procedure of the external insulation of outdoor switchgear as per DIN IEC 60060-1 (VDE 0432 Part 1)
– Limit temperature tests of high voltage circuit-breakers as per DIN VDE 0670-104 (VDE 0670 Part 104)
– Switching of disconnectors and earthing switches under severe icing conditions as per DIN EN 60129 (VDE 0670 Part 2)
– Testing of indoor enclosed switchgear and controlgear (1 kV to 72.5 kV) for use under severe climatic conditions (humidity, pollution) as per IEC Report 60932.

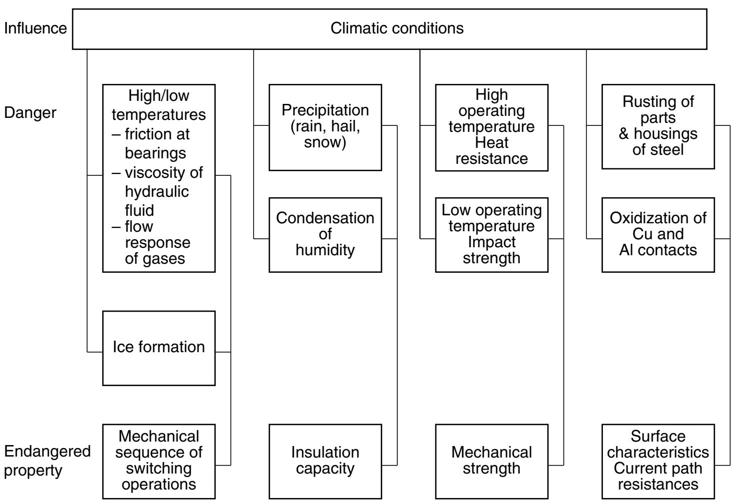


Fig. 5-37

Ways that switchgear and installations are affected by climatic conditions

5.7.3 Reduction of insulation capacity by humidity

The reduction of insulation capacity by humidity is particularly significant on the surface of insulators. With outdoor devices, humidity results primarily from precipitation, such as rain, hail, snow, while in the case of air-insulated indoor switchgear and inside gas-insulated installations (GIS), the problem is condensation from moisture that was previously a component of the ambient gas or the atmosphere.

The moisture content of a gas mixture can be expressed in different ways. From the physicist's point of view, the scale for the fractions of the components of a gas mixture is the partial pressures. The partial pressure of a component is the pressure that is measured at a given temperature if this component is the only constituent of the total volume of the mixture. In the event of unintended admixtures, as observed here, the partial pressure of water vapour varies in the mbar range or when considered as absolute moisture in the range of a few g/m^3. Another possibility of expressing the moisture content quantitatively is to determine the "dew point", i.e. the temperature at which condensation occurs. This information is the most meaningful for the switchgear operator. Fig. 5-38 shows the relations.

The sequence of the reduction of insulation capacity by moisture is the same for all three types of insulator surfaces: Initially only a very slight current flows over the humidity film along the insulator surface because of the very low conductivity of the pure water of the film. Partial discharges along the current path yield decomposition products that continually increase the conductivity until the insulator surface is permanently damaged or a flashover occurs. Any outside contamination that is present already in the beginning significantly accelerates the deterioration process.

Countermeasures for outdoor switchgear are limited to the selection of material (ceramic, glass, cycloaliphatic resins, silicone rubber) and the selection of the creepage distance (cf. DIN EN 60071-2 (VDE 0111 Part 2)). Usage of specific minimum lengths for creepage paths and also material selection are also very important for indoor insulation in atmospheric air. However, condensation can also be prevented if required by the use of air-conditioning or by raising the temperature slightly inside switchbays and cubicles with small anticondensation heaters.

In the case of gas-insulated switchgear (GIS), the problem is different. The moisture content of the insulating gas is not due to climatic conditions but is primarily brought in as the moisture content of solid insulation materials and only gradually transferred to the insulation gas. The installation of drying filter inserts with sufficient moisture-absorbing capacity has been found to be a suitable means of keeping the moisture content of the gas or the dew point low ($\leq -5°C$).

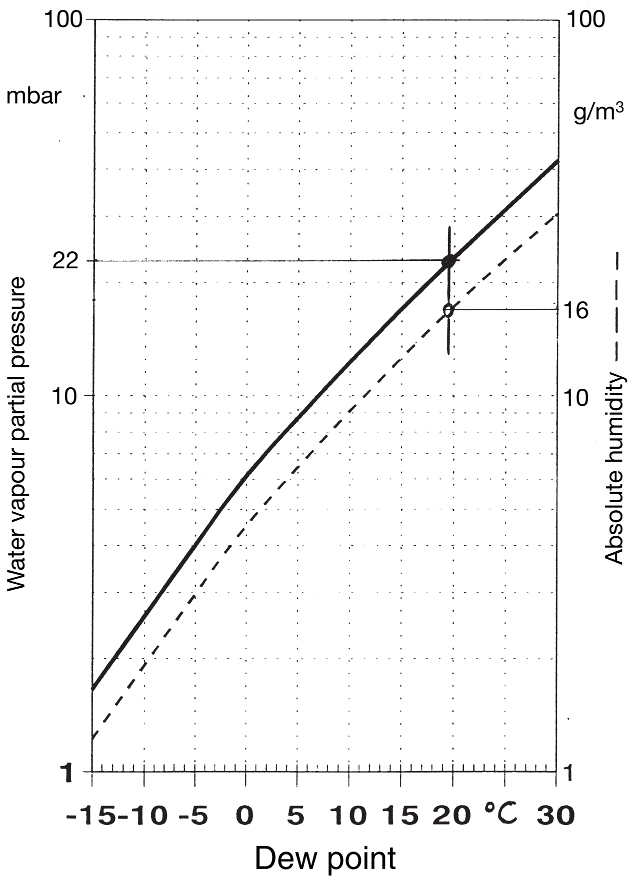


Fig. 5-38

Relation between water-vapour partial pressure,
absolute humidity and dew point
10 mbar = 1 kPa

5.7.4 Corrosion protection

Design regulations for preventing corrosion are not included in national and international standards. They are a part of the manufacturer's experience and can be found in internal documents and also occasionally in the supply regulations of experienced users. The following are examples of proven measures:

– Painting and galvanizing sheet metal and sections of steel, aluminium and stainless steel (Fig. 5-39)
  Note: Top-coat varnishing can be done in one pass with the powder-coating process applied to the appropriate thickness instead of several wet-coating passes.

– Structural components of mechanical drives and similar of steel, which are required to meet close tolerances or antifriction properties, such as shafts, latches and guideways, can be effectively protected from corrosion for use indoors by manganese or zinc phosphor treatment (5-8 μm) concluded by an oil bath.

– Structural components of steel which are not subjected to any specific mechanical demands and standard parts are generally galvanized with zinc (12 μm) and then chromatized (passivization).

– Conductor materials such as copper and aluminium must be silver galvanized (20 μm) in contact areas with spring-loaded contacts. Aluminium requires application of a copper coating (10 μm) before the silver is applied. A silver coating of about 20 μm has the optimum resistance to mechanical friction.
  The appearance of dark patches on silver surfaces is generally no reason for concern, because the oxidation products of silver are conductive and this will not greatly affect the conductivity of the contact. The oxidation products of copper are non-conductive, so oxidation on copper surfaces can easily result in an increase in the temperature of the contact and then result in serious problems.
  Oxidation gradually reduces the thickness of the silver coating. Under normal indoor conditions, climatic influences will not generally result in complete loss of the silver coating. However, this must be taken into consideration in industrial premises with particularly chemically aggressive atmospheres. Under these circumstances it may be necessary to use partially gold-plated contacts, even in the area of power engineering.

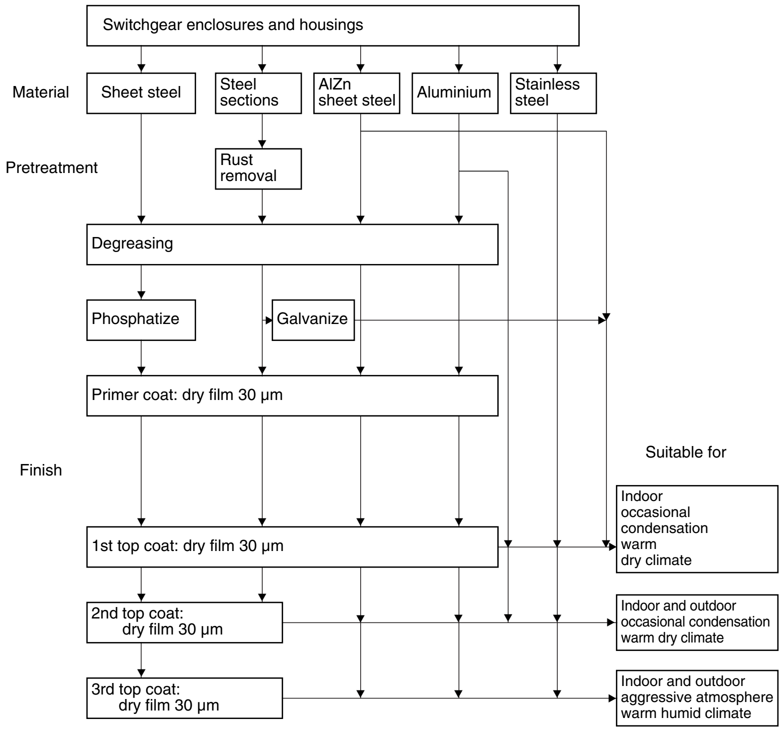


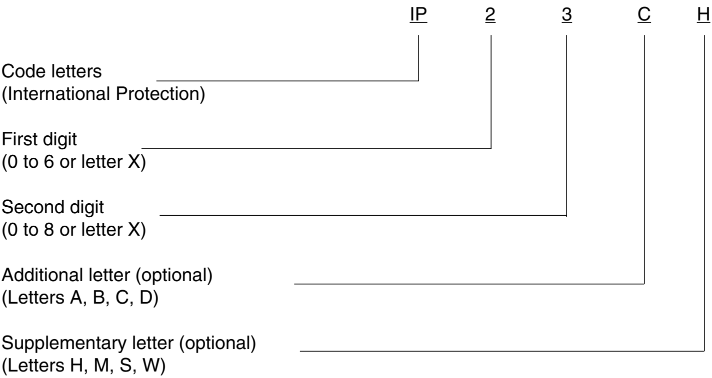
Fig. 5-39

Surface treatment and coating for switchgear installations

5.8 Degrees of protection for electrical equipment of up to 72.5 kV (VDE 0470 Part 1, EN 60529)

The degrees of protection provided by enclosures are identified by a symbol comprising the two letters IP (International Protection), which always remain the same, and two digits indicating the degree of protection. The term ”degree of protection” must be used to indicate the full symbol (code letters, code digits).

Layout of the IP Code



If a code digit is not required, it must be replaced by the letter “X” (“XX”, if both digits are not used).

Table 5-19

IP - degrees of protection

Component	Digits or letters	Significance for protection of the **equipment**	Significance for protection of **persons**
Code letters	IP	–	–-
First digit	0	not protected	
		Protection against ingress of solid bodies	Protection against access to hazardous parts with
	1	≥ 50 mm diameter	back of the hand
	2	≥ 12.5 mm diameter	fingers
	3	≥ 2.5 mm diameter	tools
	4	≥ 1.0 mm diameter	wire ≥ 1.0 mm Ø
	5	dust-protected	wire ≥ 1.0 mm Ø
	6	dustproof	wire ≥ 1.0 mm Ø
Second digit	0	not protected	
		Protection against ingress of water with harmful effects for	
	1	vertical drops	
	2	drops (15 ° angle)	
	3	spray water	
	4	splash water	
	5	jet water	
	6	strong jet water	
	7	temporary immersion	
	8	continuous immersion	
Additional letter (optional)			Protection against access to hazardous parts with
	A		back of hand
	B		finger
	C		tool
	D		wire (1.0 mm Ø, 100 mm long)
Supplementary letter (optional)		Supplementary information especially for	–
	H	High-voltage devices	
	M	Movement during water test	
	S	Stationary during water test	
	W	Weather conditions	

Examples for application of letters in the IP code

The following examples are intended to explain the application and the configuration of letters in the IP code.

IP44 – no letters, no options
IPX5 – first digit omitted
IP2X – second digit omitted
IP20C – use of additional letters
IPXXC – omission of both digits, use of the additional letter
IPX1C – omission of the first digit, use of the additional letter
IP2XD – omission of the second digit, use of the additional letter
IP23C – use of the supplementary letter
IP21CM – use of the additional letter and the supplementary letter
IPX5/ – indication of two different protection classes by one housing against
IPX7 – jet water and against temporary immersion for “versatile” application.