Calculation of the quantity of cooling air:

$$\dot{V}_0 = \frac{Q_L}{c_{pL} \cdot \Delta\vartheta}; \qquad \Delta\vartheta = T_2 - T_1$$

With temperature and height correction[1] the following applies for the incoming air flow:

$$\dot{V}_1 = \dot{V}_0 \cdot \frac{T_1}{T_0} \cdot e^{-\frac{g \cdot H}{R_L \cdot T_0}}$$

4

V_0 = standard air volume flow at sea level, p_0 = 1013 mbar, T_0 = 273 K = 0 °C,
T_1 = cooling air temperature (in K),
T_2 = exhaust air temperature (in K),
g = gravitational acceleration, $g = 9.81 \frac{m}{s^2}$,
H_0 = height above sea level,
R_L = gas constant of the air, $R_L = 0.287 \frac{kJ}{kg \cdot K}$,
c_{pL} = specific heat capacity of the air, $c_{pL} = 1.298 \frac{kJ}{m^3 \cdot K}$,
Q_L = total quantity of heat exhausted by ventilation: $Q_L = P_V + \Sigma Q$,
P_V = device power loss,
ΣQ = heat exchange with the environment.

[1] May be neglected at up to medium installation height and in moderate climates

At high power dissipation and high temperatures, solar radiation and thermal conduction through the walls can be neglected. Then $Q_L = P_V$.

Example:

At given incoming air and exhaust air temperature, the power dissipation P_V should be exhausted by natural ventilation. The volume of air required should be calculated:

T_2 = 40 °C = 313 K, T_1 = 30°C = 303 K, P_V = 30 kW = 30 kJ/s, height above sea level = 500 m

$$\dot{V}_1 = \frac{P_V}{c_{pL}\,(T_2 - T_1)} \cdot \frac{T_1}{T_0} \cdot e^{-\frac{g \cdot H}{R_L \cdot T_0}} = 2{,}4\ \frac{m^3}{s} = 8640\ \frac{m^3}{h}$$

If the warm air is exhausted directly over the heat source, this will increase the effective temperature difference $\Delta\vartheta$ to the difference between the temperature of the outside air and the equipment exhaust air temperature. This will allow the required volume of cooling air to be reduced.

Calculation of the resistances in the air duct and the ventilation cross section:

Based on the example in Fig. 4-28a, the following applies:

for incoming air:	acceleration	1
	screen	0.75
	widening in cross section	0.55
	gradual change of direction	0.6
	R_1 =	2.9
for exhaust air:	acceleration	1
	right-angle bend	1.5
	slats	3
	R_2 =	5.5

If the exhaust air duct is 10 % larger than the incoming air duct, then

$$m = \frac{A_1}{A_2} = \frac{1}{1.1} = 0.91 \text{ and } m^2 = 0.83,$$

then $R = 2.9 + 0.83 \cdot 5.5 = 7.5$.

The ventilation ratios can be calculated with the formula

$$(\Delta\,\vartheta)^3 \cdot H = 13.2\,\frac{P_V^2}{A_1^2}\,(R_1 + m^2 R_2).$$

numerical value equation with $\Delta\,\vartheta$ in K, H in m, P_V in kW and A_1 in m².

Example:

transformer losses $P_V = 10$ kW, $\Delta\,\vartheta = 12$ K, $R = 7.5$ and H = 6 m yield:

$$A_1 \approx 1 \text{ m}^2.$$

Practical experience has shown that the ventilation cross sections can be reduced if the transformer is not continuously operated at full load, the compartment is on the north side or there are other suitable intervals for cooling. A small part of the heat is also dissipated through the walls of the compartment. The accurate calculation can be done as per DIN 4701. For the design of transformer substations and fire-prevention measures, see Section 4.7.5 to 4.7.6.

Fans for switchgear and transformer rooms

Ventilation fans, in addition to their capacity, must compensate for the pressure losses in the air path and provide blow-out or dynamic pressure for the cooling air flow. This static and dynamic pressure can be applied with $\Delta p \approx 0.2 \ldots 0.4$ mbar.

Then the propulsion power of the fan is:

$$P_L = \frac{\dot{V} \cdot \Delta p}{\eta}, \qquad \eta = \text{efficiency}$$

Example:

For the cooling air requirement of the transformer in the example above, where
$P_v = 30$ kW, with $\dot{V} = 2.4$ m³/s, $\eta = 0.2$, $\Delta p = 0.35$ mbar = 35 Ws/m³
the fan capacity is calculated as:

$$P_L = \frac{2.4 \cdot 0.35}{0.2} = 0.42 \text{ kW}.$$

Resistances in the ventilation ducts and supplementary system components, such as dust filters, must be considered separately in consultation with the supplier.

For sufficient air circulation, a minimum clearance between the equipment and the wall is required, depending on the heat output. For auxiliary transformers, this is about 0.4 m, for power transformers about 1 m.

4.4.3 Forced ventilation and air-conditioning of switchgear installations

Overview and selection

When planning switchgear installations, thermal loads resulting from heat dissipation from the installation and environmental conditions (local climate) must be taken into account. This is generally done by:

- designing the switchgear installation for increased temperature,
- reducing the thermal load by ventilating, cooling or air-conditioning installations (HVAC).

In compliance with relevant DIN and VDI requirements, the following simplified installation configuration can be used:

- *ventilation devices and installations* for ventilation and exhaust, e.g. when the permissible ambient temperature is higher than the (max.) outside temperature, see Fig. 4-29
- *refrigeration units and installations* for heat exhaust only, e.g. when the permissible ambient temperature is equal to or less than the (max.) outside temperature, see Fig. 4-30
- *air-condtioning units and installations* for air-conditioning, when in addition to heat removal specific ambient climate conditions are required (temperature, humidity, air quality, etc.), see Fig. 4-31.

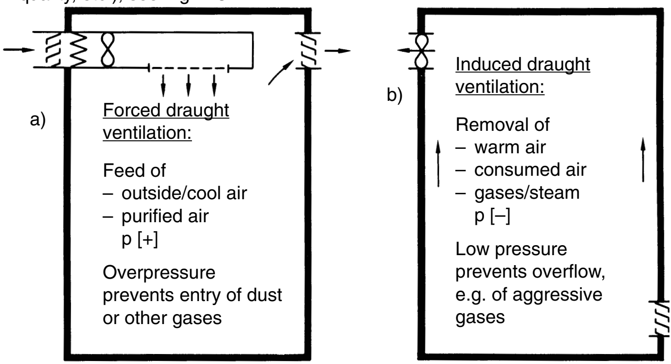
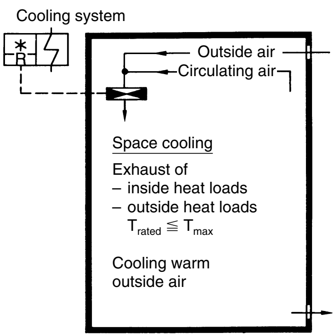


Fig. 4-29

Schematic view of a ventilation system: a) forced draught ventilation, b) Induced draught ventilation



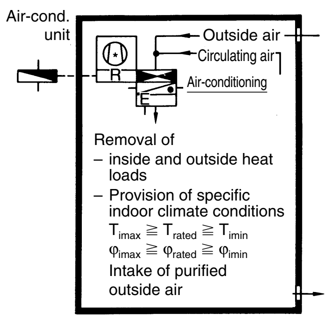


Fig. 4-30

Schematic view of a cooling system

Fig. 4-31

Schematic view of an air-conditioning system

- *Permissible ambient temperatures* are the max. permissible compartment temperatures as specified in DIN VDE or other standards.
- Telecommunications and electronics modules require special *environmental conditions* and are specified in DIN 40040.
- In addition to the technical requirements, human (physiological) requirements may determine the *compartment climate*, e.g. the workplace regulations in Germany.
- The (max.) *outside temperature* is defined as the maximum outside temperatures occurring at the set-up area. It is selected from relevant climate tables, such as given in an encyclopedia or using information from meteorological organizations.
- *Space heating systems* in substation design is only relevant for occupied compartments. It is used almost exclusively in connection with ventilation or air-conditioning systems.
- Some of the most important and internationally accepted *regulations (standards) are listed below:*
  - *DIN 4701 – Calculating heat requirements –*
  - *DIN 1946 – Ventilation engineering –*
  - *VDI 2078 – Calculating cooling loads –*
  - *Ashrae Handbook (NEW YORK)*
  - *Carrier Handbook of air-conditioning system design (NEW YORK)*.

Basis for HVAC design is calculation of the thermal loads (Q_{th}) (heat balance).

$Q_{th} = Q_{tr} + Q_{str} + Q_i + Q_a$

Q_{tr} = heat transmission by the areas around the room (outside heat loads)

= $A\ (m^2) \cdot k\ (W/m^2 \cdot K) \cdot \Delta\ T\ (K)$

Q_{str} = radiation heat from exterior areas exposed to the sun

Q_i = installation and personnel heat (inside heat loads)

Q_a = heat from outside air, humidifiers and dehumidifiers (outside heat loads)

= $\dot{m}\ (kg/h) \cdot c\ (W\ h\ /\ kg \cdot K) \cdot \Delta T\ (K)$ (without dehumidifiers)

= $\dot{m}\ (kg/s) \cdot \Delta h\ (kJ/kg)$ (with dehumidifiers)

A = *areas around the compartment* (m^2)
k = heat transmission coefficient (W/m^2)
ΔT = temperature difference
$\dot{m}$ = quantity of air flow/outside air flow (kg/h])
c = specific heat capacity of air (Wh/kg.K)
Δh = difference of the specific outside air enthalpy (Wh/kg)

This is calculated in compliance with various DIN, VDI or relevant international rules.

4.4.4 Temperature rise in enclosed busbars

Busbars in medium and low-voltage substation design are often installed in small compartments or in conduits. For this reason they are subject to different thermal conditions to busbar configurations installed in the open general compartment.

It is not possible to select the busbar cross sections directly from the load tables in Section 13.1.2. Because of the number of parameters influencing the temperature of enclosed busbars (such as position of the busbars in the conduit, conduit dimensions, ventilation conditions), the permissible current load must be calculated for the specific configuration.

The heat network method has proven useful for this calculation; Fig. 4-32 b.

Heat flows are generated by power dissipation.

Symbols used:

- α Heat transfer coefficient
- A Effective area
- P Heat output
- R Equivalent thermal resistance
- $\Delta\vartheta$ Temperature difference
- D Throughput of circulating cooling medium (D = V/t)
- C *Radiant exchange number*
- T *Absolute temperature*
- c_p Specific heat
- ρ Density

Indices used:

- D Forced cooling
- K Convector
- S Radiation
- O Environment
- 1 Busbar
- 2 Inside air
- 3 Enclosure

Thermal transfer and thermal resistances for radiation:

$$P_S = \alpha_S \cdot A_S \cdot \Delta\vartheta \text{ or } R_S = \frac{1}{\alpha_S \cdot A_S}$$

$$= C_{13} \cdot A_s \cdot (T_1^4 - T_3^4) \quad \text{where } \alpha_s = \frac{C_{13}\,(T_1^4 - T_3^4)}{\Delta\vartheta}$$

for the convection:

$$P_K = \alpha_K \cdot A_K \cdot \Delta\vartheta \text{ or } R_K = \frac{1}{\alpha_K \cdot A_K}$$

for the circulating cooling medium:

$$P_D = c_p \cdot \rho \cdot D \cdot \Delta\vartheta \text{ or } R_D = \frac{1}{c_p \cdot \rho \cdot D}$$

For additional information, see Section 1.2.5.

For information on temperature rise of high-current busbars, see Section 9.2.

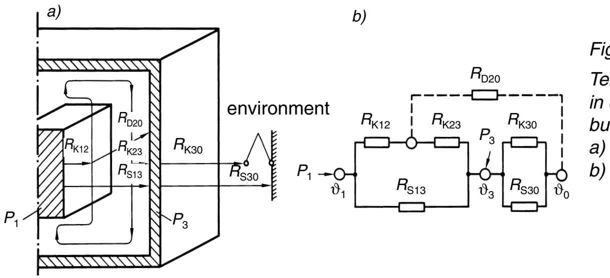


Fig. 4-32

Temperature rise in enclosed busbars
a) thermal flow,
b) heat network

4.4.5 Temperature rise in insulated conductors

Conductors have a real resistance. This causes current thermal losses by current flow. The conductors and the insulation around them become warmer.

One part of the heat quantity developed in the line (power dissipation):

$P_c = c \cdot \gamma \cdot A \frac{d}{dt} \Delta \vartheta$ is stored and the other part is

$P_A = \alpha \cdot U \cdot \Delta \vartheta$ dissipated to the environment.

The heat process can be described as follows:

$$\frac{c \cdot \gamma \cdot A}{\alpha \cdot U} \cdot \frac{d}{dt} \Delta \vartheta + \Delta \vartheta = \frac{A \cdot \rho}{\alpha \cdot U} \left(\frac{I}{A}\right)^2$$

Here:

$\Delta \vartheta$ = conductor overtemperature (K)
$\Delta \vartheta_e$ = end value of the conductor overtemperature (K)
α = heat transfer coefficient (9…40 W/(m^2 K)
c = specific heat (384.38 Ws/K · kg for copper)
γ = density ($8.92 \cdot 10^{-3}$ kg/cm^3 for copper)
ρ = specific resistance (0.0178 Ωmm^2/m at 20 °C for copper)
A = conductor cross section
U = conductor circumference
I = current in conductor (A)

The stationary state in the temperature rise occurs when all the power dissipation generated can be dissipated to the environment. This is the case when the temperature change is zero:

$$\Delta \vartheta_e = \frac{\rho \cdot A}{\alpha \cdot U} \left(\frac{I}{A}\right)^2.$$

The solution of the differential equation yields the overtemperature in relation to time:

$$\Delta \vartheta = \Delta \vartheta_e \cdot (1 - e^{-\frac{1}{T}}).$$

T is referred to as the time constant. It is the scale for the time in which the end temperature $\Delta \vartheta_e$ would be reached if the temperature rise were constant, therefore if the generated heat is completely stored in the conductor and the thermal dissipation is equal to zero. It is:

$$T = \frac{c \cdot \gamma \cdot A}{\alpha \cdot U} = \frac{\text{thermal storage capacity}}{\text{thermal dissipation capacity}}$$

The result of this is that T increases with the cross section of the conductor and by α also depends on the way it is laid and the accumulation of conductors. For example, multicore PVC copper conductors or cables laid well apart on the wall have the following heating time constants:

A	= 1.5	2.5	4	10	25	95	150	240	mm^2
T	= 0.7	1.0	1.5	3	6	16	23	32	min

Continuous operation occurs when the equilibrium temperature is reached. In practice, this is the case with 4 to 5 times the value of the time constants. A higher load may be approved for intermittent operation, so long as $t < 4 \cdot T$.

Excessively high conductor temperatures endanger the conductors and the environment. Care must be taken to ensure that non-permissible temperatures cannot occur. The limit temperature of the conductors for continuous load is:

- with rubber insulation 60 °C and
- with plastic insulation 70 °C
- with plastic insulation with increased heat resistance 100 °C.

In the event of a short circuit, the DIN VDE regulations allow a higher limit temperature for a brief period, see also Section 4.2.5.

4

The maximum load duration t_{Bmax} in which a conductor with the current carrying capacity I_z at higher load $I_a = a \cdot I_z$ has been heated to the still permissible limit temperature is:

$$t_{Bmax} = T \cdot \ln\left(\frac{a^2}{a^2 - 1}\right)$$

Example:

Is a conductor of 1.5 mm² Cu for a three-phase a.c. motor ($I_{start} = 6 \cdot I_{n\,Mot}$) sufficiently protected against overload with the motor protection switch when the rotor is blocked?

The current-carrying capacity of the conductor is $I_{n\,Mot} \cdot 0.8$.

$$a = 0.8 \cdot 6 = 4{,}8$$
$$T = 0.7\ \text{min} = 42\ \text{s}$$
$$t_{Bmax} = 42\ \text{s} \cdot \ln\left(\frac{4.8^2}{4.8^2 - 1}\right) = 1.86\ \text{s}$$

Because the overload protection device only responds after about 6 s at 6 times current value, a 1.5 mm² Cu is not sufficiently protected. After 6 s this wire already reaches 152 °C. A larger conductor cross section must be selected.

A 2.5 mm² Cu wire (utilization 0.53) only reaches the limit temperature after 6.2 s.

4.4.6 Longitudinal expansion of busbars

Operational temperature variations result in longitudinal expansion or contraction of the busbars. This is calculated from

$$\Delta l = l_o\, \alpha\, \Delta \vartheta.$$

For a busbar of 10 m in length at 50 K temperature difference, the following typical values are obtained:

with Cu: $\Delta l = 10 \cdot 0.000017 \cdot 50 = 0.0085\ \text{m} = 8.5\ \text{mm}$,
with Al: $\Delta l = 10 \cdot 0.000023 \cdot 50 = 0.0115\ \text{m} = 11.5\ \text{mm}$.

These temperature-caused longitudinal changes may cause significant mechanical stresses on the conductors, on their supports and on connections to apparatus if there are no e x p a n s i o n s e c t i o n s installed in long line segments.

The forces generated are very easy to calculate if the longitudinal change caused by the difference in temperature $(\vartheta - \vartheta_0) = \Delta\vartheta$ is assumed to be equal to the longitudinal change that would be caused by a mechanical force F, which means:

$$\Delta l = l_o\, \alpha\, \Delta \vartheta = \frac{F\, l_o}{E\, A}$$

Where:

l_0 length of the conductor at temperature at which it was laid ϑ_o
$\Delta\vartheta$ temperature difference
F mechanical stress
A conductor cross section
α linear coefficient of thermal expansion, for Cu = $0.000017 \cdot K^{-1}$,
for Al = $0.000023 \cdot K^{-1}$
E module of elasticity, for Cu = 110 000 N/mm², for Al = 65 000 N/mm².

The above equation gives the mechanical stress as:

$$F = \alpha \cdot E \cdot A \cdot \Delta\vartheta$$

and for $\Delta\vartheta$ = 1 K and A = 1 mm² the specific stress:

$$F' = \alpha \cdot E.$$

Therefore, for copper conductors:

$$F'_{Cu} = 0.000017 \cdot 110\,000 = \approx 1.87 \text{ N/(K} \cdot \text{mm}^2)$$

and for aluminium conductors:

$$F'_{Al} = 0.000023 \cdot 65\,000 = \approx 1.5 \text{ N/(K} \cdot \text{mm}^2).$$

4.5 Rating power systems for earthquake safety

4.5.1 General principles

Earthquakes in 95 of 100 cases originate from faults at the edges of the tectonic plates. The remainder are caused by volcanic action and landslides. The tectonic plates float on the surface of the viscous mantle of the earth and are subject to strong convection currents. The relative motion of the rigid plates in relation to one another generates local mechanical tension peaks at their edges, which from time to time are released by sudden deformations. These vibrations are spread by seismic waves, which propagate in accordance with the laws of wave propagation by reflection and refraction in complex waveforms and occur primarily as energetic surface waves in the frequency range of 0.1 Hz to 30 Hz with strong horizontal acceleration at the surface of the earth. The most energetic waves are therefore in the range of the natural frequencies of devices and components in high-voltage substations, but they must not adversely affect their functioning in the preset limits. The ground acceleration amplitudes are mostly in the range of 0.3 to 0.7 g. The strong earthquake phase only lasts a few seconds. In total, an earthquake rarely lasts more than 1 to 2 minutes.
The edges of the plates subject to earthquakes are primarily found in line reaching from south-eastern Europe through central Asia to Indonesia and around the Pacific Ocean. Even in central Europe earthquakes of moderate power occur occasionally. For this reason, even here nuclear installations also require verification of earthquake safety for all important components. This is also required for high-voltage power systems.

The most important parameters of an earthquake with respect to the mechanical stress on equipment and installations is the limit value of the acceleration of the ground at the installation site.

Characteristic values are:

– 5 m/s² (≈ 0.5 g, qualification class AF5),
– 3 m/s² (≈ 0.3 g, qualification class AF3) and
– 2 m/s² (≈ 0.2 g, qualification class AF2)

For the oscillation in the horizontal direction (x and y component). The vertical stress is calculated with half that value for every case. Of primary importance for the mechanical stress of equipment and device combinations is their mechanical natural frequencies, which are generally in the frequency spectrum of the seismic excitation. When verifying earthquake safety, the excitation with the natural frequency values of the equipment must be regarded as the "worst case".

The temporal process of the seismic excitation, i.e. the process of the oscillation of the ground at the installation site, can be selected differently for the verification. The following options are available:

- Continuous sine wave with natural frequencies
- Several (5) groups of 5 sinusoidal increasing and decreasing load cycle oscillations with natural frequency (5-sine beat, Fig. 4-33) separated by pauses
- Exponentially damped decaying load cycle oscillations with natural frequency (e-beat, Fig. 4-34)
- Simulation of an earthquake sequence typical for the installation site (Fig. 4-35)

The earthquake safety of equipment and installations (DIN EN 61166 (VDE 0670 Part 111), IEC 60068-3-3) can be verified in different ways, i.e.

- by testing,
- by a combination of testing and calculation or
- by calculation alone.

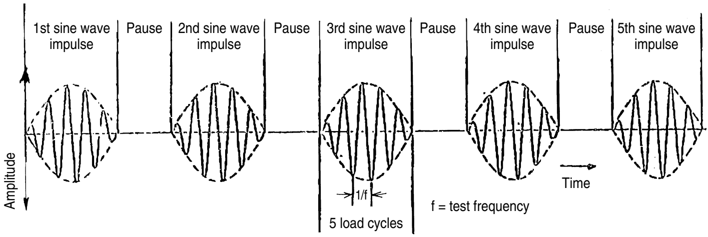


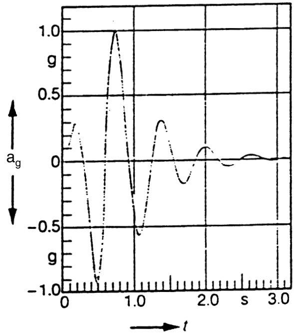
Fig. 4-33

Result of 5 sine wave impulses with 5 load cycles each

Fig. 4-34

a_g ground acceleration

Exponential beat,
"e-beat" for short,
as excitation function for simulation
of an earthquake shock



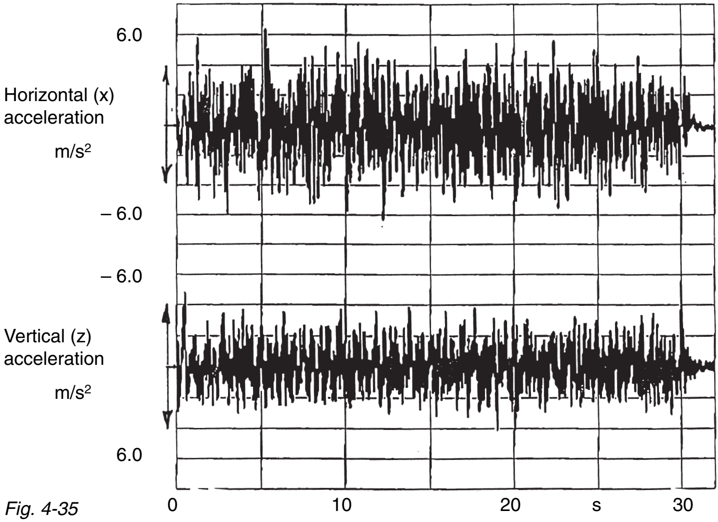


Fig. 4-35

Process of acceleration of the test table during a simulated earthquake
1 $m/s^2 \approx 0.1$ g

Medium-voltage switchgear installations and equipment, are difficult to handle by calculation because of their complex design, but their compact dimensions make it quite easy to test them fully in existing test installations. High-voltage equipment can also be tested, but particularly in the development phase and with spatially extended installations a calculated verification of earthquake safety is preferred, particularly when dealing with rotation-symmetrical configurations.

4.5.2 Experimental verification

Very complex test installations are required for these tests, such as a vibration table with an area of 5 x 5 m and a mass of up to 25 t, which can vibrate with the above parameters.

Before the actual qualification test, the natural mechanical frequencies of the test object are determined in a resonance search run. A continuous sine wave with which the relevant frequency range of 0.5 – 35 Hz with a speed increase of 1 octave/min in all 3 axes running through in succession is selected as the test excitation. The acceleration here is only about 0.1 g.

During the qualification test, one of three different processes of the excitation of oscillations can be selected:

– Continuous sine wave method

  The relevant frequency range is run corresponding to the resonance search run procedure, with the difference that the amplitude is increased to the required value.

This test procedure only reproduces the stresses poorly in practice and represents an unrealistically sharp stress for the test object.

- Sine beat method (5-sine beat)

  The vibration table is excited with several sine impulses separated by pauses in this test procedure, as shown in Fig. 4-33. The frequency of the load cycle oscillation corresponds to the natural frequencies, i.e. the test is run in all natural frequencies of the installation in 2 axes, with generally one horizontal axis being combined with one vertical axis.

  A test with sine impulses yields quite useful conclusions respecting the response of the installation to an earthquake and is particularly useful if there is no accurate seismic information available for the installation site. However, the test takes time if the installation has many natural frequencies.

- Time history method

  This process simulates an actual earthquake. It lasts for about 30 s and the excitation is on 2 or 3 axes. An example of a synthetic earthquake time characteristic is shown in Fig. 4-35.

  This procedure simulates an earthquake very well if accurate information on ground acceleration is available. It also enables safety-relevant functions such as secure contact of conducting paths or tripping and reclosing the switchgear to be checked during the test. For this reason this test is often required for nuclear installations.

After the qualification test, the resonance search run is generally repeated to check whether the test object has deteriorated because of the test. If the natural frequencies have changed significantly, this indicates damage.

The greater part of the current medium-voltage switchgear range from ABB Calor Emag has been verified for earthquake safety by testing, in some cases with the 5-sine-beat method, in part while using the time history method with excitation accelerations to 0.7 g.

4.5.3 Verification by calculation

In the past, the dynamic load resulting from earthquakes was generally only roughly estimated with static loads. The dynamics of the process were simulated with correction and damping factors. The development of powerful computers now makes it possible to use mathematical simulation with the finite-element method (FEM), which has been in use around the world for some years as a tool for investigating complex processes of any type. Its application to the stress on switchgear, modules and complete switchbays caused by earthquakes is possible in principle, but the expense of modelling still limits the testing to individual components and device combinations. However, it is easier to analyse variations than use the vibration test. Natural frequencies, stiffness and the maximum permissible mechanical basic data are input into the computer as starting parameters. The excitation of oscillations by the earthquake is best simulated here by the exponentially decaying load cycle surge, the e-beat (Fig. 4-34).

The FEM was initially successfully used by ABB to determine the stress caused by earthquakes in the finely structured model for some ABB switchgear, such as the 550-kV circuit-breakers of the ELF SP 7-2 type including device table, the 245-kV pantograph disconnector of the TFB 245 type, the 123 kV rotary disconnector of the SGF 123 type and a 245-kV switchbay with pantograph disconnector, current transformer, circuit-breaker and rotary disconnector. Simpler approximate solutions are currently being developed in two directions, in one case an FEM with a roughly structured model and in the other case an alternative calculation procedure with statically equivalent loads derived from the dynamic process with earthquakes.

4.6 Minimum clearances, protective barrier clearances and widths of gangways

Key to symbols used

U_m	(kV)	maximum voltage for apparatus
U_n	(kV)	nominal voltage
U_{rB}	(kV)	rated lightning impulse withstand voltage
U_{rS}	(kV)	rated switching impulse withstand voltage
N	(mm)	minimum clearance (Table 4-10)
B_1	(mm)	protective barrier clearances for solid-panel walls (≥ 1800 mm high) with no openings. The dimension applies from the interior of the solid wall. $B_1 = N$
B_2	(mm)	protective barrier clearances with wire mesh, screens or solid walls (≥ 1800 mm high) ≤ 52 kv: $B_2 = N$ + 80 mm and protection class IP2X, > 52 kV: $B_2 = N$ + 100 mm and protection class IP1XB.
O_1, O_2	(mm)	protective barrier clearances for obstacles, such as rails, chains, wires, screens, walls (< 1800 mm high) for indoor installations: $O_1 = N$ + 200 mm (minimum 500 mm), for outdoor installations: $O_2 = N$ + 300 mm (minimum 600 mm). rails, chains and wires must be placed at a height of 1200 mm to 1400 mm. With chains or wires, the protective barrier clearance must be increased by the sag.
C, E	(mm)	protective barrier clearances at the outer fence (≥ 1800 mm high) with solid walls C = N + 1000 mm, with wire mesh, screens (mesh size ≤ 50 mm) E = N + 1500 mm
H	(mm)	minimum height of live parts (without protective barrier) above accessible areas H = N + 2250 mm (minimum 2500 mm)
H'	(mm)	minimum height of overhead lines at the outer fencing. ≤ 52 kv: H' = 4300 mm > 52 kV: H' = N + 4500 mm (minimum 6000 mm)
T	(mm)	minimum transport clearance for vehicles T = N + 100 mm (minimum 500 mm)

4.6.1 Minimum clearances and protective barrier clearances in power systems with rated voltages over 1 kV (DIN VDE 0101)

Minimum clearances

The clearances of live parts of a system from one another and from earthed parts must at least comply with Table 4-10. This table lists the minimum clearances for the maximum apparatus voltages assigned to the associated insulation levels as per DIN EN 60071-1 (VDE 0111 Part 1). The various insulation levels available should be selected in accordance with the insulation coordination as per this standard.

Table 4-10

Minimum clearances of live parts of a system from one another and from earth as per DIN VDE 0101 (HD 637 S1).

In the areas of 1 kV < U_m < 300 kV, the rated lightning impulse withstand voltage is the basis for the rating.

In the area of 1 kV < U_m < 52 kV

<table>
<tr><th>Nominal voltage
U_n
kV</th><th>Maximum voltage for apparatus
U_m
kV</th><th>Short-duration power frequency withstand voltage
kV</th><th>Rated lightning impulse withstand voltage 1.2/50 µs
U_{rB}
kV</th><th>Minimum clearance (N) phase-to-earth and phase-to-phase
Indoor installation
mm</th><th>Minimum clearance (N) phase-to-earth and phase-to-phase
Outdoor installation
mm</th></tr>
<tr><td rowspan="2">3</td><td rowspan="2">3.6</td><td rowspan="2">10</td><td>20</td><td>60</td><td>120</td></tr>
<tr><td>40</td><td>60</td><td>120</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2">7.2</td><td rowspan="2">20</td><td>40</td><td>60</td><td>120</td></tr>
<tr><td>60</td><td>90</td><td>120</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">12</td><td rowspan="2">28</td><td>60</td><td>90</td><td>150</td></tr>
<tr><td>75</td><td>120</td><td>150</td></tr>
<tr><td rowspan="2">15 [1)]</td><td rowspan="2">17.5</td><td rowspan="2">38</td><td>75</td><td>120</td><td>160</td></tr>
<tr><td>95</td><td>160</td><td>160</td></tr>
<tr><td rowspan="2">20</td><td rowspan="2">24</td><td rowspan="2">50</td><td>95</td><td colspan="2">160</td></tr>
<tr><td>125</td><td colspan="2">220</td></tr>
<tr><td rowspan="2">30</td><td rowspan="2">36</td><td rowspan="2">70</td><td>145</td><td colspan="2">270</td></tr>
<tr><td>170</td><td colspan="2">320</td></tr>
<tr><td rowspan="2">36 [2)]</td><td rowspan="2">41.5</td><td rowspan="2">80</td><td>170</td><td colspan="2">320</td></tr>
<tr><td>200</td><td colspan="2">360</td></tr>
</table>

1) These nominal voltages are not recommended for planning of new networks.
2) This voltage value is not included in DIN EN 60071-1.

In the area of 52 kV < U_m < 300 kV

Nominal voltage U_n kV	Maximum voltage for apparatus U_m kV	Short-duration power frequency withstand voltage kV	Rated lightning impulse withstand voltage 1.2/50 µs U_{rB} kV	Minimum clearance (*N*) phase-to-earth and phase-to-phase mm
45 [1)]	52	95	250	480
66 [2)]	72.5	140	325	630
70 [6)]	82.5	150	380	750
110 [3)]	123	185 [4)]	450	900
		230	550	1100
132	145	185 [4)]	450	900
		230	550	1100
		275	650	1300
150 [1)]	170	230 [4)]	550	1100
		275	650	1300
		325	750	1500
220	245 [5)]	325 [4)]	750	1500
		360	850	1700
		395	950	1900
		460	1050	2100

1) These nominal voltages are not recommended for planning of new networks.
2) For U_n = 60 KV the values for U_n = 66 kV are recommended.
3) For U_n = 90 KV / U_n = 100 kV the lower values are recommended.
4) The values in this line should only be considered for application in special cases.
5) A fifth (even lower) level for 245 kV is given in EN 60071-1.
6) This voltage value is not included in DIN EN 60071-1.

In the area of U_m > 300 kV, the rated switching impulse withstand voltage is the basis for the rating

Nominal voltage U_n kV	Maximum voltage for apparatus U_m kV	Rated switching impulse withstand voltage phase-to-earth 250/2500 µs U_{rS} kV	Minimum clearance (*N*) phase-to-earth Conductor/ design mm	Minimum clearance (*N*) phase-to-earth Bar/ design mm	Rated switching impulse withstand voltage phase-to-phase 250/2500 µs kV	Minimum clearance phase-to-phase Conductor mm	Minimum clearance phase-to-phase Bar/ conductor mm
275	300	750	1600	1900	1125	2300	2600
		850	1800	2400	1275	2600	3100
380	420	950	2200	2900	1425	3100	3600
		1050	2600	3400	1575	3600	4200
480	525	1050	2600	3400	1680	3900	4600
		1175	3100	4100	1763	4200	5000
700	765	1425	4200	5600	2423	7200	9000
		1550	4900	6400	2480	7600	9400

Protective barrier clearances

As per DIN VDE 0105-100 (VDE 0105 Part 100), bare live parts are surrounded by a danger zone whose dimensions comply with the maximum values of the minimum clearances *N* given in Table 4-10. (Exception: U_m = 380 kV, both values are applicable there). Being in the vicinity of the outer limit of the danger zone and its penetration by body parts or objects are treated as work on electrically energized systems.

Protection against direct contact in installations as per DIN VDE 0101 (HD 637 S1) must therefore prevent such a hazardous proximity to live parts. In closed electrical premises, protection against accidental contact is sufficient. This can be done by installing protective barriers, e.g. solid walls, doors, screens, arc screens, rails, chains or ropes. An additional safety clearance is required corresponding to the possibilities of reaching through between the danger zone (minimum clearance *N*) and the protective barrier (Fig. 4-36).

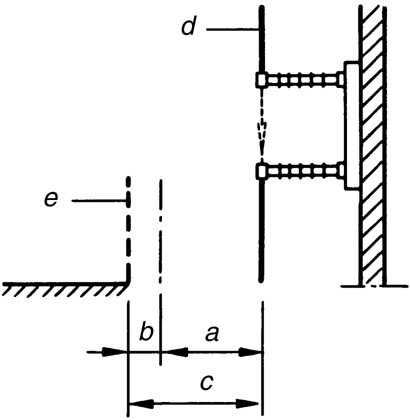


Fig. 4-36

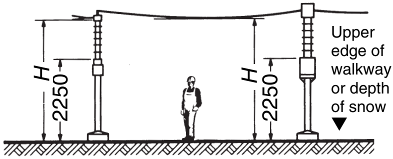
Minimum clearance + safety clearance = protective barrier clearance:
a = minimum clearance,
b = safety clearance,
c = protective barrier clearance,
d = live part,
e = protective barrier

The position of abbreviations and explanations at the beginning of this section meets the requirements of DIN VDE 0101 (HD 637 S1) with reference to the minimum clearances from the various types of obstacles. Tables 4-11 and 4-12 list the maximum values of the assigned minimum clearances *N* listed in Table 4-10 and the associated protective barrier minimum clearances for all standard-nominal system voltages as guidance values.

Protection against accidental contact is then assured when live parts above walkways, where they are not behind barriers, are installed at the minimum heights *H* or *H'* given in Tables 4-11 and 4-12 (Fig. 4-37), where the greatest conductor sag must be considered. With transport paths, the height of the transport units may make it necessary to increase the height requirements.

Fig. 4-37

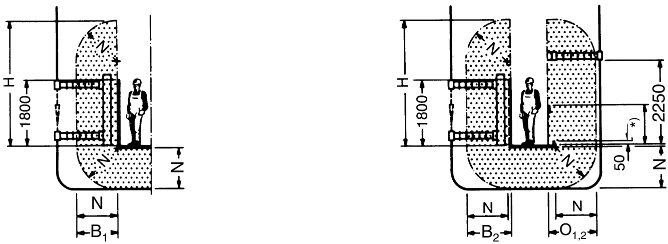
Minimum heights of live parts over walkways



The upper edge of an insulator base must be at least 2250 mm over walkways if there is no protective barrier installed.

If the protective barrier clearance is partly or completely bridged by insulators, protection against direct contact must be assured by panel walls, panel doors, screens or screen doors with a minimum height of 1800 mm (Fig. 4-38). Where the insulators are installed above 2250 mm, rails, chains or wires are sufficient (Fig. 4-38 b).

a) b)



Panel wall or panel door

Screen or screen door

Rail, chain or wire

Fig. 4-38

Minimum clearance bridged by insulators and design of walkways over live parts (dimensions in mm):

a) panel wall or panel door, b) screen or screen door, rail, chain or wire
**) min. 1200 mm, max. 1400 mm*

Walkways over live parts accessible during operation must be of solid plate. If rails, chains or wires are installed as protective barriers, they must be widened by the safety clearance and a minimum 50 mm high edge must be installed as a limit (see Fig. 4-38b). This is intended to prevent objects from falling on live parts.

4.6.2 Walkways and gangways in power installations with rated voltages over 1 kV (DIN VDE 0101)

The minimum width of walkways within outdoor installations should be a minimum of 1000 mm, the minimum width of gangways in indoor installations should be 800 mm. For safety reasons these dimensions must not be reduced. Service aisles behind metall-enclosed installations may be an exception; a minimum gangway width of 500 mm is permissible here.

The minimum width of walkways and gangways must not be reduced, not even by projecting parts such as fixed drives, control cabinets, switchgear truck in isolated position. When measuring the gangway width of indoor switchgear installations, the open position of the cubicle door must be taken into account. Cubicle doors must slam shut in the escape direction. When the door is open, the gangway width must still be 500 mm.

In the case of transport paths inside enclosed electrical premises, the dimensions for the transport unit must be agreed between the installer and the operator. The following regulations are applicable (Fig. 4-39):

Vehicles and similar may pass below live parts (without protection devices) or in their vicinity when

- the vehicle, even with its doors open, and its load do not come into the danger zone (minimum transport clearance $T = N + 100$ mm; minimum 500 mm) and
- the minimum height H of live parts over walkways is maintained.

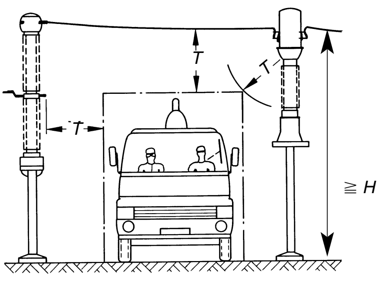
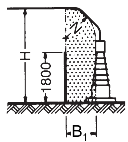


Fig. 4-39

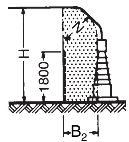
Limit of the transport path in outdoor switchgear installations

Table 4-11

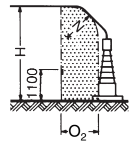
Minimum height and protective barrier clearances in outdoor installations as per DIN VDE 0101



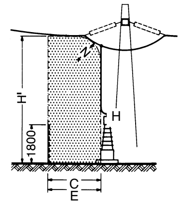
Solid-panel wall



Wire mesh, screen



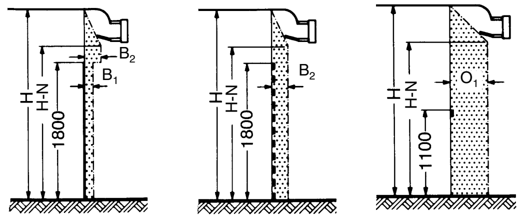
Rail, chain, rope



Nominal voltage	Maximum voltage for equipment	Minimum clearances *N* as per Table 4-10	Minimum height	Protective barrier clearances of live parts inside the installation			at the outer fence			Transport clearances as per Fig. 4-39
				Solid-panel wall	Wire mesh, screen	Rail, chain, rope		Solid wall	Screen	
U_n kV	U_m kV	N mm	H mm	B_1 mm	B_2 mm	O_2 mm	H' mm	C mm	E mm	T mm
3	3.6	120	2 500	120	200	600	4 300	1 120	1 620	500
6	7.2	120	2 500	120	200	600	4 300	1 120	1 620	500
10	12	150	2 500	150	230	600	4 300	1 150	1 650	500
20	24	220	2 500	220	300	600	4 300	1 220	1 720	500
30	36	320	2 570	320	400	620	4 300	1 320	1 820	500
45	52	480	2 730	480	560	780	4 300	1 480	1 980	580
60	72.5	630	2 880	630	730	930	6 000	1 630	2 130	730
110	123	1 100	3 350	1 100	1 200	1 400	6 000	2 100	2 600	1 200
150	170	1 500	3 750	1 500	1 600	1 800	6 000	2 500	3 000	1 600
220	245	2 100	4 350	2 100	2 200	2 400	6 600	3 100	3 600	2 200
380	420	3 400	5 650	3 400	3 500	3 700	7 900	4 400	4 900	3 500
480	525	4 100	6 350	4 100	4 200	4 400	8 600	5 100	5 600	4 200
700	765	6 400	8 650	6 400	6 500	6 700	10 900	7 400	7 900	6 500

Table 4-12

Minimum height and protective barrier clearances in indoor installations as per DIN VDE 0101



Solid-panel wall — Wire mesh, screen — Rail, chain or rope

Nominal voltage	Maximum voltage for equipment	Minimum clearances *N* as per Table 4-10	Minimum height	Protective barrier clearances of live parts		
U_n kV	U_m kV	*N* mm	*H* mm	B_1 mm	B_2 mm	O_1 mm
3	3.6	60	2 500	60	140	500
6	7.2	90	2 500	90	170	500
10	12	120	2 500	120	200	500
20	24	220	2 500	220	300	500
30	36	320	2 570	320	400	520
45	52	430	2 730	480	560	680
60	72.5	630	2 880	630	730	830
110	123	1 100	3 350	1 100	1 200	1 300

4.6.3 Gangway widths in power installations with rated voltages of up to 1 kV (DIN VDE 0100 Part 729)

Specifications for the arrangement of switchgear installations

They apply for both type-tested and partially type-tested switchgear installations and switchboards

Control and service gangways

Switchgear installations and distribution boards must be configured and installed so the width and height of gangways are not less than the dimensions shown in Fig. 4-40. The exits must also be accessible in emergencies even when the panel and housing doors are open. These conditions are considered fulfilled if doors slam shut in the escape direction or open completely. The remaining minimum accesses may not be less than 500 mm.

Service and operational accesses with a length of more than 20 m must be accessible from both ends. Access from both ends is also recommended for gangways that are longer than 6 m. Exits must be placed so that the escape path inside a room of electrical or enclosed electrical premises is no more than 40 m long.

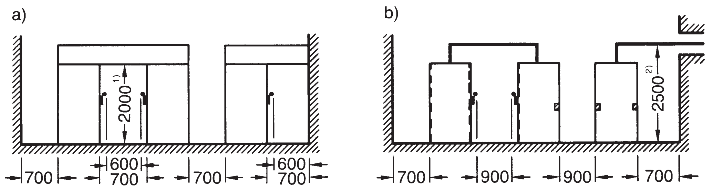


Fig. 4-40

Minimum dimensions for gangways

a) gangways for low-voltage installations with the minimum degree of protection IP 2X as per DIN 40 050.

b) gangways for low-voltage installations with degrees of protection below IP 2X.

1) minimum passage height under obstacles, such as barriers
2) minimum passage height under bare live parts

See Section 5.7 for degrees of protection

The values of DIN VDE 0101 as the dimension for gangways are applicable for the gangway widths where low-voltage and high-voltage device combinations are installed front-to-front in the same room (see Section 4.6.2).

Protective clearances DIN VDE 0660

Removable parts that are intended to prevent direct contact with live parts may only be removable with a tool or key.

Fig. 4-40a shows the minimum dimensions for closed installations. The minimum dimensions in Fig. 4-40b are applicable for open installations in locked electrical premisses only.

In the case of barriers, such as wooden railings, the gangway widths must meet the minimum dimensions for operating handles (900 or 700 mm) listed in Fig. 4-40b and also the additional minimum clearance of 200 mm between barrier and live part given in Fig. 4-41.

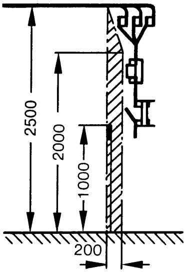


Fig. 4-41

Minimum dimensions for barriers

4.7 Civil construction requirements

The civil engineering consultant must determine a large quantity of information and details for the structural drawings required to design switchgear installations. The structural drawings are the basis for producing the structural design plans (foundation, shell and reinforcement plans, equipment plans). In Germany the Arbeitsgemeinschaft Industriebau e. V. (AGI) has issued the following datasheets:

datasheet J11 for transformer compartments
datasheet J12 for indoor switchgear
datasheet J21 for outdoor transformers
datasheet J31 for battery compartments

The structural information includes the following data:

- spatial configuration of the installation components
- aisle widths for control, transport and assembly
- main dimensions of the station components
- load specifications
- doors, gates, windows with type of opening and type of fire-preventive or fire-resistant design
- ceiling and wall openings for cables, pipes or conduits
- information on compartments with special equipment
- information on building services
- ventilation, air-conditioning information
- floors including steel base frames
- foundation and building earth switches
- lightning protection
- drainage.

The following design details must be observed:

4.7.1 Indoor installations

When planning indoor installations (substation buildings and switchboard rooms), in addition to configuration to meet operational requirements, ensure that the selected compartments are not affected by groundwater and flooding and are also easily accessible for control and transport equipment and also for firefighting. The current applicable construction codes, regulations and directives must be observed. Construction laws include regulations that must be observed and in addition, the generally accepted engineering requirements apply.

Walls, ceilings and floors must be dry. Pipes carrying liquids, steam and flammable gases must not be laid in, above or under rooms intended for switchgear installations. If, however, necessary, structural measures for protection of the electrical installations are required.

The clearance dimensions of an equipment room depend on the type, size and configuration of the switchbays, on their number and on the operating conditions. The required minimum aisle widths and safety clearances are specified in DIN VDE 0101 or DIN VDE 0105 Part 1.

The exits must be laid out so the escape route from the installation is no more than 40 m for rated voltages over 52 kV and no more than 20 m for rated voltages of up to 52 kV. A servicel aisle more than 10 m long must have two exits, one of which may be an emergency exit.

The interiors of the switchgear house walls must be as smooth as possible to prevent dust from accumulating. The brickwork must be plastered, but not ceilings in the area of open installations, so switchgear parts are not subject to falling plaster.

The floor covering must be easy to clean, pressure-resistant, non-slippery and abrasion-proof (e.g. stoneware tiles, plastic covering, gravel set in concrete with abrasion-resistant protective coating to reduce dust formation); the pressure load on the floor from transport of station components must be considered.

Steps or sloping floor areas must always be avoided in switchgear compartments.

Opening windows must be positioned so they can be operated. In open areas, this must not place personnel in danger of contacting live parts.

Windows in locked electrical premises must be secured to prevent access. This condition is considered to be met by one of the following measures:

- The window consists of unbreakable materials.
- The window is barred.
- The bottom edge of the window is at least 1.8 m above the access level.
- The building is surrounded by a fence at least 1.8 m high.

Ventilation and pressure relief

The compartments should be ventilated sufficiently to prevent the formation of condensation. To prevent corrosion and reduction of the creepage distance by high humidity and condensation, it is recommended that the typical values for climate stress listed in DIN VDE 0101 be observed in switchgear rooms. The following apply:

- the maximum relative humidity is 95 % in the 24 hour average,
- the highest and lowest ambient temperature in the 24 hour average is 35 °C and – 5 °C with “Minus 5 Indoor” class.

In areas of high pollution, the compartments must be kept at a low level of overpressure with filtered air. The air vents required for this must prevent the entry of rain, spray water and small animals. Sheetmetal covers must also be installed over the vents at heights to about 2.50 m above ground. See Sections 4.4.2 and 4.4.3 for additional information on ventilation.

SF_6 installations

For SF_6 installations, it is recommended that the building be extended by the length of one bay for installation and renovation purposes and that a hoist system with a lifting capacity equal to the heaviest installation components be installed.

Natural cross-ventilation in above-ground compartments is sufficient to remove the SF_6 gas that escapes because of leakage losses. This requires about half of the required ventilation cross section to be close to the floor.

It must be possible to ventilate compartments, conduits and the like under compartments with SF_6 installations.

Mechanical ventilation is not necessary so long as the gas content of the largest contiguous gas space including the content of all connected SF_6 tanks (based on atmospheric pressure) does not exceed 10% of the volume of the compartment receiving the leakage gas.

Mechanical ventilation may be required in the event of faults with arcing.

Reference is also made to the requirement to observe the code of practice "SF_6 Installations" (Edition 10/92) of the professional association for precision engineering and electrical engineering (BGFE, Germany).

Pressure relief

In the event of an accidental internal arc in a switchgear installation, significant overpressure occurs in switchgear compartments, in particular in those with conventional air insulation with high arc lengths. Damage to walls and ceilings caused by unacceptably high pressure load can be prevented by appropriate pressure relief vents. Floor plates must be properly secured. Pressure relief facilities in switchgear rooms should meet the following criteria:

– they should normally be closed to prevent the entry of small animals, snow, rain etc.; light, self-actuating opening of the facility at an overpressure of less than 10 mbar;
– pressure relief in an area where there are usually no personnel;
– no parts should become detached during pressure relief.

Cable laying

The options listed below are available for cable laying:

Tubes or cable conduit forms, covered cable conduits, cable conduits accessible as crawl space and cable floors, accessible cable levels.

Tubes or cable conduit forms are used to lay single cables. To avoid water damage when laid outside they should be sloped. The bending radius of the cable used should be observed for proper cable layout.

Covered cable conduits are intended when several cables are laid together, with the width and depth of the conduit depending on the number of cables. The covers of the conduits should be fireproof, non-slip and non-rattling and should not have a raised edge. They must able to take the weight of transport vehicles carrying electrical equipment during installation. The conduits should be placed before the compartments to allow cable work to be done at any time without having to disconnect equipment.

Cable conduits accessible as crawl spaces and cable floors should be at least 1.50 m wide; the overhead clearance should not be less than 1.00 m to allow for any cable crossings. Access and ventilation openings and the required cable accesses must be taken into account.

Accessible cable conduits and cable levels are required for a large accumulation of cables in larger installations. A height of 2.10 m (to the lower edge of the support girder) is recommended to provide space for the required lighting and suspended cables. The cables can be laid on cable racks and also fastened to supports using cable clamps. Escape paths (emergency exits) must be available. Access doors must open outwards, should be airtight when closed, must be fire-resistant and have a panic lock.

Auxiliary cables are laid on separate cable racks or on supports beneath the ceiling.

The VDEW directives “Empfehlungen für Maßnahmen zur Herabsetzung von transienten Überspannungen” (recommendations for measures to reduce transient overvoltages) in secondary lines are particularly important in the selection and laying of cables; for this reason power cables should be laid apart from control cables. Separate conduits should be provided for cable laying where possible.

The cable conduits, particularly for the power cables, must be dimensioned to provide sufficient space for the heat from power dissipation.

4.7.2 Outdoor installations

Foundations

Foundations for portals, supports (for equipment) and similar and also for transformers are constructed as simple concrete foundations.

As well as the static loads, they must be able to resist operational loads, such as the effects of switching forces, short-circuit forces, tension caused by temperature variations and wind and ice load. The foundation types, such as slab or individual, depend on the soil quality or other installation-specific criteria.

Foundation design is determined by the installation structure and the steel structure design.

The base of the foundation must be frost-free, i.e. at a depth of around 0.8 – 1.2 m. The foundations must have the appropriate openings for earth wires and any necessary cables.

The relevant regulations for outdoor construction specified in DIN VDE 0210 apply for the mechanical strength analyses.

Access roads

The type, design, surveying and layout of access roads is determined by the purpose of the roads and the installation design:

– for transport of switchgear (up to approx. 123 kV) roads are provided only in specially extended installations, (otherwise possible for higher voltage levels) min. 2.50 m wide and with a load rating corresponding to the maximum transport component;
– for transport of transformers, min. 5 m wide, load capacity corresponding to the transport conditions. When laying out the road, the radius of the curves should be suitable for multi-axle transport vehicles.

When planning the roads, the required cable conduits, such as for earthing conductors or cable connections that cross the road, must be taken into account.

The height of live parts over access roads depends on the height of the transport units (this must be agreed between the contractor and the operator) and the required minimum clearances T as shown in Fig. 4-39.

Design and rating must be suited for transport of the heaviest station components.

Cable trenches

Covered cable trenches are planned for cables in outdoor installations. In large installations with conventional secondary technology, an accessible cable trench with single or double-sided cable racks may be required for most of the control cables.

Main trenches should not be more than 100 cm wide because of the weight of the cover plates. The depth depends on the number of cables. Cable racks are installed on the sides.

Branch ducts, which can be designed as finished parts, run from the control cabinets or relay compartments to the high-voltage equipment. The upper part of the main conduits and branch ducts is placed a little above ground level to keep the trench dry even in heavy rain.

Cables to individual devices can also be laid in prefabricated cable ducts or directly in the ground and covered with bricks or similar material.

Otherwise refer to the information given in Section 4.7.1 on laying cables as applicable. For preferred cable trench designs, see Section 11.3.2 Fig. 11-17.

4.7.3 Installations subject to special conditions

Electrical installations subject to special conditions include:

- installations in equipment rooms that are subject to the German Elt-Bau-VO,
- installations in enclosed design outside locked electrical premises,
- mast and tower substations to 30 kV nominal voltage,
- installations in premises subject to fire hazard.

Installations that are subject to the Elt-Bau-VO are subject to the implementation regulations for Elt-Bau-VO issued by the various German states with respect to their structural design. This particularly covers structural measures required for fire prevention.

The other installations subject to special conditions are subject to the structural requirements as in Section 4.6.1.

4.7.4 Battery compartments

The following specifications must be observed for the structural design:

The *layout of the compartments* should be such that they are easily accessible for transporting batteries. In addition, the compartments should be proof against groundwater and flooding, well ventilated – either natural or forced ventilation –, well lit, dry, cool, frost-free and free from vibrations. Temperature variations and direct solar radiation should be avoided. The room temperature should not fall below 0 °C and not exceed 35 °C so far as possible.

The *floor* must be rated for the anticipated load, including any point loads that might occur. It must be resistant to the effects of electrolytes and should be sloping. Very large compartments may require the installation of a drain for cleaning the floor. This will require a sloping floor leading to the drain. A neutralization trap must be installed between the drain outlet and the sewer system. The ground leakage resistance of the soil must comply with DIN 51953 $\leq 10^8\ \Omega$.

Ceilings and walls must be smooth and abrasion-resistant; they should be painted with an acid-resistant coating that does not release toxic vapours.

Windows are not required in a battery room with forced ventilation. If there are any, they should be resistant to corrosion by electrolyte. If the compartment has natural ventilation, aluminium windows should not be used. The windows should have vents that cannot be closed to ensure a continuous circulation of air.

The VDE standards do not require *gas or air locks*. However, if they are planned, they must be ventilated and fitted with a water connection and drain, unless these are already provided in the battery room. The outlet must pass though a neutralization system.

Battery compartments must have *natural* or forced ventilation.

The fresh air should enter near ground level and be sucked out below the ceiling so far as possible. This ensures that the fresh air passes over the cells.

Natural ventilation is preferable. This can be done with windows, air ducts or chimneys. Air ducts must be of acid-resistant material. Chimneys must not be connected to any sources of fire because of the danger of explosion.

With forced ventilation, the fan motors must be designed for protection against explosion and acid-resistant or they must be installed outside the hazard zone. The fan blades must be manufactured of material that does not take a static charge and does not generate sparks on contact with foreign bodies.

The forced ventilation should include extractor fans. The installation of forced-air fans is not advisable for reasons of ventilation technology.

As per DIN VDE 0510 Part 2, the ventilation is considered satisfactory when the measured air-flow volume complies with the numerical comparison below. This information is applicable for ventilation of rooms, containers or cabinets in which batteries are operated:

$$Q = 0{,}05 \cdot n \cdot I \ [\mathrm{m^3/h}]$$

where n = number of cells,

I = current value in A as per DIN VDE 0510 that initiates the development of hydrogen.

The requirements for the installation of batteries are dealt with in Section 15.3.5.

Additional information on the subject of ventilation can be found in Section 4.4.3.

Electrical equipment should meet the degree of protection IPX2 as per DIN 40050 as a minimum.

4.7.5 Transformer installation

The transformers and switchgear compartments should be configured for easy access, because the power supply components in the transformer substation must be quickly and safely accessible from outside at all times.

The compartment dimensions must be determined from the point of view of temperature rise, noise generation, transmission of structural noise, fire hazard and replacement of equipment. The structure must be planned subject to these criteria. See Section 1.2.6 for information on measuring noise and noise reduction.

Oil-insulated transformers may be installed in large buildings only with specified structural and electrical requirements satisfied.

Indoor and outdoor oil-insulated transformers do not require special protection against environmental influences. Cast-resin transformers in the IP00 design (without housing) may be installed in dry indoor rooms. Outdoor installation of cast-resin transformers requires a housing complying with the degree of protection of minimum IP23 with a roof protecting them against rain.

The requirements of DIN VDE 0100, 0101 and 0108 must be observed for the installation and connection of transformers. The installation of surge arrestors is recommended as protection against overvoltages caused by lightning and switching operations (Section 10.6).

If transformers are installed in indoor compartments for natural cooling, sufficiently large cooling vents above and below the transformers must be provided for venting the heat dissipation. If natural ventilation is not sufficient, forced ventilation is required, see Section 4.4.2, Fig. 4-28.

In detail, the following requirements for installation of transformers must be observed:

- clearances
- safety distances
- design of high-voltage connections
- accessibility for operation and maintenance
- transport paths
- cooling/ventilation (see Section 4.4.3)
- fire prevention (see Section 4.7.6)
- auxiliary equipment
- setup
- withdrawal for future replacement of transformers.

For construction details see AG datasheet J21, Arbeitsgemeinschaft Industriebau (industrial construction workgroup).

Catchment pans, sumps and sump groups must be installed under transformers with liquid insulation (cooling types O and L) for fire and water protection. Their design must prevent the insulation fluid from leaking into the soil.

Connection lines between catchment pans and sumps must be designed to prevent insulation fluid from continuing to burn in the collection sumps (longer pipes or gravel system).

Catchment or collection sumps must be large enough to catch water flowing in (rain, extinguishing and washing water) as well as insulation fluid.

Water flows must be directed to an oil separator, or otherwise it must be possible to pump out the contents of the catchment sump.

The local water authority may allow concessions in accordance with DIN VDE 0101 for specified local conditions (soil characteristics) and transformers with less than 1000 l of insulation fluid .

Fig. 4-42 shows the preferred configuration of oil catchment equipment.

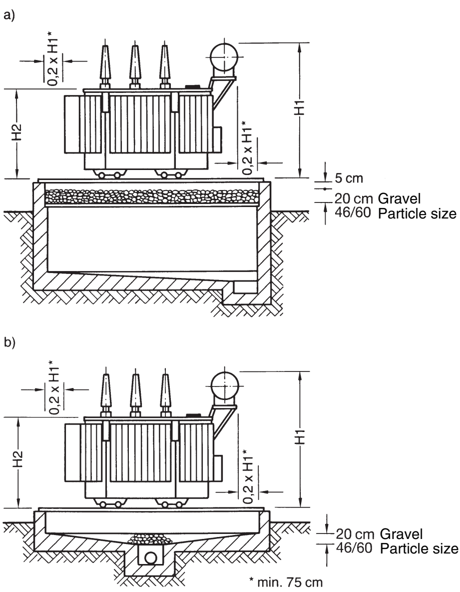


Fig. 4-42

Configuration of oil sumps a) and oil catchment pans b)

4.7.6 Fire prevention

The possibility of fire in switchgear and transformer rooms cannot be excluded. The seriousness of the fire risk depends on the type of installation, the structure, the installation components (devices, apparatus etc.) and on the fire load.

Targeted structural fire prevention measures (e.g. small fire compartments, fire-reducing and fire-resistant barriers, cable and conductor compartmentalization) can significantly reduce the risk of a fire spreading.

Fires caused by electrical equipment may occur due to: short-circuit arcing, unacceptable temperature rise caused by operational overload or short-circuit currents.

Fire load, effects of fire

The fire load corresponds to the theoretical energy that can be released from all flammable material with reference to a defined area. It is expressed in kWh per m^2 of fire compartment area. Data from the association of insurers (VdS) provides guidance values on the combustion heat of cables and wires.

Measures

The following measures for protection of installations emphasize cable compartments, cable ducts and transformers:

a) partitioning of cable feeds by ceilings and walls, see Fig. 4-43

b) partitioning of cable infeeds in switchgear cubicles or bays, see Fig. 4-44

c) cable sheathing – insulation layer formation

d) fire-resistant sheathing of cable racks and supports

e) compartmentalization of cable ducts, use of small fire compartments, see Fig. 4-45, installation of fire-protection valves in inlet and outlet air ducts

f) sprinkler systems in buildings

g) installation of venting and smoke removal systems

h) fire-protection walls for transformers, see Fig. 4-46

i) oil catchment systems for transformers, see Section 4.7.5, Fig. 4-42

k) water spray extinguishing systems for transformers, see Fig. 4-47, for preventing fires in leaked flammable insulation and cooling fluids

l) fire alarms, see Section 15.4.4.

If cables and conductors are run through walls and ceilings with planned fire resistance class (e.g. F 30, F 90), the openings must be closed with tested cable barrier systems in accordance with DIN 4102, Part 9, corresponding to the fire-resistance class (e.g. S 30, S 90) of the component.

Functional endurance of cable and wiring systems

On the basis of DIN VDE 0108 and in accordance with DIN 4102 Part 12, there are special fire-prevention requirements for the functioning of cables and wires for "buildings of special types or usage". Various German states have introduced corresponding administrative regulations covering the above structural standards. These requirements specifically cover government-supported safety equipment.

DIN 4102 is divided into the functional classes E 30, E 60 and E 90 corresponding to the fire resistance class. It can be satisfied by laying cables under plaster, in tested cables ducts or by the electrical lines themselves.

The functional duration for government-supported and required safety equipment must be at least:

- 30 minutes with
  - Fire alarm systems
  - Installations for alarming and distributing instructions to visitors and employees
  - Safety lighting and other emergency electric lighting, except for branch circuits
  - Lift systems with evacuation setting
- 90 minutes with
  - Water pressure-lifting systems for water supply for extinguishing fires
  - Ventilation systems for safety stairwells, interior stairwells
  - Lift shafts and machinery compartments for firefighting lifts
  - Smoke and heat removal systems
  - Firefighting lifts

Escape routes

All installations must have escape routes leading outside. They must be protected by fire-preventive and fire-resistant structures. The safest escape route length in accordance with the German sample construction code is 40 m or in accordance with the workplace regulations 35 m.

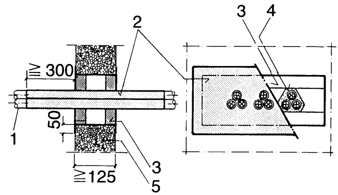


Fig. 4-43

Partition construction of a cable feed for wall or ceiling:

1 cable, 2 sheath of fire-resistant insulation material, 3 mineral fibre plates, 4 mineral wool stuffing, 5 firewall

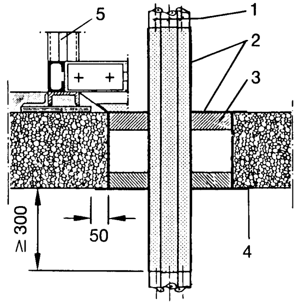


Fig. 4-44

Partition construction of a switchgear cubicle infeed:

1 cable, 2 sheath of fire-resistant insulation material, 3 mineral fibre plates, 4 fire ceiling, 5 base frame of cubicle

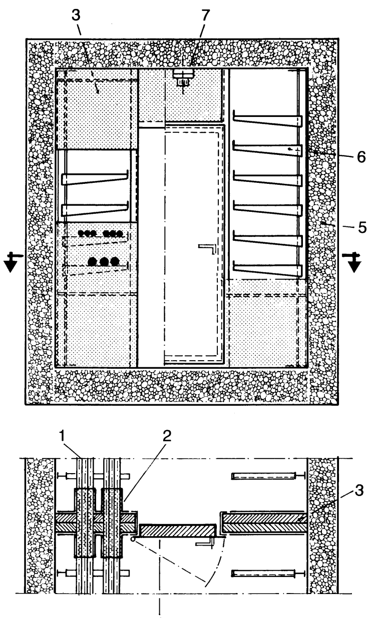
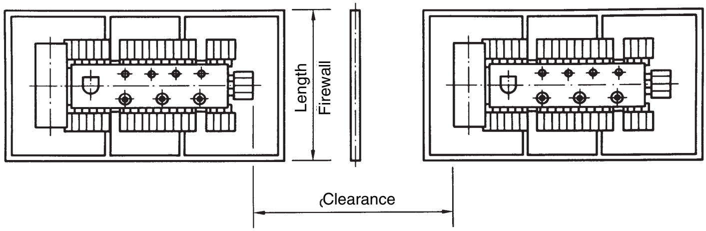


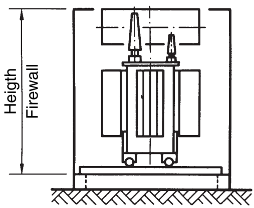
Fig. 4-45

Partition construction of an accessible cable duct:

1 cable, 2 sheath of fire-resistant insulation material, 3 mineral fibre plates, 4 fire-protection door, 5 concrete or brickwork, 6 cable rack, 7 smoke alarm a)



b)



c)

Transformer output over	Clearances less than
1 MVA	3 m
10 MVA	5 m
40 MVA	10 m
200 MVA	15 m

Fig. 4-46

Configuration of firewall for transformers:

a) Top view b) Side view c) Typical value table for installation of firewalls, dependent on transformer output and clearance

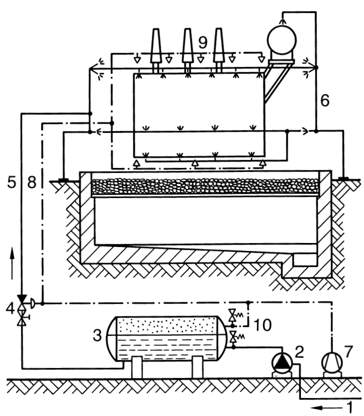


Fig. 4-47

Spray fire-extinguishing system (sprinkler) for a transformer with the following functional elements:

1. *Water supply*
2. *Filler pump*
3. *Air/Water pressure vessel*
4. *Valve block*
5. *Water feed*
6. *Pipe cage with spray nozzles*
7. *Compressor*
8. *Detector line*
9. *Pipe cage with detectors*
10. *Safety valves*

4.7.7 Shipping dimensions

Table 4-13

Container for land, sea and air freight, general data.

Type (' foot, " inch) ft. in. weight	External dimensions			Internal dimensions – minimum dimension –			Clearance dimension of door – minimum –		Volume	Weights permitted Total weight [1]	Tare	max. cargo weight
	Length mm	Width mm	Height mm	Length mm	Width mm	Height mm	Width nm	Height mm	m³	kg	from to kg	from to kg
20' × 8' × 8'	6 058	2 438	2 438	5 935	2 370	2 248	2 280	2 135	31.6	20 320	2 030 1 950	18 290 18 370
20' × 8' × 8'6"	6 058	2 438	2 591	5 880	2 330	2 340	2 330	2 270	32.7	20 320	2 450 2 080	17 870 18 240
40' × 8' × 8'6"	12 192	2 438	2 591	12 010	2 330	2 365	2 335	2 280	66.4	30 480	4 200 3 490	26 280 26 990
40' × 8' × 9'6" [2] (High Cube)	12 192	2 438	2 895	12 069	2 773	2 709	2 335	2 587	77.5	30 480	3 820	26 660

[1] Observe permissible load limit for road and rail vehicles.

[2] Observe overheight for road and rail transport.

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.

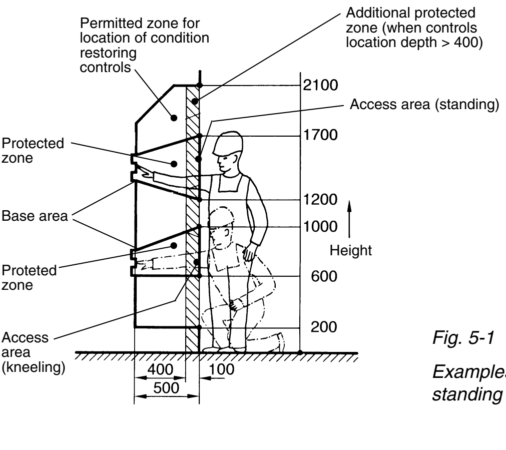


Fig. 5-1

Examples for protected zones for standing or kneeling positions

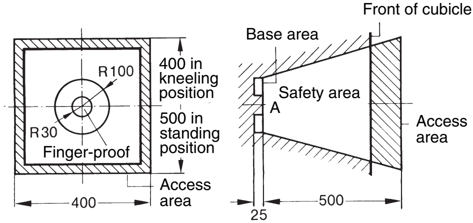
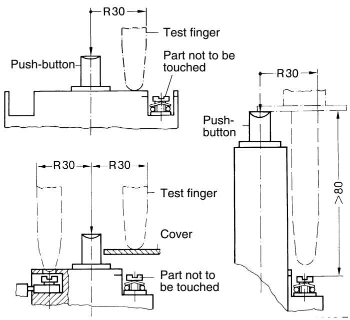


Fig. 5-2

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



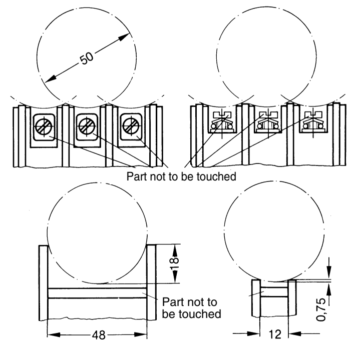


Fig. 5-3

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

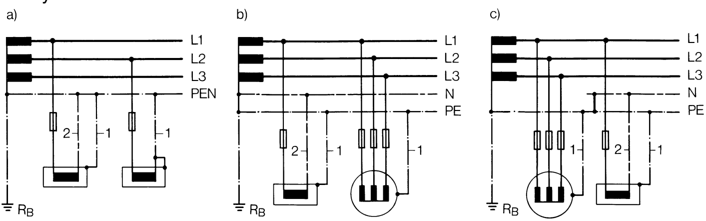


Fig. 5-5 (Part 1)

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.

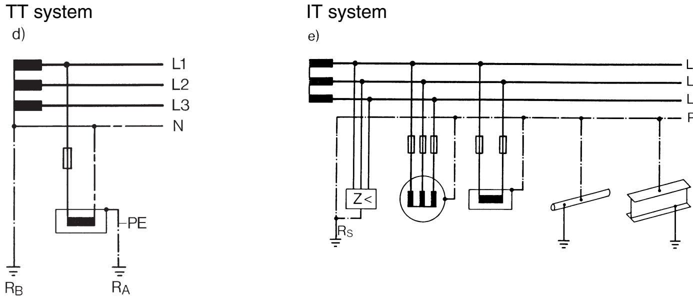


Fig. 5-5 (Part 2)

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.

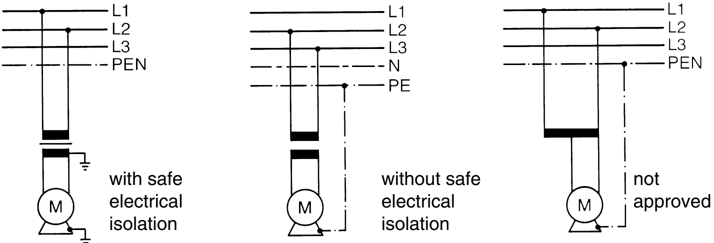


Fig. 5-6 Power sources for extra low voltages

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.

5

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.

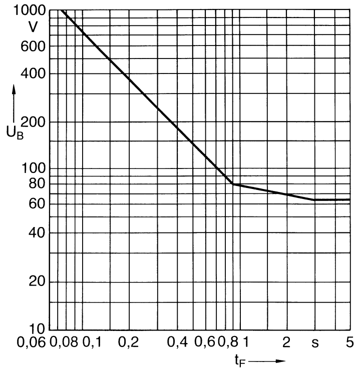


Fig. 5-7

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

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 = Ω m and indicates the resistance between two opposite cube faces of a cube of soil with sides of 1 m.

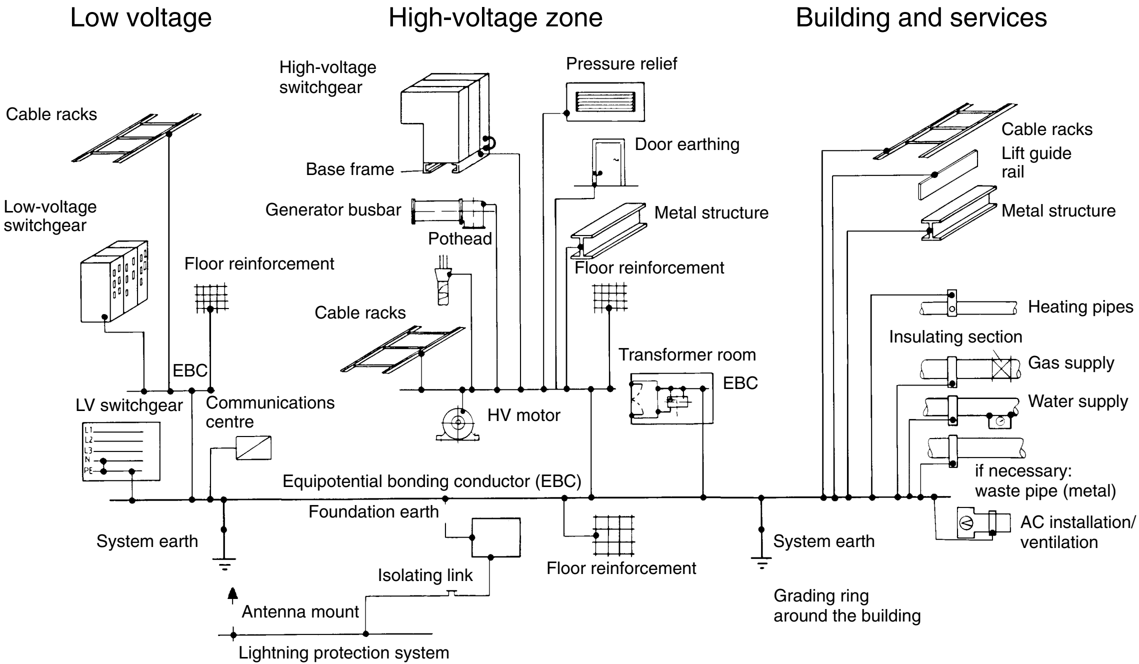


Fig. 5-8

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.*

5

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 mm² [1)] 16 mm² [2)]	25 mm² 16 mm² [3)]
	Stranded wire, copper bar	25 mm² 16 mm² [2)]	
Steel[4)]	Strip	90 mm² [5)] 50 mm² [2)]	50 mm² 16 mm² [3)]
	Steel bar	78 mm² [6) 7)] 50 mm² [2)]	
	Tube	25 mm Ø [8)]	
	Steel sections	90 mm² [9)]	
Steel coated with copper	Steel bar	50 mm² [10)]	no data
Aluminium[2)]		35 mm²	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 mm²), 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} 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	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

$I''_{k1} = I''_{k3} \dfrac{3}{2 + x_0/x_1}$			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			ϑ_i = 30°C, ϑ_f = 150 °C		
			1.0 s	0.5 s	0.2 s	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:

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

5

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	Underground 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

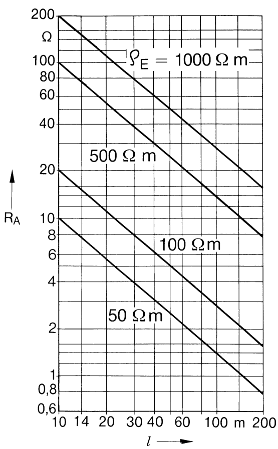


Fig. 5-9

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

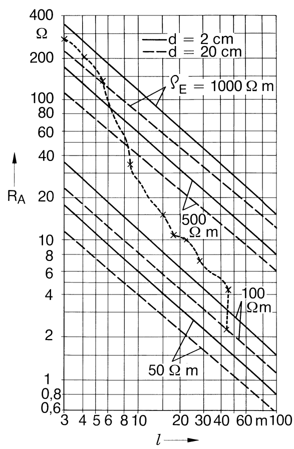


Fig. 5-10

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

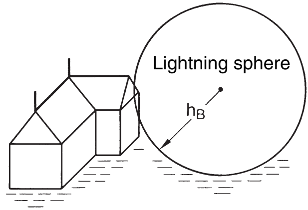
The lightning sphere method ensures complete lightning protection. It is used for residential buildings or high-hazard locations (warehouses with highly flammable materials such as oil, gas, cotton etc.). It is not used for electrical power systems.

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.

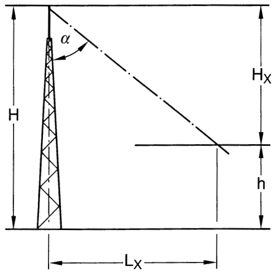


Fig. 5-12

Determining the protected zone by the universal method (Linck)

Method as per DIN VDE 0101

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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.

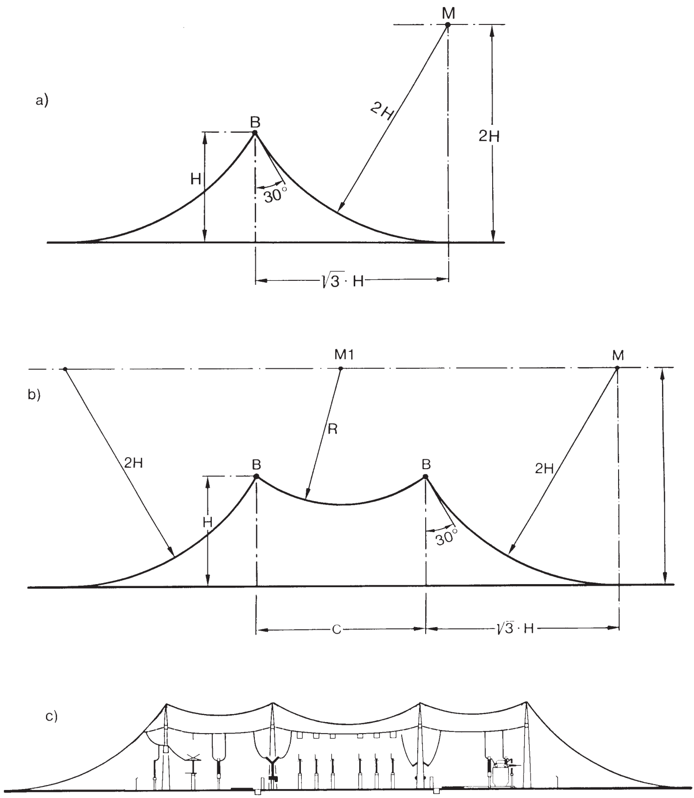

Fig. 5-13

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).

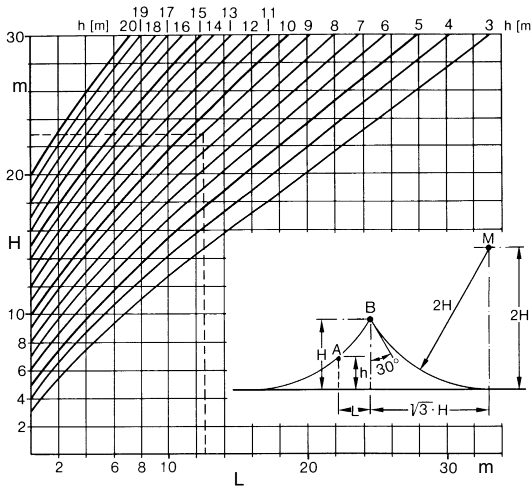

Fig. 5-14

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.

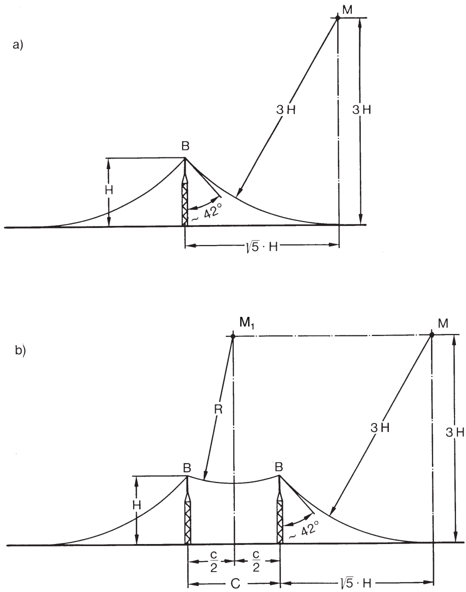

Fig. 5-15

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.

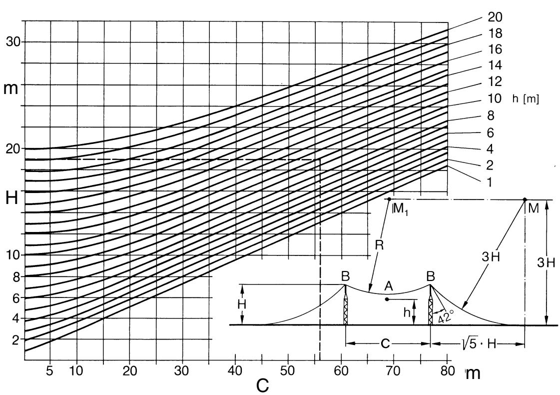

Fig. 5-16

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).

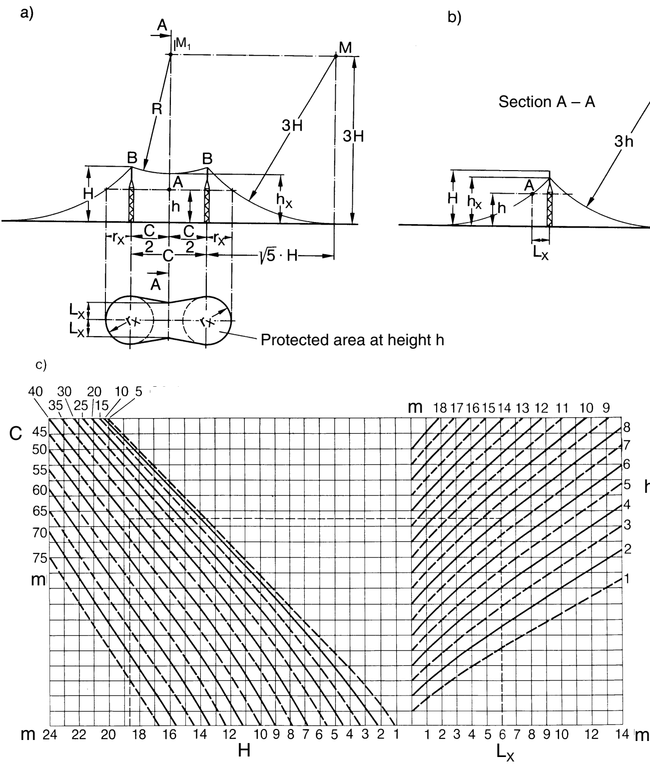

Fig. 5-17

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

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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.

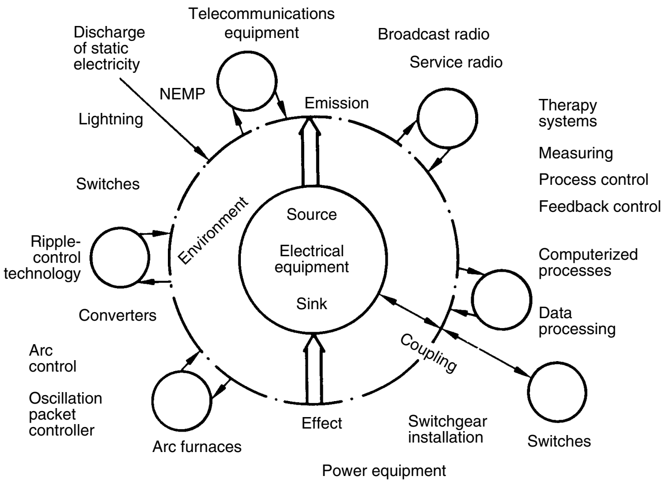


Fig. 5-18

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.

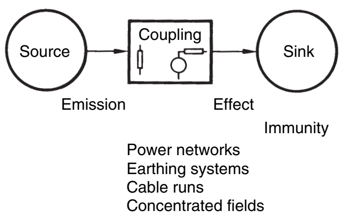


Fig. 5-19

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.

5.5.1 Origin and propagation of interference quantities

5

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.

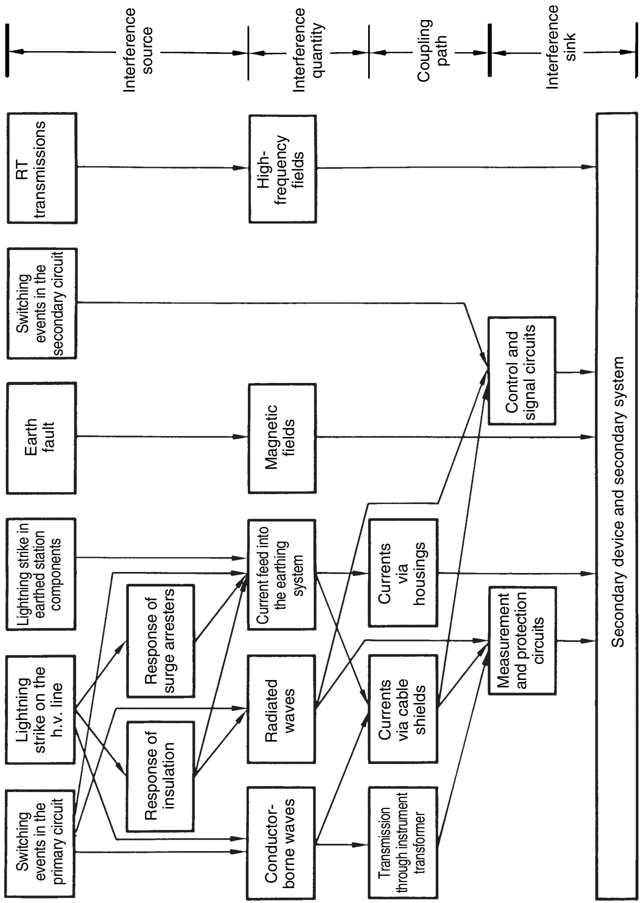
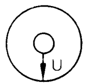
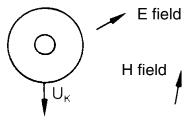
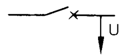
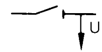
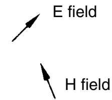


Fig. 5-20

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	4 – 7 ns	15 – 50 ns			50 – 100 ns	200 ns	180 – 700 ns	60 – 100 ns
Frequency	kHz – 10 MHz	MHz	– 20 MHz	– 20 MHz	kHz – MHz	kHz – MHz		
Height	system-specific	system-specific	$1^{1)} – 50^{2)}\ \frac{kV}{m}$	$2.5^{1)} – 125^{2)}\ \frac{A}{m}$	system-specific	system-specific	$5^{3)} – 50^{4)}\ \frac{kV}{m}$	$1^{3)} – 2^{4)}\ \frac{A}{m}$
Damping	weak	strong	strong	strong	strong	strong	strong	strong
Geometrical distances	small	large			large	large		

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.

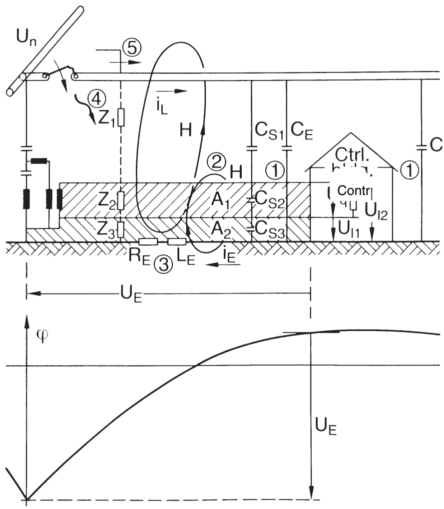


Fig. 5-21

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

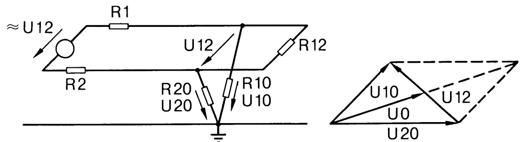


Fig. 5-22

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.

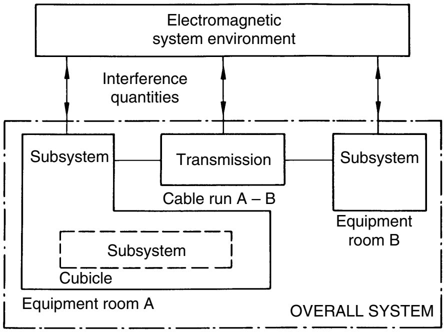


Fig. 5-23

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:

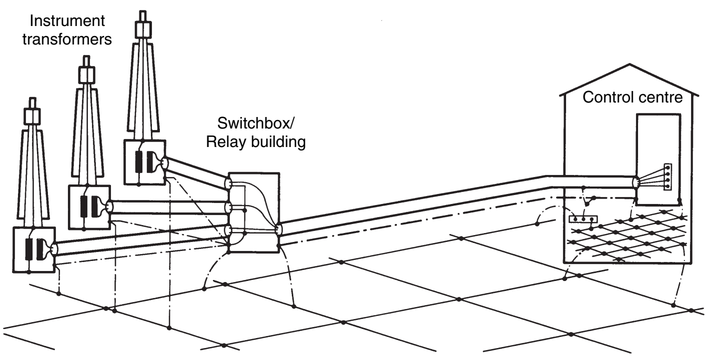


Fig. 5-24

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.

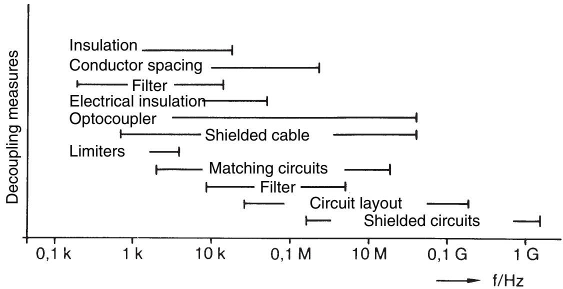


Fig. 5-25

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.

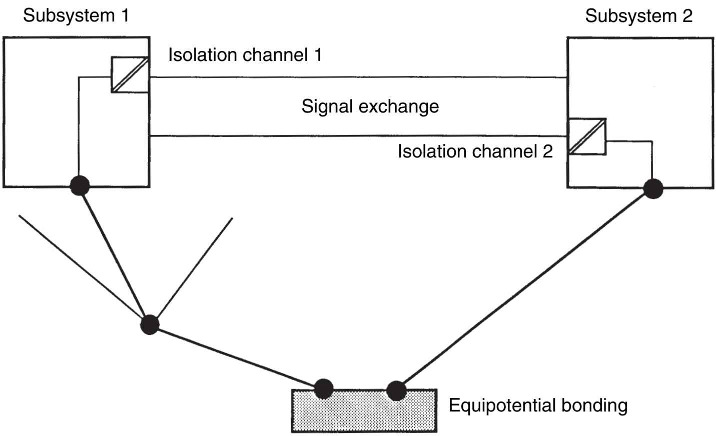


Fig. 5-26

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.

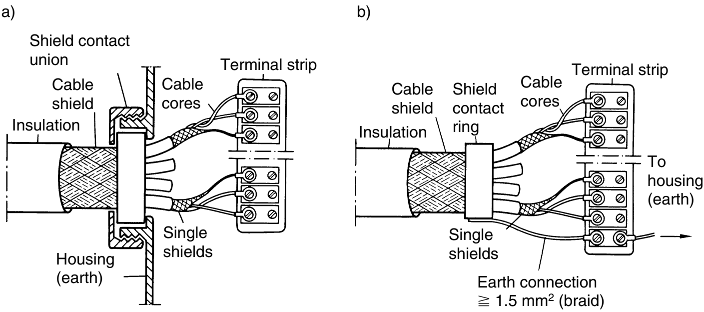


Fig. 5-27

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.

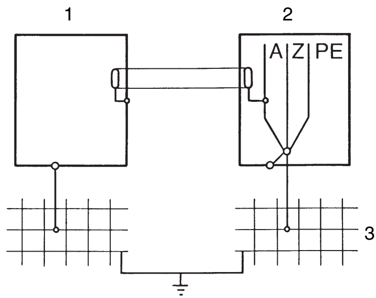


Fig. 5-28

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.

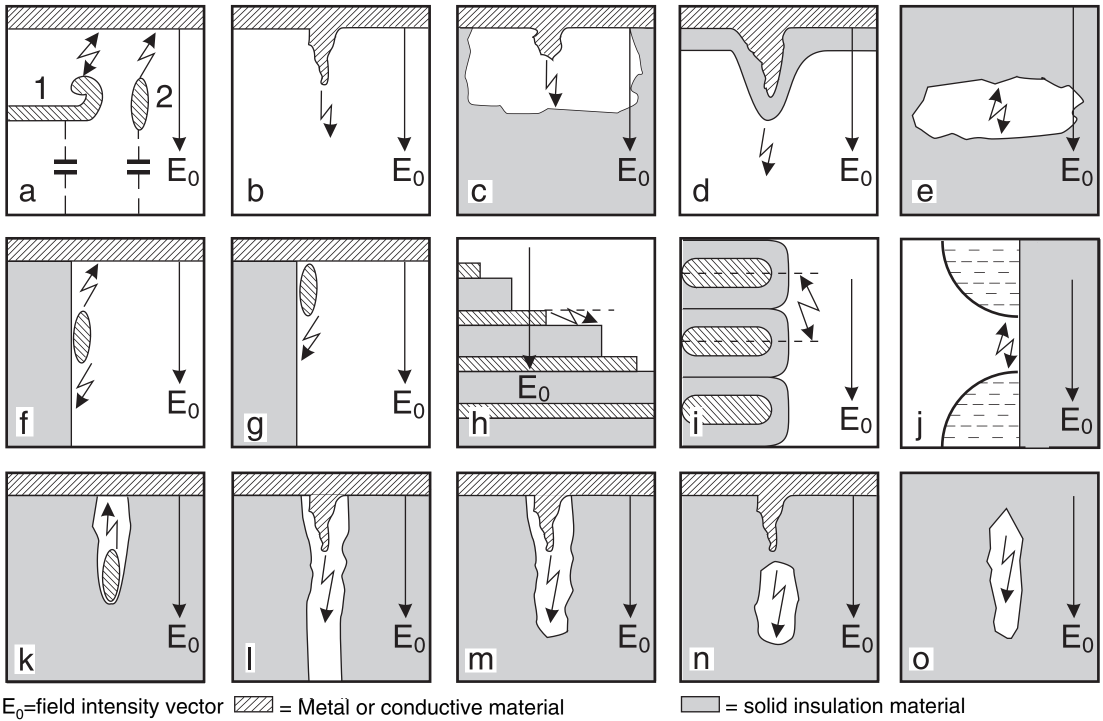


Fig. 5-29
Sources of partial discharge at electrodes, insulation and in gas

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.

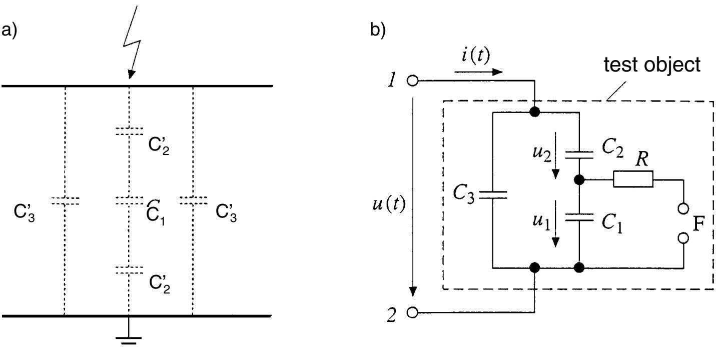


Fig. 5-30

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

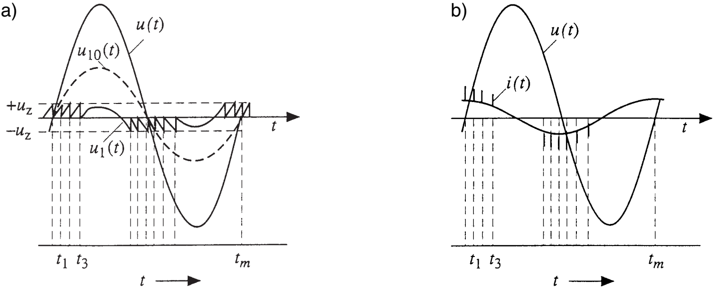


Fig. 5-31

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.

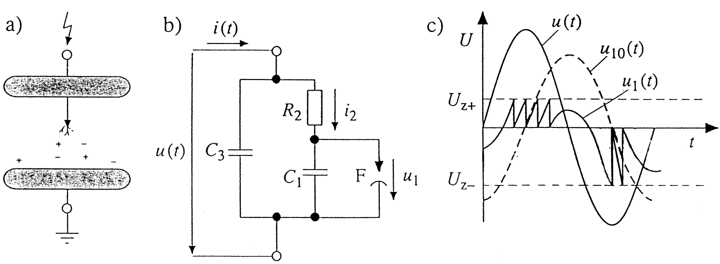


Fig. 5-32

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

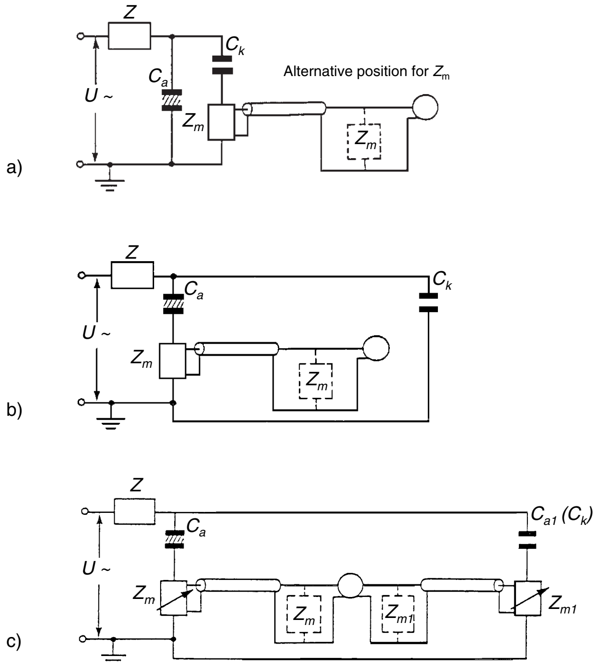


Fig. 5-33

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

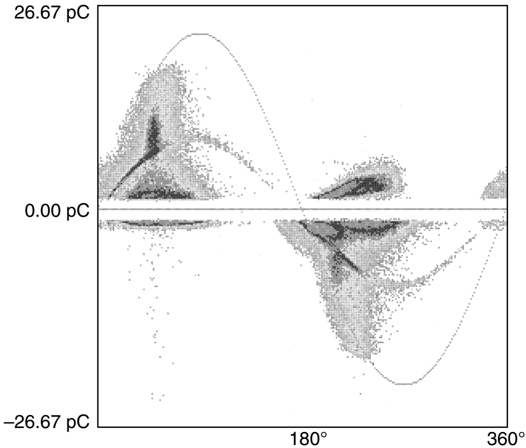


Fig. 5-34

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.

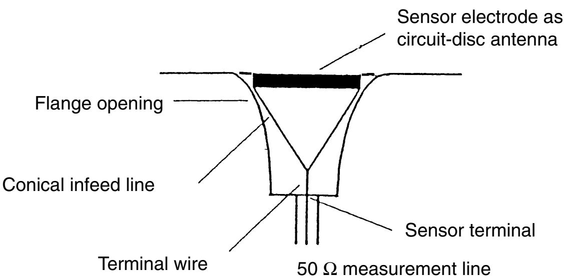


Fig. 5-35

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

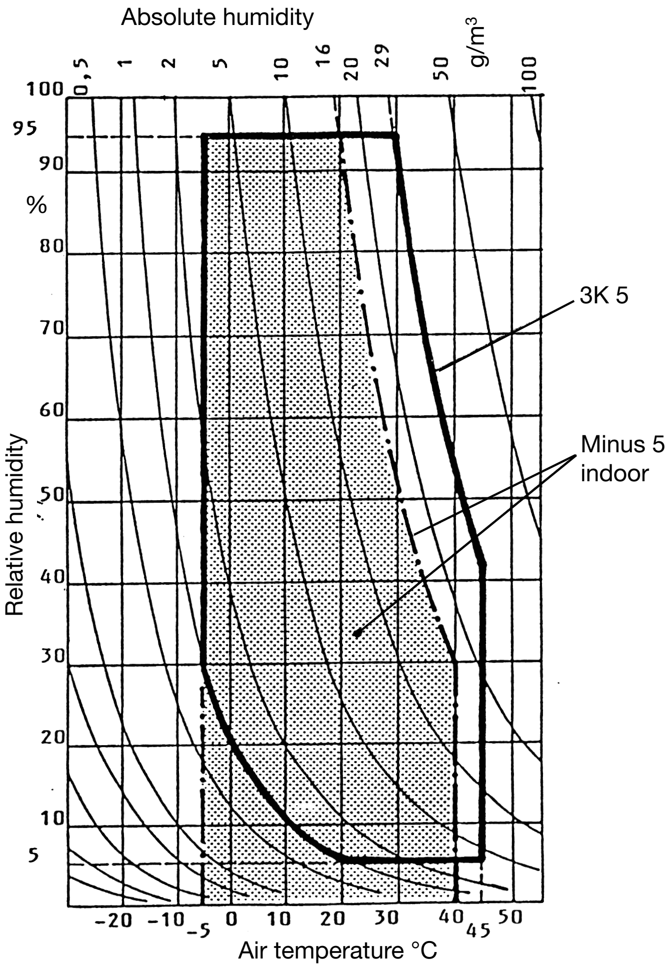


Fig. 5-36

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.

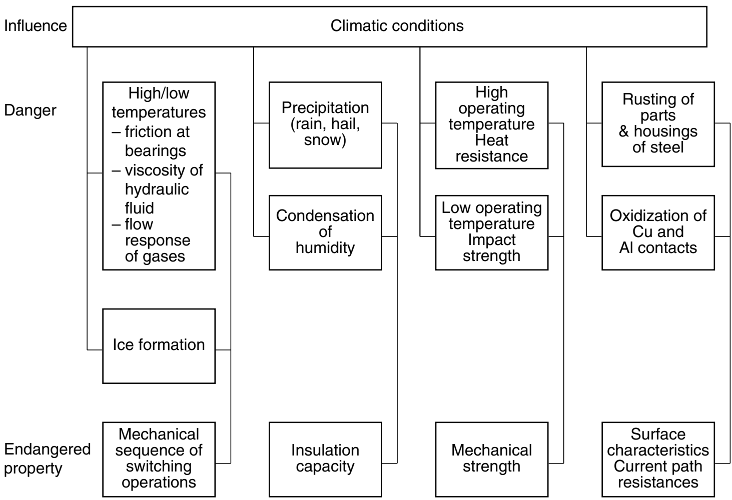


Fig. 5-37

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 ($\leq -5°C$).

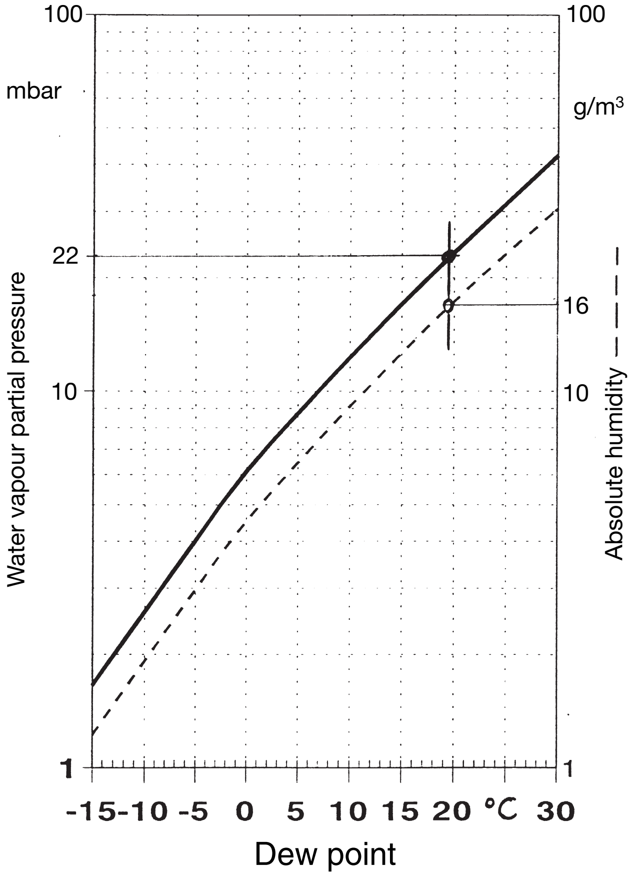


Fig. 5-38

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.

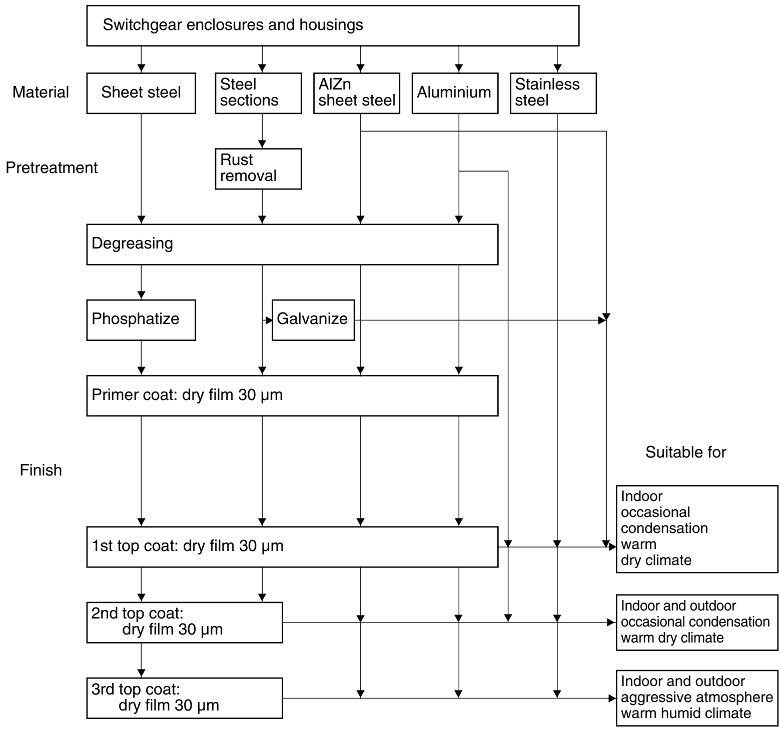


Fig. 5-39

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

IP 2 3 C H

- IP — Code letters (International Protection)
- 2 — First digit (0 to 6 or letter X)
- 3 — Second digit (0 to 8 or letter X)
- C — Additional letter (optional) (Letters A, B, C, D)
- H — Supplementary letter (optional) (Letters H, M, S, W)

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.

6 Methods and aids for planning installations

6.1 Planning of switchgear installations

6.1.1 Concept, boundary conditions, pc calculation aid

The process of planning switchgear installations for all voltage levels consists of establishing the boundary conditions, defining the plant concept and deciding the planning principles to be applied.

The planning phase is a time of close cooperation between the customer, the consulting engineer and the contractor.

The boundary conditions are governed by environmental circumstances (plant location, local climatic factors, influence of environment), the overall power system (voltage level, short-circuit rating and arrangement of neutral point), the frequency of operation, the required availability, safety requirements and also specific operating conditions.

Table 6-1 gives an indication of the boundary conditions which influence the design concept and the measures to be considered for the different parts of a switchgear installation.

In view of the equipment and plant costs, the necessity of each measure must also be examined from an economic standpoint.

Taking the busbar concept as an example (Table 6-3), the alternatives are evaluated technically and economically. The example is valid for h.v. installations, and to some extent m.v. installations as well.

PC calculation aid

Numerous computer programs are available for use in planning switchgear installations, particularly for design calculation. Sections 6.1.5 to 6.1.7 deal with computer-aided methods for:

– short-circuit current
– cable cross section
– cable routing.

Table 6-2 summarizes the computer programs used in planning switchgear installations, together with their fields of application and contents.

Table 6-1

Choice of plant concept and measures taken in relation to given boundary conditions

Boundary conditions	Concept and measures
Environment, climate, location:	Outdoor/indoor Conventional/GIS/hybrid Equipment utilization Construction Protection class of enclosures Creepage, arcing distances Corrosion protection Earthquake immunity
Network data,network form:	Short-circuit loadings Protection concept Lightning protection Neutral point arrangement Insulation coordination
Availability and redundancy of power supply:	Busbar concept Multiple infeed Branch configuration Standby facilities Uninterruptible supplies Fixed/drawout apparatus Choice of equipment Network layout
Power balance:	Scope for expansion Equipment utilization Instrument transformer design
Ease of operation:	Automatic/conventional control Remote/local control Construction/configuration
Safety requirements:	Network layout Arcing fault immunity Lightning protection Earthing Fire protection Touch protection Explosion protection

Table 6-2

Computer programs for project planning and calculations for switchgear installations (CAD programs, see Section 6.3.3)

Program Name	Application area	Testing, determination, dimensioning
EMTP	Calculation of transient processes in any meshed multiphase electrical systems	– Internal and external overvoltages – Interference voltage affecting telecom cables – Transient voltage elevation in earthing systems on lightning strike – Operational response of battery power systems
PPCP	Calculation of potential-course in earthing systems	– Determination of the propagation resistance – Determination of step and touch voltages
STÖRLI	Calculation of the pressure characteristic in switchgear rooms on arcing	– Checking the pressure resistance of medium-voltage switchgear rooms – Dimensioning pressure relief equipment
KURWIN	Dynamic resistance	– Static resistance and thermal and dynamic short-circuit current capability of switchgear installations with conductor cables and tubular conductors as per DIN EN 60865-1 (VDE 0103)
ROBI	Static resistance	– Deflection line and torque curve of waves and tubular conductors
CALPOS®	Programming system for network calculation with the following modules:	
	Phase fault current calculation; calculation of symmetrical and non-symmetrical fault currents as per – DIN VDE 0102/IEC60909 – Superposting method	– Switchgear installations (busbars, connections) – Equipment (switches, transformers) – Protection devices
	Load flow calculation	– Switchgear installations – Equipment and power – Minimum loss system operation methods – Critical system states – Directed switchovers after equipment failure – Voltage drop on motor startup

(continued)

Table 6-2 (continued)

Computer programs for project planning and calculations for switchgear installations (CAD programs, see Section 6.3.3)

Program Name	Application area	Testing, determination, dimensioning
CALPOS®	Selectivity analysis (over-current protection)	– Checking protection coordination in MS and NS networks
	Distance protection	– Protection coordination of cable units – Creation of selective tripping schedules
	Harmonic analysis	– Harmonic currents and voltages in networks with converters – System perturbation by harmonics – Compensation equipment – Propagation of audiofrequency ripple control signals
	Dimensioning of earthing systems (VDE 0141, IEEE 80)	– Cross sections for earthing material – Hazardous voltages
	Dimensioning low-voltage cables	– Specification of cable type – Maximum length – Selection of protective devices
	Motor startup	– Dynamic simulation in the time range
	Dynamic network simulation	– Investigation of system response to dynamic processes
CALPOS® –	Ramses	– Determination of reliability quantities in networks
CALPOS® –	Main	– Determining an optimum maintenance strategy for installation equipment

6.1.2 Planning of high-voltage installations

The following criteria must be considered when planning high-voltage switchgear installations:

Voltage levels

High-voltage installations are primarily for power transmission, but they are also used for distribution and for coupling power supplies in three-phase and HVDC systems. Factors determining their use include network configuration, voltage, power, distance, environmental considerations and type of consumer:

Distribution and urban networks	> 52 – 245 kV
Industrial centres	> 52 – 245 kV
Power plants and transformer stations	> 52 – 800 kV
Transmission and grid networks	245 – 800 kV
HVDC transmission and system interties	> 300 kV
Railway substations	123 – 245 kV

Plant concept, configuration

The circuitry of an installation is specified in the single-phase block diagram as the basis for all further planning stages. Table 6-3 shows the advantages and disadvantages of some major station concepts. For more details and circuit configurations, see Section 11.1.2.

The availability of a switching station is determined mainly by:

- circuit configuration, i. e. the number of possibilities of linking the network nodes via circuit-breakers and isolators, in other words the amount of current path redundancy,
- reliability/failure rate of the principal components such as circuit-breakers, isolators and busbars,
- maintenance intervals and repair times for the principal components.

Table 6-3

Comparison of important busbar concepts for high-voltage installations

Concept configuration	Advantages	Disadvantages
Single busbar	– least cost	– BB fault causes complete station outage – maintenance difficult – no station extensions without disconnecting the installation – for use only where loads can be disconnected or supplied from elsewhere
Single busbar with bypass	– low cost – each breaker accessible for maintenance without disconnecting	– extra breaker for bypass tie – BB fault or any breaker fault causes complete station outage
Double busbar with one circuit-breaker per branch	– high changeover flexibility with two busbars of equal merit – each busbar can be isolated for maintenance – each branch can be connected to each bus with tie breaker and BB isolator without interruption	– extra breaker for coupling – BB protection disconnects all branches connected with the faulty bus – fault at branch breaker disconnects all branches on the affected busbar – fault at tie breaker causes complete station outage
2-breaker system	– each branch has two circuit-breakers – connection possible to either busbar – each breaker can be serviced without disconnecting the branch – high availability	– most expensive method – breaker defect causes half the branches to drop out if they are not connected to both bus bars – branch circuits to be considered in protection system; applies also to other multiple-breaker concepts

(continued)

Table 6-3 (continued)

Comparison of important busbar concepts for high-voltage installations

Concept configuration	Advantages	Disadvantages
Ring bus	– low cost – each breaker can be maintained without disconnecting load – only one breaker needed per branch – no main busbar required – each branch connected to network by two breakers – all changeover switching done with circuit-breakers	– breaker maintenance and any faults interrupt the ring – potential draw-off necessary in all branches – little scope for changeover switching
1½-breaker system	– great operational flexibility – high availability – breaker fault on the busbar side disconnects only one branch – each bus can be isolated at any time – all switching operations executed with circuit-breakers – changeover switching is easy, without using isolators – BB fault does not lead to branch disconnections	– three circuit-breakers required for two branches – greater outlay for protection and auto-reclosure, as the middle breaker must respond independently in the direction of both feeders

Dimensioning

On the basis of the selected voltage level and station concept, the distribution of power and current is checked and the currents occurring in the various parts of the station under normal and short-circuit conditions are determined. The basis for dimensioning the station and its components is defined in respect of

– insulation coordination
– clearances, safety measures
– protection scheme
– thermal and mechanical stresses

For these, see Sections 3, 4, and 5.

Basic designs and constructions

The basic designs available for switching stations and equipment together with different forms of construction offer a wide range of possibilities, see Table 6-4. The choice depends on environmental conditions and also constructional, operational and economic considerations.

For further details, see Sections 10 and 11.

Table 6-4

The principal types of design for high-voltage switchgear installations and their location

Basic design	Insulating medium	Used mainly for voltage level (kV)	Location Outdoor	Location Indoor
Conventional	Air	>52 – 123	×	×
Conventional	Air	123 – 800	×	
GIS	SF_6	>52 – 800	× [1]	×
Hybrid[2]	Air/SF_6	245 – 500	×	

[1] GIS used outdoors in special cases
[2] Hybrid principle offers economical solutions for station conversion, expansion or upgrading, see Section 11.4.2.2.

There are various layouts for optimizing the operation and space use of conventional outdoor switchgear installations (switchyards), with different arrangement schemes of busbars and disconnectors, see Section 11.3.3

6.1.3 Project planning of medium-voltage installations

Medium-voltage networks carry electrical energy to the vicinity of consumers. In public networks (electrical utility networks), they carry the power to local and private substations. In industrial and power station auxillary systems, larger motorized consumers are directly connected as well as the low-voltage consumers.

Most common voltage levels for medium-voltage networks (in Germany):

Electrical utility networks:	10 kV, 20 kV, (30 kV),
Industrial and power station service networks:	6 kV, 10 kV.

Industrial and power station service installations are primarily supplied by radial systems. Important installations are redundantly designed to meet the requirements regarding availability.

Characteristics of industrial and power station auxillary networks:

- high load density
- high proportion of motorized consumers
- occurrence of high short-circuit power.

Planning medium voltage distribution networks

Distribution networks have, in general, developed historically and as a result are frequently characterized by a high degree of meshing. The task of system planning is to design these networks to be simple and easy to comprehend.
In planning electrical networks, a distinction is made between operational structural planning and basic strategic planning. Basic planning covers the following points:

- Supply principles,
- Network concepts,
- Standard equipment,
- Standard installations.

The following forms of network are used with the corresponding switchgear installation configurations (DSS, ESS):

Ring network | Network with opposite station | Network with load-centre substation

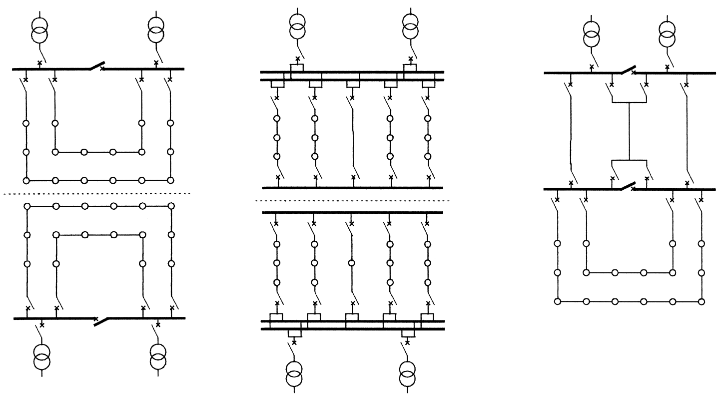


Fig. 6-1:

Networks in which the individual transformer substations on the medium-voltage side are not interconnected

Corresponding transformer substations

Corresponding transformer substations with opposite station

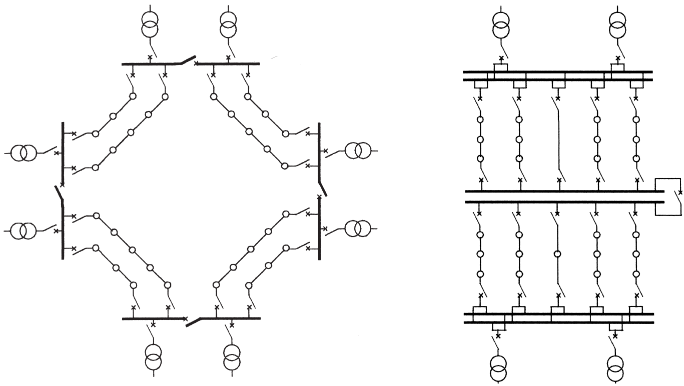


Fig. 6-2:

Networks in which the individual transformer substations on the medium-voltage side are interconnected

A simple protection concept can be implemented in radial networks. Troubleshooting in the event of a fault is much easier, particularly with single-phase faults.

An important aspect of system planning is the neutral treatment. Public distribution systems today are still mostly operated with earth fault compensation, with no tripping in the event of an earth fault. The low-resistance neutral earthing is available for selective breaking of single-phase faults. However, a new trend is to operate the networks with compensation and also to install short-time low-resistance neutral earthing (Kurzzeitige NiederOhmige SternPunktErdung, KNOSPE). The advantage of KNOSPE is its selective interception of earth faults without interruptions of power supply. The networks must be operated primarily as radial systems. Short-circuit indicators must be installed in the substations to allow selective fault location.

Planning medium-voltage switchgear

The standard structure of medium-voltage switchgear today is the factory-assembled type-tested switchgear installation conforming to DIN EN 60298 (VDE 0670 Part 6). The most common structural types are described in Section 8.2.

The most important distinguishing characteristics of the currently available structural types and the associated decision-making criteria are:

Distinguishing characteristics		Technical decision-making criteria
Low costs	Higher costs	—
Single busbars	Double busbars	Network concept
Air-insulated	Gas-insulated	Dimensions of the installation environmental conditions (contamination, moisture, service requirements, cleaning)
Cubile	Metal-clad	Personnel safety during wiring work Restriction of damage in the event of internal arcing (if compartmentalization is designed for this)
Switch disconnector installation type	Circuit-breaker installation type	Rating data – Short-circuit currents – Operating currents – Switching frequency Protection concept

6

6.1.4 Planning of low-voltage installations

Low-voltage installations are usually near the consumer and generally accessible, so they can be particularly dangerous if not installed properly.

The choice of network configuration and related safety measures is of crucial importance. The availability of electricity is equally dependent on these considerations.

Table 6-5 compares the advantages and disadvantages of commonly used network configurations, see also Section 5.1.

Another important step in the planning of low-voltage switchgear installations consists of drawing up a power balance for each distribution point. Here, one needs to consider the following:

– nominal power requirement of consumers,
– short-time power requirement (e.g. motor startup),
– load variations.

The IEC recommendations and DIN VDE standards give no guidance on these factors and point out the individual aspects of each installation.

For power plants and industrial installations, the circumstances must be investigated separately in each case.

The following Tables 6-5 and 6-6 are intended as a planner's guide. The planners can use the information in Table 6-6 for reference.The total power is derived from the sum of the installed individual power consumers multiplied by the requirement factor with the formula:

$$P_{max} = \Sigma Pi \cdot g$$

P_{max} = power requirement
Pi = installed individual power producer
g = requirement factor

Table 6-5

Summary of network configurations and protection measures for low-voltage installations

System[1)]	Advantages	Disadvantages	Main application
TN system	Fast disconnection of fault or short circuit. Least danger for people and property.	High cost of wiring and cable due to protective conductors. Any fault interrupts operations.	Power plants, public power supply and networks.
TT system	Less wiring and cable required. Zones with different touch voltages permitted. Can be combined with TN networks.	Complex operational earthing ($\leq 2\ \Omega$). Equipotential bonding necessary for each building.	Livestock farming.
IT system	Less expensive in respect of wiring and cables. Higher availability: 1st fault is only signalled, 2nd fault is disconnected.	Equipment must be insulated throughout for the voltage between the outside conductors. Equipotential bonding necessary.	Hospitals Industry.
Total insulation	Maximum safety. Can be combined with other networks.	Equipment doubly insulated, economical only for small consumers. With heat-generating loads, insulation constitutes fire hazard.	Residential, small-scale switchboards and equipment
Safety extra-low voltage Functional extra-low voltage	No dangerous touch voltages.	Limited power with cost-effective equipment use. Special requirements for circuitry.	Small apparatus.

[1)]For definitions and block diagram of the systems, see Section 5.1.2

Table 6-6

Demand factor g for main infeed of different electrical installations

Type of installation or building	Demand factor *g* for main infeed	Remarks
Residential buildings		
Houses	0.4	Apply *g* to average use per dwelling.
Blocks of flats		Total demand = heating + a.c. + general.
– general demand (excl. elec. heating)	0.6 typical	
– electric heating and air-conditioning	0.8 to 1.0	
Public buildings		
Hotels, etc	0.6 to 0.8	Power demand strongly influenced by climate, e.g. – in tropics high demand for air-conditioning – in arctic high heating demand
Small offices	0.5 to 0.7	
Large offices (banks, insurance companies, public administration)	0.7 to 0.8	
Shops	0.5 to 0.7	
Department stores	0.7 to 0.9	
Schools, etc.	0.6 to 0.7	
Hospitals	0.5 to 0.75	
Places of assembly (stadiums, theatres, restaurants, churches)	0.6 to 0.8	
Railway stations, airports, etc.	no general figure	Power demand strongly influenced by facilities
Mechanical engineering		
Metalworking	0.25	Elec. drives often generously sized.
Car manufacture	0.25	
Pulp and paper mills	0.5 to 0.7	*g* depends very much on standby drives.
Textile industry		
Spinning mills	0.75	
Weaving mills, finishing	0.6 to 0.7	
Miscellaneous Industries		
Timber industry	0.6 to 0.7	
Rubber industry	0.6 to 0.7	
Leather industry	0.6 to 0.7	
Chemical Industry } **Petroleum Industry** }	0.5 to 0.7	Infeed must be generously sized owing to sensitivity of chemical production processes to power failures.
Cement works	0.8 to 0.9	Output about 3500 t/day with 500 motors. (Large mills with h.v. motor drives.)
Food Industry	0.7 to 0.9	
Silos	0.8 to 0.9	
Mining		
Hard coal		
Underground working	1	
Processing	0.8 to 1	
Brown coal		
General	0.7	
Underground working	0.8	

(continued)

Table 6-6 (continued)

Demand factor g for main infeed of different electrical installations

Type of installation or building	Demand factor *g* for main infeed	Remarks
Iron and steel industry		
(blast furnaces, convertors)		
Blowers	0.8 to 0.9	
Auxiliary drives	0.5	
Rolling mills		
General	0.5 to 0.8[1)]	[1)] *g* depends on number of standby drives.
Water supply } Ventilation }	0.8 to 0.9[1)]	
Aux. drives for		
– mill train with cooling table	0.5 to 0.7[1)]	
– mill train with looper	0.6 to 0.8[1)]	
– mill train with cooling table and looper	0.3 to 0.5[1)]	
Finishing mills	0.2 to 0.6[1)]	
Floating docks		
Pumps during lifting	0.9	Pumping and repair work do not occur simultaneously.
Repair work without pumps	0.5	
Lighting for road tunnels	1	
Traffic systems	1	Escalators, tunnel ventilation, traffic lights
Power generation		
Power plants in general		
– low-voltage station services	no general figure	
– emergency supplies	1	
Nuclear power plants		
– special needs, e.g. pipe heating, sodium circuit	1	
Cranes	0.7 per crane	Cranes operate on short-time: power requirements depend on operation mode (ports, rolling mills, ship-yards) .
Lifts	0.5 varying widely with time of day	Design voltage drop for simultaneous startup of several lifts

The *type of construction* depends on the station's importance and use (required availability), local environmental conditions and electromechanical stresses.

Construction	Main application
Type-tested draw-out switchgear	Main switching stations Emergency power distribution Motor control centres
Type-tested fixed-mounted switchgear	Substations a.c./d.c. services for h.v. stations Load centres
Cubicles or racks	Light/power switchboards Load centres
Box design	Local distribution, Miniature switchboards

The short-circuit currents must be calculated in terms of project planning activity, the equipment selected in accordance with thermal stresses and the power cable ratings defined. See also Sections 3.2, 7.1 and 13.2. Particularly *important is the selectivity* of the overload and short-circuit protection.

Selective protection means that a fault due to overloading or a short circuit is interrupted by the nearest located switchgear apparatus. Only then can the intact part of the system continue to operate. This is done by suitably grading the current/time characteristics of the protection devices, see also Sections 7.1.4,14.3 and 15.4. The choice of relays can be difficult if account has to be taken of operating conditions with powerful mains infeeds and comparatively weak standby power sources. In some cases changeover secondary protective devices have to be provided.

6.1.5 Calculation of short-circuit currents, computer-aided

A knowledge of the expected short-circuit currents in an installation is essential to the correct selection of the switching stations and the line-side connected networks. The methods of calculation are described in chapter 3.

The upper limit value of these fault currents determines:
– power ratings of the circuit-breaker,
– mechanical design of the installation,
– thermal design of the equipment,
– electrical design and configuration of earthing systems,
– maximum permissible interference in telecommunications systems.

The lower limit value of these fault currents determines:
– protective relays and their settings.

The calculation of short-circuit currents therefore helps to solve the following problems:
– dimensioning of equipment on the basis of (dynamic) stresses on closing and opening and also the thermal stress,
– designing the network protection system,
– questions of compensation and earthing,
– interference problems (e.g. in relation to telecommunications lines).

The CALPOS computer program enables simple but comprehensive calculation of short-circuit currents. It takes account of:
– different switching conditions of the installation,
– emergency operation,
– cold and hot states of the cable network,
– contribution of motors to short-circuit currents.

The program output provides the short-circuit currents at the fault location and in the branches

a) for the transient phase after occurrence of the fault:
– initial symmetrical short-circuit current I''_k,
– peak short-circuit current i_p,
– symmetrical short-circuit breaking current I_a.

b) for the steady-state phase after occurrence of the fault:
– sustained short-circuit current I_k,
– short-circuit powers S''_k,
– voltages at the nodes.

The results can be printed out both as phase values (L1, L2, L3) and as component values (1, 0, 2).

The comprehensive graphic functions offered by Calpos enable phase fault results to be displayed and plotted on the monitor as well as the network topology, see Fig. 6-3. The user creates and edits the graphic network display interactively with the mouse or the digitizing tablet. The calculation as done by the program closely follows the method described in Section 3.3 according to DIN VDE 0102/IEC 60909.

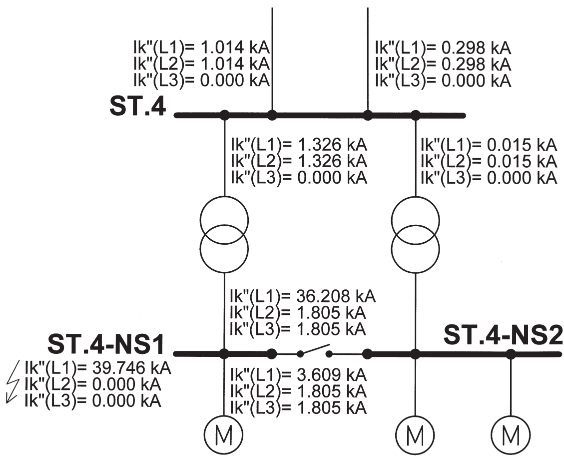


Fig. 6-3

Example of graphic output (plot) of a computer-supported short-circuit current calculation (partial section) done with the CALPOS program.

6.1.6 Calculation of cable cross-sections, computer-aided

Before the cross-sections of cables between the switchgear and their connected loads are finalized, they must be calculated in relation to the operating conditions and cable length.

Factors influencing the cross-section in this calculation are:

- permitted loadings under normal conditions, taking into account ambient temperatures and methods of laying,
- thermal short-circuit strength,
- permitted voltage drop along the cable run under normal conditions, and also during the starting phase when feeding motors,
- response of protective devices in the event of overloads and the smallest possible short-circuit current to interrupt dangerous touch voltages.

The ABB-developed LEIOP computer program and the matching Calpos module makes it possible to carry out this comprehensive calculation for every current circuit. By entering the circuit data, such as operating current, max. and min. short-circuit current, tripping currents/times of the protective devices and maximum permitted voltage drops, the program selects the appropriate minimum cross-section for the considered cable length. With the aid of program parameters, the range of cable types to be used can be limited, and a choice provided of the number of parallel cables for a given cable cross section. The method of calculation is in accordance with DIN VDE 0100, VDE 0276 and the respective cable manufacturer's data.

6.1.7 Planning of cable routing, computer-aided

The routing of cables in complex industrial installations, power plants and switching stations requires a great deal of work on the part of the planner. It involves arranging the cables to give the shortest path between their starting point and destination, while at the same time ensuring that certain combinations do not adversely influence each other.

The ABB program LEIOP offers very effective support here. It can provide data on the following:

- Cable lists
- Cable quantities incl. fittings (number of terminal ends, individual cable lengths)
- Cable markings
- Information on cable installation
- Information on tailoring cables for racks, trenches and conduit

6.2 Reference designations and preparation of documents

Two important series of standards in the last few years have guided the rules for the reference designation of equipment and the preparation of circuit documents. The symbols for individual equipments are specified in the series DIN 40900, and the series DIN 40719 regulates reference designation and representation.

The two series of standards have been or are being superseded due to international standardization in the IEC. DIN 40900 has been replaced by the series DIN EN 60617. The changes are minor, because DIN 40900 was already based on an earlier version of the international standard IEC 60617. The new revision corrects errors and includes essential supplementary symbols. The most important parts of DIN 40719 were superseded by DIN EN 61082 in 1996/97. Part 2 of DIN 40719, which covers the identification of electrical equipment, and Part 6, covering the area of function charts, are still applicable for Germany. The structure of reference designation systematics has been fundamentally revised on an international level. With the publication of DIN EN 61346-1, the first part – the basic rules – has already appeared. Part 2 with the important tables of code letters is currently in preparation. DIN 40719 Part 2 will remain in force until the German version is published. In the following section, the current designation systematics practice is reproduced virtually unchanged from the 9th edition, because this system is still used for extensions and for running projects. Section 6.2.4 gives an overview of future developments in reference designation systematics, in accordance with the new international standard IEC 61346.

6.2.1 Item designation of electrical equipment as per DIN 40719 Part 2

Four designation blocks are available to identify every single device (equipment) in the plant and in the circuit diagrams. They are distinguished by prefix signs.

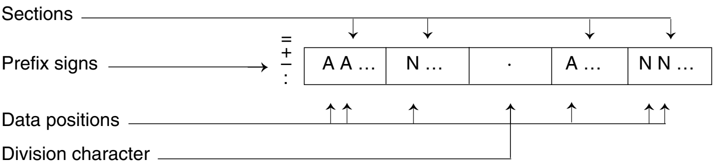
Prefix signs	Designation block
=	Higher level designation
+	Location of item
–	Type, number, function of the item
:	Terminal designation

Each designation block consists of a sequence of alphanumeric characters. It is divided into sections and each section into data positions. These signify:
A – an alphabetic data position (letter),
N – a numerical data position (digit).

Defined for each designation block are:

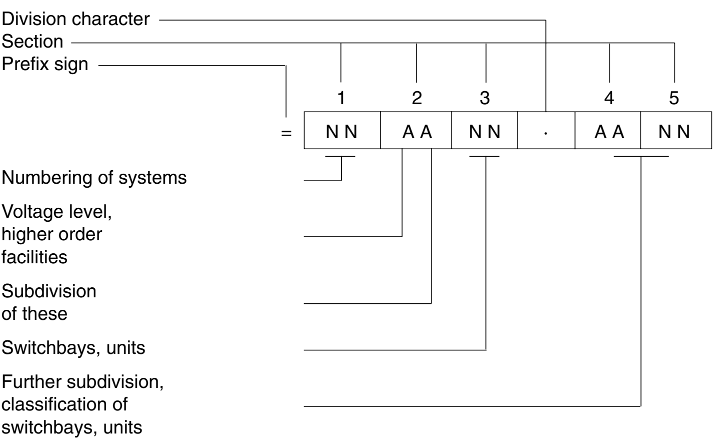
- the prefix signs,
- the maximum number of sections,
- the maximum number of data positions per section,
- the meaning of specific data positions in individual sections,
- whether and where an designation block is to be subdivided by the division character of a full stop (.) in order to split up its contents and make it easier to read.

The general structure of the four designation blocks is therefore as follows:



Designation block 'higher level'

The designation block for 'higher level' consists of five sections and is split between sections 3 and 4 by the division character (.). It begins on the left with the largest system component, and ends on the right with the smallest.

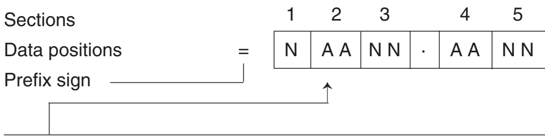


6

The meanings of the alphabetical data positions in section 2 are defined in the standard and can be seen in Tables 6-7 and 6-8.

Table 6-7

Letters for identifying voltage level in the designation block ‘higher level assignment’, 2nd section, 1st alphabetical data position (as Table C7 of DIN 40 719 Part 2).

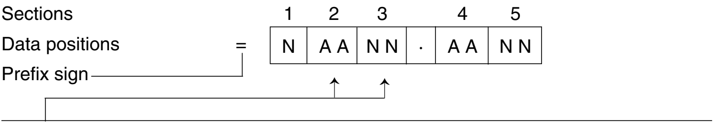


Identifying letter	System	
A	–	
B	> 420 kV	
C	380 kV to 420 kV	
D	220 kV to < 380 kV	
E	110 kV to < 220 kV	
F	60 kV to < 110 kV	
G	45 kV to < 60 kV	
H	30 kV to < 45 kV	
J	20 kV to < 30 kV	
K	10 kV to < 20 kV	
L	6 kV to < 10 kV	
M	1 kV to < 6 kV	
N	< 1 kV	
P	–	
Q	Facilities for measuring and metering	Facilities and systems not specifically referring to a branch or voltage
R	Facilities for protection	
S	–	
T	Facilities for transformers	
U	Facilities for control, signalling and auxiliary equipment	
V	–	
W	Facilities for control rooms	
X	Central facilities, e g process computers, alarm systems	
Y	Facilities for telecommunications	
Z	–	

Note: The letters A to N for voltage level are the same as in Table 6-9, but there they are used for a different identification purpose.

Table 6-8

Letters for identifying voltage levels < 1 kV in designation block ‘higher level assignments’, 2nd section, 2nd alphabetical data position when the letter N is defined for the first alphabetical data position in *Table 6-7* (as Table C9 of DIN 40719 Part 2)



Identifying letter	Meaning
N	Systems < 1 kV
NA	AC 500 to 1000 V
NB	AC 500 to 1000 V
NC	AC 500 to 1000 V
ND	–
NE	AC 400/230 V
NF	AC 400/230 V
NG	AC 400/230 V
NH	AC 400/230 V
NJ	–
NK	DC 220/110 V
NL	DC 220/110 V
NM	DC 220/110 V
NN	DC 220/110 V
NP	–
NQ	DC 60/48 V
NR	DC 60/48 V
NS	DC 60/48 V
NT	–
NU	DC 24/12 V
NV	DC 24/12 V
NW	DC 24/12 V
NX	–
NY	–
NZ	–

Designation block ‘location’

The ‘location’ designation block is qualified by a plus sign (+) and indicates where an item of equipment is situated, e.g. topographical site: building, room, cubicle, rack and position.

The designation block is divided into six sections:

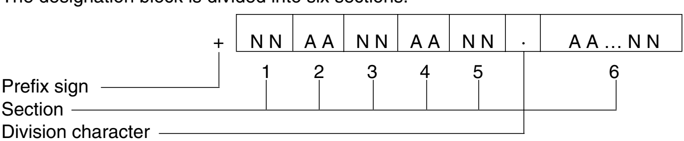


Table 6-9

Letters for identifying locations in designation block ‘location’, 4th section, 1st alphabetical data position (as Table C10 of DIN 40719 Part 2)

Sections		1	2	3	4	5		6
Data positions	+	N N	A A	N N	A A	N N	·	A A … N N
Prefix sign					↑			

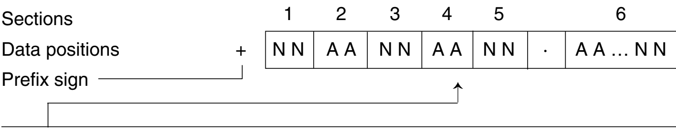
Identifying letter	Meaning
A	–
B	> 420 kV
C	380 to 420 kV
D	220 to < 380 kV
E	110 to < 220 kV
F	60 to < 110 kV
G	45 to < 60 kV
H	30 to < 45 kV
J	20 to < 30 kV
K	10 to < 20 kV
L	6 to < 10 kV
M	1 to < 6 kV
N	< 1 kV bays
P	Desks
Q	Boards and cubicles for measuring and metering
R	Boards and cubicles for protective devices
S	Boards and cubicles decentralized
T	Boards and cubicles for transformers
U	Boards and cubicles for control, signalling and auxiliary systems
V	Marshalling cubicles
W	Control room board
X	Boards and cubicles for central facilities, e. g. alarm systems and process computers
Y	Boards and cubicles for telecommunications
Z	–

Application: The letters A to N for voltage level are the same as in Table 6-7, but there they are used for a different identificatiaon purpose.

The designation block begins on the left with the unit of largest volume or construction, and ends on the right with the smallest.
The designation block can be subdivided by the division charakter (·) between sections 5 and 6.
To the left of the division character is information on the location (building, room, row, etc.) and the nature of the structural unit (bay, cubicle, rack).
To the right of the division character in section 6 is information on the position (row, column, etc.) of an item of equipment within the structural unit. Section 6 may have up to eight data positions (letters and numbers in any sequence).
The meanings of the alphabetical data positions in section 4 are shown in Tables 6-9

Table 6-10

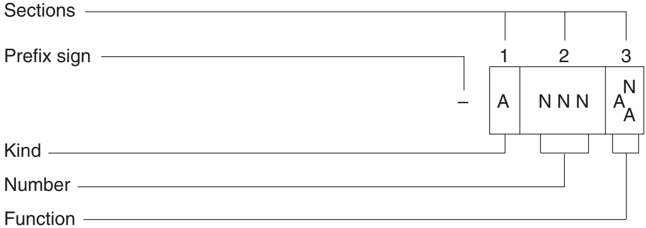
Letters for identifying application in designation block ‘location’, 4th section, 2nd alphabetical data position (as *Table C11* of DIN 40719, Part 2)



Identifying letter	Meaning
A	Circuit-breaker accessories
B	Multiply, re-position, decouple
C	Instrument transformer accessories
D	Compressed air, hydraulics
E	–
F	–
G	–
H	–
J	Automatic, closed-loop control
K	–
L	Simulating network, voltage selection
M	Measurement
N	System services
P	Recorder
Q	Metering
R	Protection
S	Synchronizing
T	Transformers
U	Auxiliaries
V	Main, secondary busbars etc.
W	Display, operation, supervision
X	Alarm system
Y	–
Z	–

Designation block 'identification of item'

The designation block for 'identification of item' is qualified by a hyphen (–) and consists of three sections.
Specified for the data positions in this designation block are the following symbols (letters and numbers) in the order given.



Section 1 identifies the kind of item as in Table 6-11.

Section 2 states the number of the equipment. Each item of equipment must be identified by a number of one to three digits.

Items of different kinds that belong together should be given the same number.

DIN 40719 Part 2 gives rules for the numbering of items in high-voltage switchgear installations, a distinction being made between numbers for

– switchgear in the main circuits (Table 6-12a)
– auxiliary devices which can be assigned to the switchgear in the main circuits (Table 6-12b)
– current and voltage transformers in the main circuits (Table 6-13)
– equipment which is specific to a branch but cannot be assigned to the main switchgear (Table 6-14).

If necessary, the function of an item of equipment can be identified in section 3. The following letters are specified for the alphabetical data position:
A – OFF function
E – ON function
L – conductor identification

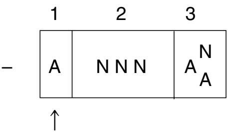
The other letters can be chosen arbitrarily.

The second data position for further subdivision/numbering can be occupied by an additional, arbitrarily chosen letter or number.

In the case of conductor identification, a distinction is made between a neutral identity LA, LB, LC and an identity assignable to the conductors L1, L2, L3. If neutral conductor identification is used, its assignment to L1, L2 and L3 must be stated in the circuit documentation.

Table 6- 11

Letters for identifying the kind of item *(as Table 1* of DIN 40719 Part 2)



Letter code	Kind of item
A	Assemblies, subassemblies
B	Conversion from non-electrical to electrical quantities and vice versa
C	Capacitors
D	Binary elements, delay devices, storage devices
E	Miscellaneous
F	Protection devices
G	Generators, power supply systems
H	Signalling systems
J	–
K	Relays, contactors
L	Inductors, reactors
M	Motors
N	Analogue elements as amplifiers, controllers
P	Measuring instruments, testing devices
Q	Switching devices for power circuits
R	Resistors
S	Switching devices for control circuits, selectors
T	Transformers
U	Modulators, converters from one electrical quantity to another
V	Tubes, semiconductors
W	Transmission paths, cables, busbars, hollow conductors, antennas
X	Terminals, plugs, sockets
Y	Electrically operated mechanical devices
Z	Terminations, bifurcations, filters, equalizers, limiters, balancing devices, bifurcation terminations

Table 6-12

Designation block ‘identification of item’

Table 6-12a (taken from *Table* C3 of DIN 40719 Part 2). Number for the designation of switchgear in the main current circuit in the title block “Type, number, function”, 2nd section, 1st and 2nd numeric data position.

	1	2	3
–	A	N N N	A N N

If in the 1st section, the letter “Q” as in *Table 6-11* is used for switchgear in the main circuit.

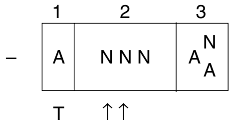
Table 6-12b (taken from *Table C4* of DIN 40 719 Part 2). Number for the designation of auxiliary devices that can be associated with the switchgear as in Table 6-12a in the title block “Type, number, function”, 2nd section, 1st and 2nd numeric data position.

	1	2	3
–	A	N N N	A N A

Kind of item	Designation	Control-discrepancy switch	Control button	
			open	closed
Circuit-breakers				
General	Q 0	S 0	S 0A	S 0E
1st circuit-breaker	Q01	S01	S01A	S01E
2nd circuit-breaker	Q02	S02	S02A	S02E
Bus system I				
Bus disconnector	Q 1	S 1	S 1A	S 1E
Bus-coupler disconnector, 2nd disconnector	Q10	S10	S10A	S10E
Bus sectionalizer	Q11…14	S11…14	S11…14	S11E…14E
Bus-earthing switch	Q15…19	S15…19	S15A…19A	S15E…19E
Maintenance earthing sw.				
General	Q 5	S 5	S 5A	S 5E
1st maint. earthing sw.	Q51	S51	S51A	S51E
2nd maint. earthing sw.	Q52	S52	S52A	S52E
Freely available neutral earthing switch, test disconnector	Q 6	S 6	S 6A	S 6E
Bypass bus				
Disconnector	Q 7	S 7	S 7A	S 7E
2nd disconnector	Q70	S70	S70A	S70E
Sectionalizer	Q71…74	S71…74	S71A…74A	S71E…74E
Earthing switch	Q75…79	S75…79	S75A…79A	S75E…79E
Earthing switches				
General	Q 8	S 8	S 8A	S 8E
1st earthing switch	Q81	S81	S81A	S81E
2nd earthing switch	Q82	S82	S82A	S82E
Feeder disconnector				
General	Q 9	S 9	S 9A	S 9E
1st feeder disconnector	Q91	S91	S91A	S91E
2nd feeder disconnector	Q92	S92	S92A	S92E

Table 6-13

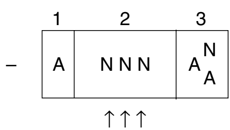
Number for identifying the application in designation block ‘identification’, 2nd section, 1st and 2nd numerical data position (as Table C5 of DIN 40 719 Part 2) if the letter “T” as in Table 5 is used in the section for instrument transformers in the main circuits.



Instrument transformers Kind of item	Designation	Kind of item	Designation
Current transformers		Voltage transformers	
Feeder transformers	T 1 to 4	Feeder transformers	T 5 to 9
Transformer bus I	T11 to 14	Transformer bus I	T15 to 19
Transformer bus II	T21 to 24	Transformer bus II	T25 to 29
Transformer bus III	T31 to 34	Transformer bus III	T35 to 39
Transformer bus IV	T41 to 44	Transformer bus IV	T45 to 49
Cable-type transformers			
General	T90		
1st transformer	T91		
2nd transformer	T92		

Table 6-14

Number for identifying purpose of non-assignable feeder-related auxiliaries in designation block ‘identification’, 2nd section, 1st, 2nd and 3rd numerical data position (as Table C6 of DIN 40719 Part 2)



Identifying letter as *Table 6-11,* three-digit number

Recommended categories for the three-digit number:
100 to 199 Station services 200 to 299 Control 300 to 399 Protection 400 to 499 Measurement from 500 arbitrary use
The number of auxiliaries in higher-order facilities and within branch-related combinations can be chosen at will.

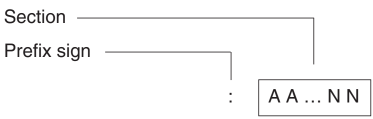
Composite items

To identify an item of equipment forming part of higher level equipment (composite item), the identifying designation blocks are arranged in sequence with the higher level equipment at the left. In the case of composite items, each item is given its own identity and the prefix sign of a hyphen (–) is repeated for each item, e.g. –QO-Y1 for a circuit-breaker –QO containing a tripping coil –Y1.

The numbers for equipment forming part of higher level equipment can be chosen arbitrarily, e.g. equipment in disconnector operating mechanisms, circuit-breakers, combinations, truck-mounted assemblies.

Designation block 'terminal'

The 'terminal' designation block has the prefix sign of a colon (:) and consists of one section.



The designation block contains the terminal identifications as stated on the equipment.

6.2.2 Preparation of documents

As per DIN EN 61082, "document" is defined as "information on a data medium"; "documentation" as:

– collection of documents related to a given subject, and
– processing of documents.

The "standard" classification for documents in electrical engineering as per DIN 40719 distinguishes between a) purpose and b) type of representation. The most important parts of DIN 40719 were superseded by DIN EN 61082 in 1996. This standard is a direct translation of the international standard IEC 61082 "Preparation of documents used in electrotechnology". Document classification is also covered here – including new terms in some cases. The following definitions of the new standard can be assigned to the term "purpose" in the old standard without problems:

– Function oriented documents
– Location documents
– Connection documents
– Item lists
– Installation-specific documents
– Other documents
– Commissioning-specific documents
– Operation-specific documents
– Maintenance-specific documents
– Reliability and maintainability-specific documents

Regarding the "type of representation", the new standard distinguishes the following types:

– Attached representation
– Semi-attached representation
– Detached representation
– Repeated representation
– Grouped representation
– Dispersed representation
– Multi-line representation
– Single-line representation

A distinction is also made between a "functional oriented layout" and a "topographical oriented layout" in the types of representations for circuit diagrams.

An important change from the former practice as per DIN 40719 is the strict separation of title block data and information on the reference designation (formerly equipment identification). Common designation blocks for represented equipment may no longer be given in the title block. Only data relevant to the document itself is given here now. Higher-order parts of the reference designation must be given at the specified positions in the drawing field (e.g. top left of the circuit diagram).

The following definitions from DIN 61082 / IEC 61082 and descriptions are given for some documents – important for substation engineering.

Overview diagram

An overview diagram is a relatively simple diagram often using single-line representation, showing the main interrelations or connections among the items within a system, subsystem, installation, part, equipment or software (Fig. 6-4).

The overview diagram of a switchgear should include, as the minimum information, the reference designation of the station components and of the equipment represented and also the most important technical data. The designation and cross-references to documents of a lower level should also be included.

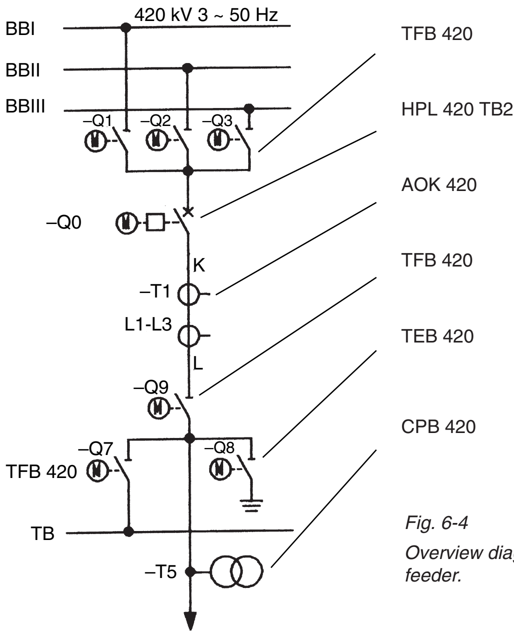


Fig. 6-4

Overview diagram of a 420 kV feeder.

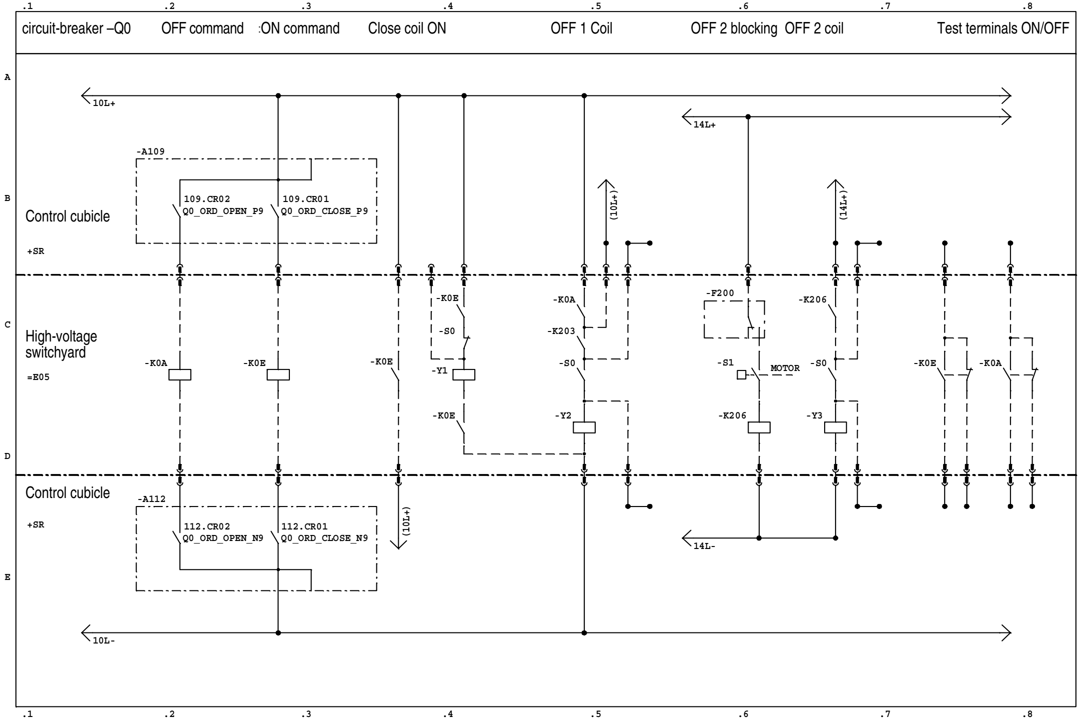
Function chart

A function chart is a diagram that describes the functions and behaviour of a control or regulation system using steps and transitions.

Circuit diagram

The circuit diagram is the diagram that shows the circuits of a functional or structural unit or an installation as they are implemented. The parts and connections are represented by graphical symbols. Their configuration must show the function. The size, shape and location of the equipment does not need to be considered (Fig. 6-5).

Fig. 6-5
Circuit diagram



The circuit diagram for a feeder or a functional unit is generally subdivided into function groups, such as control, position indication, interlocking, alarm, synchronization, protection, measuring etc. Above the current path, a short description of the represented subfunction using keywords is useful. The most important part of the circuit diagram is the information on following circuits or signals and notes on further representations.

Terminal function diagram
A circuit diagram for a functional unit, which shows the terminals for the interface connection and describes the internal functions. The internal functions may be shown or described in simplified form.

Arrangement drawing
A drawing showing the location and/or the physical implementation of a group of associated or assembled parts.

Terminal connection diagram
A diagram that shows the terminals of a construtional unit and the internal and/
or external connections.

6.2.3 Classification and designation of documents

The international standard IEC 61355 has the title “Classification and designation of documents for plants, systems and equipment”. The goal of this standard is described as follows in its introduction:

> *One aim of this standard is to establish a method for better communication and understanding between parties involved in document interchange. In order to get a basis for a system, it is necessary to disregard, more or less, what a document is called today. Different names are in use for the same document kind or the names may have different meanings for different parties. The purpose and object of interest are sometimes also part of document titles, which hampers general understanding. Therefore the basis for a common understanding should be a classification scheme which is based only on the content of information.*
>
> *Another aim of this standard is to set up rules for relating documents to the objects they describe. For this purpose a document designation system is provided, linking the document kind designation to the object designation used within the plant, system or equipment. Following the rules and recommendations given, the documentation reflects the structure of the “real installation”. By that also guidance is given for order and filing as well as for structured searching for information, for example in document retrieval systems.*

The principle of classification also covers the needs of computer-based documentation in general. An increasing amount of information will be stored and interchanged in a standardized data base format. The information to be delivered may be specified in such a way that each document kind required and agreed tby parties can be derived from that data base by the receiver's computer system.

This standard specifies a generally valid "Document kind Classification Code (DCC)" for the first time and explains it in a detailed table with examples – see the fields with grey background in the following table.
Documents are identified in accordance with the following scheme:

= + –	A .... N	&	A1	A2	A3	N	N	N	/	A	....	N

Object designation
Prefix sign
Identifying letters and numbers
Prefix sign
Counting numbers of sheets

The letter symbol "A1" stands for the Technical Area, e.g. "E" for electrotechnology; the letter symbol "A2" stands for the "Main Document Kind Class", e.g. "F" for function-describing documents; the letter symbol "A3" stands for the "Document Type Subclass", e.g. "S" for circuit diagram.
Object designation follows the rules of IEC 61346, and currently still DIN 40719-2. The page number after the prefix sign "/" has a maximum of six data spaces and can be formed by the customary procedure (e.g. "D" for power supply AC, or "N" for protection).
Table 6-15 shows examples of document kind classes from switchgear installation technology.

Table 6-15
Examples for documents in switchgear installations

Letter symbol 2^{nd} & 3^{rd} A position as per IEC 61355	Document kind; examples from switchgear installation technology
	Documentation describing documents
AA	Administrative documents: cover sheets, documentation structure, designation system
AB	Tables: lists of documents, lists of contents
	Management documents
B.	Document list, schedule, delivery list, training documentation, letters, memos
	General technical documents
DA	Dimension drawings, circuit diagrams for equipment
DC	Operating and maintenance instructions
	Technical requirements and dimensioning documents
E.	Environmental conditions, studies, calculations
	Function-describing documents
FA	Overview diagrams, network maps
FB	Flowcharts, block diagrams
FE	Function descriptions
FF	Function diagrams
FP	Signal descriptions, signal lists
FS	Circuit diagrams
FT	Software-specific documents
	Location documents
LD	Site plan, cable routing drawings, earthing plans, layouts, dispositions, sections
LH	Building plans
LU	Assembly drawings, arrangement drawings, equipment layout ˇˇ diagrams
	Connection-describing documents
MA	Terminal diagrams, connection diagrams, interconnection diagram
MB	Cable tables, cable lists
	Documents listing material
PA	Material lists (conduits, stranded wires, terminals, bolts ...)
PB	Parts lists, spare parts lists, lable lists
	Quality managment documents
QA	Test reports, test certifications, audit reports

6.2.4 Structural principles and reference designation as per IEC 61346

As noted in the introduction to Section 6.2, this section gives an outlook on the expected structural principles and reference designations in installations for energy distribution. The significance of this change from the former practice justifies this early explanation.

Formerly designation in installations was done with designation blocks and tables with a fixed arrangement for particular, specified data positions within the designation blocks. However, in future, the hierarchical structure will be in the foreground and at the centre. Hierarchical structures are characterized in that they build on “component relationships". The elements in a lower-order level in such a structure are always a complete component of the next higher level. The structure formed in this way can be depicted as a tree structure with nodes and branches (Fig. 6-6).

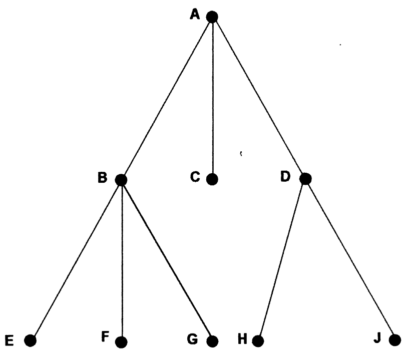


Fig. 6-6
Example of tree structure
B, C and D are components of A
E, F and G are components of B

The letters are for explanation only; they have nothing to do with any coding.

In its practical application for a switchgear installation, a structure will be implemented in accordance with the purpose under the following familiar classes: “association with voltage level” and “function”. Every object considered in a hierarchical structure, in fact the entire structure, the entire system itself can be considered from various points of view, referred to as “aspects”, e. g.:

- what it does;
- how it is constructed;
- where it is located.

With reference to these three types of aspect, the new designation system distinguishes system structures under the following three views:

- function-oriented structure;
- product-oriented structure;
- location-oriented structure.

Reference designations derived from this are identified with the allocated prefix signs "=", "–" and "+". Note the following: the functional identification "=" is used only for identifying pure functions, such as "= F" for "protection"; implementation with any product is not considered at this stage! An example of an application would be a neutral description independant of manufacturer as a request in a specification. In actual use this function might be implemented with, for example, the protection device "- F 312". Consultations have shown that it makes sense for equipment in installations of energy distribution to be designated under a product-based structure. Designation in the location-oriented structure "+" remains open for straight topographical information, such as waypoints, floors, room numbers, etc. The difference from the previous equipment designation is primarily that there is no combination of the designation blocks "=", "–" and "+".
An actuating element in a 380 kV control cubicle would for example be uniquely described with the reference identification **"– C3 – S1 – K1"** in the product-oriented structure.

6.3 CAD/CAE methods applied to switchgear engineering

The first CAD systems came on the market early in 1970. They were suitable for 2-dimensional design work, e.g. drafting circuit diagrams, circuit board layouts and simple design drawings. Now there is a wide variety of CAD workstations available, from low- to high-performance and all kinds of applications. Since 1970, CAD stations and methods have evolved into a powerful tool. This development process can be expected even to accelerate in coming years. The following section aims to explain the most important terms that have grown out of this new technology, and to give a general picture of the hardware and software systems employed. Attention is focused on the CAD methods used by ABB for switchgear engineering, together with examples.

6.3.1 Terminology, standards

Table 6-16 gives an outline of the principal CAD terms and their related fields of application.

Table 6-16

CAD terms, summary and applications

CIM	Computer-Integrated Manufacturing		
	CAE	Computer-Aided Engineering	
			Typical applications
		CAD Computer-Aided Design Computer-Aided Drafting	Design development; Preparation of drawings and calculation
		CAP Computer-Aided Planning	Production planning e.g. pricing and deployment
		CAM Computer-Aided Manufacturing	Production control e.g. parts lists, documentation for NC machines
	CAT	Computer-Aided Testing	Control of automatic testing; test reports

Depending on the degree of standardization, the solutions stored in the computer and the ability to help the designer find the right solution, CAD = Computer-Aided Drafting becomes a complete design system. By further processing of CAD data for manufacturing documents, production planning and testing, you can create a CAM or CIM system. Fig. 6-7 gives a general overview of the CAD areas in relation of the engineering and manufacturing, showing the possibilities for standardization in the preparation of circuit diagrams.

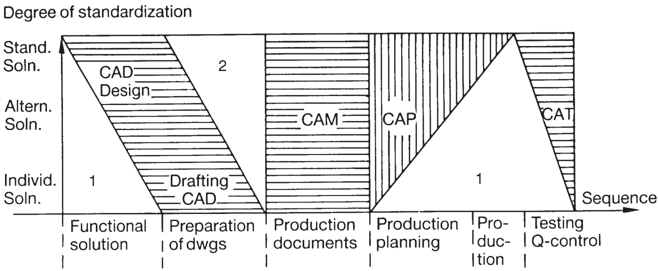


Fig. 6-7

Possibilities of standardization using CAD for producing circuit diagrams
hatching = CAD/CAE solutions
1 Preparatlon by hand, 2 Manual preparation is replaced by advancing use of CAE

Table 6-17

Overview of the most important CAD standards

Standard	Status	Working title
DIN V 40719 -1000	04/93	Rules for computer-supported creation of circuit diagrams
DIN EN 61355	11/97	Classification and identification of documents for installations, systems and equipment
DIN EN 61082-1 bis-4	*)	Documents of electrical engineering
DIN EN 61360-1, -2 und -4	*)	Standard data element types with associated classification scheme for electrical components
DIN EN 81714 -2	09/99	Generating graphic symbols for application in the documentation of products
DIN EN 60617-2 bis -13	*)	Graphic symbols for circuit diagrams

*) See Table 6-24

(continued)

Table 6-17 (continued)

Overview of the most important CAD standards

Standard	Status	Working title
DKE standard symbol file	04/96	Standard symbol file for graphic symbols according to DIN EN 60617 standards series based on DIN V 40900-100 and DIN V 40950
CAD-Lib		Standard library with standard mechanical parts
VDA-PS		FORTRAN interface for graphic design
IGES		Initial graphics exchange standard, interface for exchange of CAD data, emphasis in geometry
EDIF		Electronic data interface format for electrical engineering, emphasis on digital and analogue elements
DIN V 40950	08/92	Process-neutral interface for circuit-diagram data (VNS) Format for exchange of documentation of electrotechnical installations 2nd edition
ISO/IEC 10303		STEP Standard for the exchange of product-model data

In the last few years, the necessity of standards in the CAD area has been recognized at both national and international level. Table 6-17 contains an overview of the most important standards and drafts in the CAD area.

All interfaces are worked out at international level by the ISO (International Organization for Standardization) in TC 184 “STEP”, with application models for the various applications being processed in special working groups.

6.3.2 Outline of hardware and software for CAD systems

A CAD station consists of a computer with its immediate peripherals such as disk and cassettes, the dialogue peripherals and the CAD output devices. Tables 6-18 to 6-21 show selection criteria and the capabilities of components for CAD systems. The CAD workstation today is a single working place with central data storage at a server in the network.

Table 6-18

CAD computer system with directly connected peripherals (without plotter);

Main processor of the CAD computer	Application	Peripheral
Personal computer with graphics processors	2D/3D	Magnetic disk Floppy disk CD drive
Workstation with graphics processors	2D/3D	Magnetic disk Cassette drive

Table 6-19 Input/output devices of CAD systems

	Input device	Output device	Graphics	Alpha-numeric
Digitizer	×		×	
Plotter		×	×	
Laser printer		×	×	×
Passive graphics terminal		×	×	
Interactive alphanumer. terminal	×	×		×
Interactive graphics workstation	×	×	×	×

Table 6- 20

Alternative hardware components of an interactive graphics CAD terminal

Graphics display unit	Coordinate positioning and input	Command input, alphanumeric
– refresh rate > 75 Hz mono/colour 15” to 19” diagonal 1024 x 768 pixels	– electronic stylus with menu tablet – mouse	– A/N keyboard – predefined fields on menu – allocation of function keys – command menu display on screen, selection mouse (windows method)

Table 6-21

The important graphics output devices

Plotter principle	Format size	Output, quality	Plot production time
Electrostatic plotter, drawing resolved into dots	Height A4 to A0 Length up to 10 m	Multicolour, quality very good	1 to 2 minutes
Ink-jet plotter, Ink spray nozzle	A4 to A0	Multicolour, filled-in areas, quality average	Up to 1 hr, depending on information volume
Microfilm plotter	Up to A0	Film, quality very good	Measured in seconds, up to 1 minute to A1/A0
Laser printer/plotter	A4 to A0	Multicolour, quality very good	Seconds to minutes

The performance of CAD systems depends not solely on the hardware, but to a very large degree on the software. While the hardware generally determines the response time and processing speed, the software influences the methodology and how the applications function.

The bottom rung in the software hierarchy is the operating system level, which is usually provided by the hardware supplier. The CAD software constitutes the user software and is the second level in the software hierarchy. This user software is usually divided into a general CAD-oriented part and a problem-oriented part which takes into account the particular criteria and boundary conditions of the engineering task in hand. A CAD system for switchgear engineering thus includes problem-oriented user software for tasks such as

- station layout and planning,
- planning of buildings,
- preparation of circuit diagrams,
- cable systems,
- mechanical design

The computer is able to generate either 2D or 3D models.

Here,
2D means representation in one plane.

3D means true working in three dimensions, showing views from different angles and perspectives. A distinction is made between edge or wire models, surface and volume models.

The objectives of introducing CAD methods are as follows:

- Improved quality of engineering solutions and drawing documentation,
- Time savings on individual steps and entire project,
- Flexible handling of modifications,
- Technically safe, common standard variants and repeating solutions,
- Comprehensive use of EDP by linking CAD, CAM, CAP and CAT.

In any overall assessment of new CAD methods or systems, these advantages must be set against the preparatory work and requirements in each individual case:

- Analysis of present situation and structuring of tasks,
- Investment for hardware and software,
- Establishment of symbol and drawing library and databases,
- Training of engineering staff,
- Initial acceptance.

6.3.3 Overview of CAD applications in ABB switchgear engineering

ABB switchgear engineering has been using CAD methods for many years and on an ever increasing scale for planning tender and order processing. The CAD systems are subject to a continuous process of development to meet the continuing progress in the area of switchgears and the increasing use of digital station control systems.

Integration of the various CAD systems into an object-oriented environment is an essential requirement for optimizing the entire planning process. This extends from processing tenders to processing orders for commissioning and further to service. So also the documentation of the installation and archiving is included.

The CAD systems in use are based on CAD operating software, which can now generally run on different hardware platforms with different operating systems. In addition, problem-oriented application programs, mostly ABB-internal, have been developed to run with them. They are designed to meet the requirements of users and customers. The quality assurance of the process is shown in Fig. 6-8.

A number of CAD systems with varying internal system logic are available on the German market in the area of electrical engineering. A decisive point in selecting a CAD system, in addition to the straight hardware and software costs, is the expense of the training required and of establishing internal company databases for symbols and components. Other important criteria are the functionality of the CAD system, the options for connecting to the internal company processes and the supported interfaces.

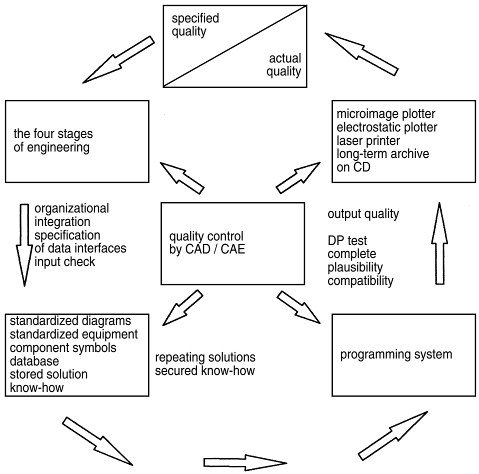
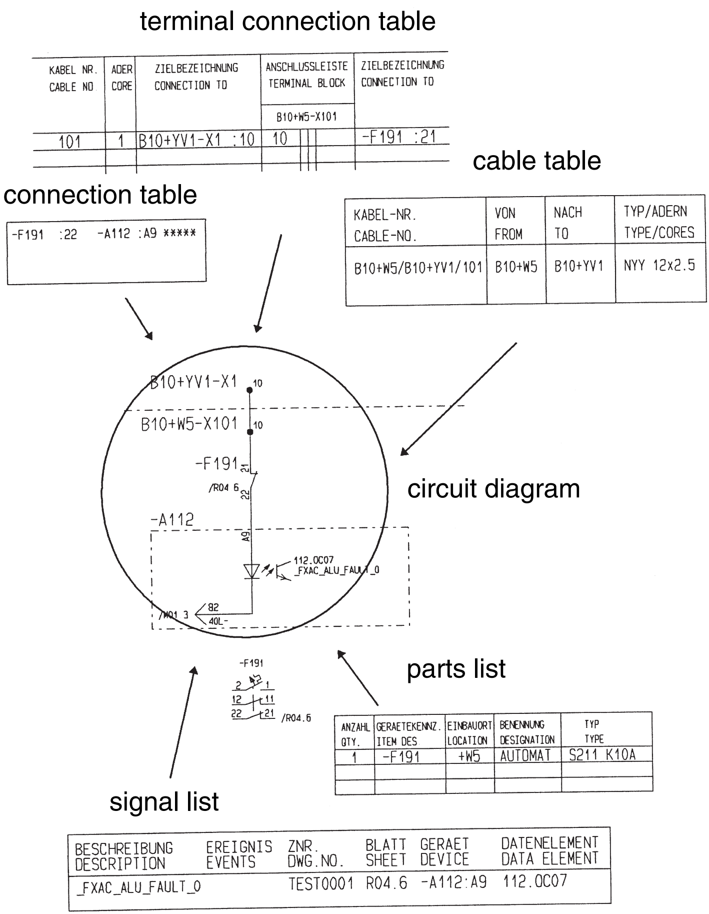


Fig. 6-8

Quality features of the CAD/CAE process. Quality loop with the engineering organization control functions, repeating solution, data processing testing and output technology.

The time sequence in switchgear engineering and the requirement for high-quality documentation (Fig. 6-9) demands the application of highly developed CAE techniques.



KABEL NR. CABLE NO	ADER CORE	ZIELBEZEICHNUNG CONNECTION TO	ANSCHLUSSLEISTE TERMINAL BLOCK B10+W5-X101	ZIELBEZEICHNUNG CONNECTION TO
101	1	B10+YV1-X1 :10	10	-F191 :21

-F191 :22 -A112 :A9 *****

KABEL-NR. CABLE-NO.	VON FROM	NACH TO	TYP/ADERN TYPE/CORES
B10+W5/B10+YV1/101	B10+W5	B10+YV1	NYY 12x2.5

ANZAHL QTY.	GERAETEKENNZ. ITEM DES	EINBAUORT LOCATION	BENENNUNG DESIGNATION	TYP TYPE
1	-F191	+W5	AUTOMAT	S211 K10A

BESCHREIBUNG DESCRIPTION	EREIGNIS EVENTS	ZNR. DWG.NO.	BLATT SHEET	GERAET DEVICE	DATENELEMENT DATA ELEMENT
_FXAC_ALU_FAULT_0		TEST0001	R04.6	-A112:A9	112.0C07

Fig. 6-9

Documentation automatically generated by CAD/CAE with cross references between circuit diagram, terminal connection table, cable table, connection table, parts list and signal list.

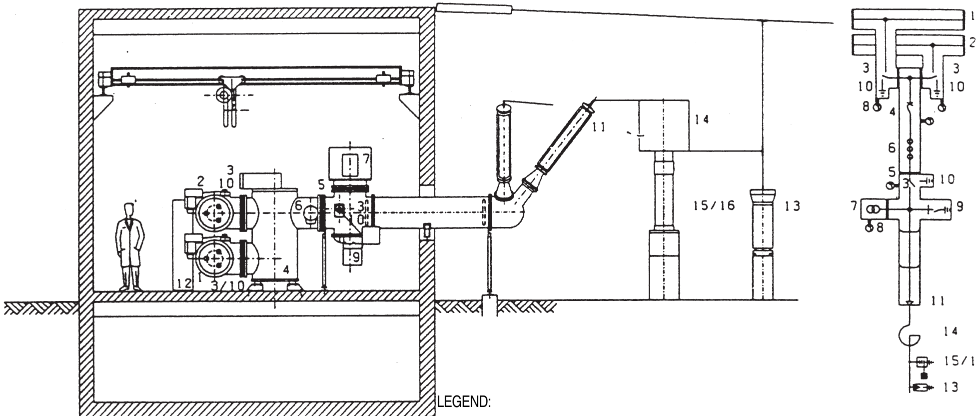
Interfaces for high-end data exchange are becoming increasingly important for CAD/CAE technologies. More and more customers today are demanding their documentation on electronic media. Particularly in Germany, the CAD system with which the documentation must be generated is frequently specified. For switchgear engineering, this is a significant restriction and above all, extremely cost-intensive. Today in particular, no company can afford to run several CAD systems internally in parallel for one application. The cost of hardware, software, administration and employment of trained staff for several systems is simply too high.

However, even within ABB, data must be forwarded to subcontractors and processed. This leaves only the subject of interfaces (and those high-end) as the only alternative for an efficient data exchange.

The standard IGES and DXF interfaces are suitable only for simple graphic data exchange. Higher-end interfaces such as VNS (process-neutral interface for circuit diagram data as per DIN V 40950 2nd edition) offer options for exchanging graphic and logical information between electrical CAD systems at a significantly higher level. A data exchange process that covers nearly everything has been developed with STEP (**ST**andard for the **E**xchange of **P**roduct model data as per ISO/IEC 10303). However, this also requires a general rethink among the software suppliers, because data exchange using STEP also requires STEP-conforming tools with object-oriented databases as a starting point. The first CAD suppliers have already started on this path. The interface properties defined as the application model for the various applications have already been published for mechanical engineering (AP 214) as a standard, and are in the process of being internationally approved for electrical engineering (AP 212).

Suitable CAD/CAE tools are also available for CAD and computer-supported processing of the primary engineering. Here the entire spectrum is being processed with the encapsulated medium-voltage substations of the voltage level from 6 kV to the 3-phase encapsulated GIS switchgears of the ELK-0 range to 170 kV up to outdoor switchgears to the 500 kV and even 800 kV maximum voltage levels. Various tools are also used here for the correspondingly varied requirements and developed structures at the various engineering locations. However, even these tools are embedded in the entire engineering process. It begins at tender preparation with automatic printout of tender documents; it includes the generation of the CAD drawings and contains check mechanisms; automatic generation of derived documents, drawings as well as material and order lists are also included. Finally, the process is complete after submission of the final documentation to the customer with long-term archiving.

Figs. 6-10 and 6-11 show disposition drawings prepared with CAD/CAE .



LEGEND:

1 =	BUSBAR I	9 =	HIGH-SPEED EARTHING SWITCH
2 =	BUSBAR II	10 =	EARTHING SWITCH
3 =	DISCONNECTOR	11 =	OUTDOOR BUSHING
4 =	CIRCUIT-BREAKER	12 =	LOCAL CONTROL CUBICLE
5 =	BARRIER INSULATOR	13 =	SURGE ARRESTER
6 =	CURRENT TRANSFORMER	14 =	REACTOR
7 =	VOLTAGE TRANSFORMER	15 =	PLC LINK
8 =	DENSITY MONITOR	16 =	COUPLING CAPACITOR

Fig. 6-10

Sectional elevation and gas diagram of a 145 kV GIS branch with cable basement and outdoor connection

Fig. 6-11 shows the plan view of a 123 kV switchyard created by using the CAD system, with double busbars and in-line layout.

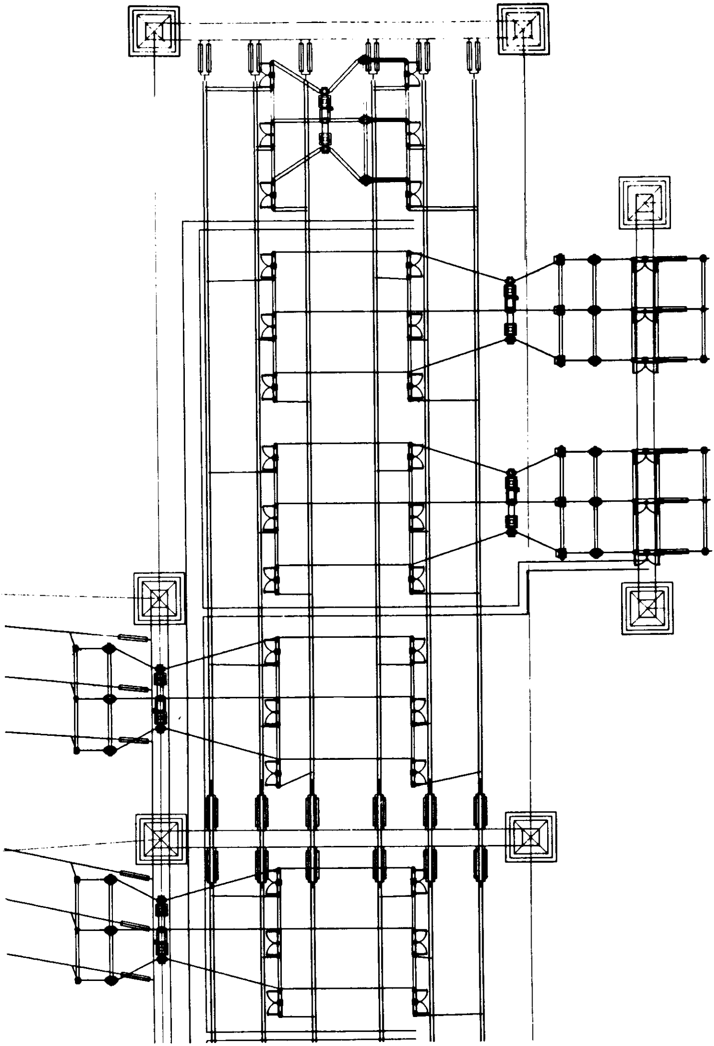


Fig. 6-11

123 kV outdoor switching station with double busbars, in-line layout

6.4 Drawings

In technical drawings the information required for constructing and operating an installation or a station component is given in a font that is “readable” for engineers and technicians. The drawings, or these days preferably referred to as documents, are therefore subject to specific, generally accepted rules and implementation guidelines, which are based on national and international standards. The specifications cover such items as:

– Paper formats, paper types
– Representation, symbols, characters
– Lettering, font sizes
– General design, header, metadata
– Document types, -identification and -order
– Creation of documents, processing
– Minimum content of documents

6.4.1 Drawing formats

Table 6-22

A-series formats as per DIN 6771-6, and ISO 5457

Format symbol	Size		Number of fields	
	cut	uncut	short side	long side
A0	841 x 1189	880 x 1230	16	24
A1	594 x 841	625 x 880	12	16
A2	420 x 594	450 x 625	8	12
A3	297 x 420	330 x 450	6	8
A4	210 x 297	240 x 330	4	6

Table 6-23

Continuous formats as per DIN 6771-6

Format symbol	Size		Number of fields	
	cut	uncut	short side	long side
A2.0	420 x 1189	450 x 1230	8	24
A2.1	420 x 841	420 x 880	8	16
A3.0	297 x 1189	330 x 1230	6	24
A3.1	297 x 841	330 x 880	6	16
A3.2	297 x 594	330 x 625	6	12

Continuous formats should be avoided as far as possible.
For formats >A0, see DIN 476.

6.4.2 Standards for representation

The rules for representation in electrical engineering documents are specified in DIN standards. There have been some modifications in connection with the incorporation of international standards since the last edition of the ABB manual; see also Section 6.2. Table 6-24 gives an overview of the most important DIN standards covering the preparation of electrical engineering documents.

Table 6-24
Overview of important DIN standards for the preparation of drawings

Standard or Part	Edition	Title
DIN 6-1, 6-2	12.86	Representation, views, sections
DIN 15-2, 15-3	12.86	Basics, lines
DIN 6771-1	12.70	Title blocks for drawings, plans and lists
DIN 6771-5	10.77	Standard forms for technical documentation; circuit diagram in A3 format
DIN 6776-1	04.76	Lettering, graphic characters
DIN 40719-2	06.78	Circuit documentation; reference designation of electrical equipment
DIN 40719-2 Sup. 1	06.87	Circuit documentation; reference designation of electrical equipment, alphabetically arranged examples
DIN 40719-6	02.92	Circuit documentation; rules for functional diagrams; IEC 848 modified
DIN EN 61082-1	05.95	Documents in electrical engineering – Part 1: General requirements
DIN EN 61082-1/A1	05.96	Documents in electrical engineering – Part 1: General rules, amendment 1
DIN EN 61082-1/A2	07.97	Documents in electrical engineering – Part 1: General rules, amendment 2
DIN EN 61082-2	05.95	Documents in electrical engineering – Part 2: Function-oriented diagrams
DIN EN 61082-3	05.95	Documents in electrical engineering – Part 3: Connection diagrams, tables and lists
DIN EN 61082-4	10.96	Documents in electrical engineering – Part 4: Location and installation documents
DIN EN 61346-1	01.97	Structuring principles and reference designations – Part 1: General requirements
DIN EN 61175	05.95	Designations for signals and connections
DIN EN 61355	11.97	Classification and designation of documents for plants, systems and equipment

(continued)

Table 6-24 (continued)
Overview of important DIN standards for the preparation of drawings

Standard or Part	Edition	Title
DIN EN 60617-2	8/97	Graphical symbols for diagrams; Part 2: Symbol elements and other symbols having general application
DIN EN 60617-3	08/97	Graphical symbols for diagrams; Part 3: Conductors and connecting devices
DIN EN 60617-4	08/97	Graphical symbols for diagrams; Part 4: Basic passive components
DIN EN 60617-5	08/97	Graphical symbols for diagrams; Part 5: Semiconductors and electron tubes
DIN EN 60617-6	08/97	Graphical symbols for diagrams; Part 6: Production and conversion electrical energy
DIN EN 60617-7	08/97	Graphical symbols for diagrams; Part 7: Switchgear, controlgear and protection devices
DIN EN 60617-8	08/97	Graphical symbols for diagrams; Part 8: Measuring instruments, lamps and signalling devices
DIN EN 60617-9	08/97	Graphical symbols for diagrams; Part 9: Telecommunications: switching and peripheral equipment
DIN EN 60617-10	08/97	Graphical symbols for diagrams; Part 10: Telecommunications: transmission
DIN EN 60617-11	08/97	Graphical symbols for diagrams; Part 11: Architectural and topographical installation plans and diagrams
DIN EN 60617-12	04/99	Graphical symbols for documentation; Part 12: Binary logic elements
DIN EN 60617-13	01/94	Graphical symbols for documentation; Part 13: Analogue elements
DIN EN 61360-1	01/96	Standard data element types with associated classification scheme for electric components – Part 1: Definitions - principles and methods
DIN EN 61360-2	11/98	Standard data element types with associated classification scheme for electric components – Part 2: EXPRESS data model
DIN EN 61360-4	06/98	Standard data element types with associated classification scheme for electric components – Part 4: IEC Reference collection of standardized data elements type, component classes and terms.

On a national german level the recommendations of the IG EVU, i.e. the “Energy Distribution Group”, have been developed into generally accepted rules with normative character for documentation of plants, process sequences and equipment.

6.4.3 Lettering in drawings, line thicknesses

Letter type B as per DIN 6776. Preferred font sizes: 2.5, 3.5, 5 and 7 mm (2 mm for CAD processing).

The font sizes, letter and line thicknesses must be selected so that the alphanumeric characters and lines are still easily readable at reduced reproduction sizes; this meets the requirements for microfilming drawings.

Table 6-25

Recommended line thickness (stroke widths in mm)

Line types		Recommended application of line thicknesses (mm)			
		A 4 / A 3	A 2 / A 1	A 0	
Thick	A G	0.5	0.7	1	1.4
Medium	D	0.25	0.35	0.5	0.7
Thin	B C E		0.25	0.35	0.5
Thick/Thin	F	0.25 / 0.5	0.25 / 0.7	0.35 / 1	0.5 / 1.4

Table 6-26

Recommended font sizes for drawings (mm)

Sheet size	Drawing title	Drawing number	Text, remarks	Item no.
A4 A3 A2	3.5-5	5 – 7	2.5 – 3.5	5 – 7
A1 A0	5 – 7	7	3.5 – 5	7

The above table values must be considered generally applicable typical values. The font sizes depend on the format. Once selected, the font size shall be retained for dimensions, positions, remarks, etc. within one drawing. A 2 mm font size is preferred for CAD-generated circuit documents.

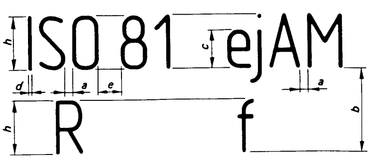


Table 6-27

Font style B (d = h / 10) to DIN 6776

Type		Ratio	Dimension in mm						
Letter height									
Upper case (capital)	*h*	(10/10) *h*	2.5	3.5	5	7	10	14	20
Lower case (small)	*c*	(7/10) *h*	–	2.5	3.5	5	7	10	14
(without ascenders/decenders)									
Minimum foot spacing	*a*	(2/10) *h*	0.5	0.7	1	1.4	2	2.8	4
Minimum line spacing	*b*	(14/10) *h*	3.5	5	7	10	14	20	28
Minimum word spacing	*e*	(6/10) *h*	1.5	2.1	3	4.2	6	8.4	12
Stroke width	*d*	(1/10) *h*	0.25	0.35	0.5	0.7	1	1.4	2

6.4.4 Text panel, identification of drawing

A drawing is a document which aids in setting up or operating an installation or a station component. It must therefore include identifications and data showing its content, status and origins.

- Origin, originator, release
- Date of production, if necessary with indication of source in view of patent claims
- Drawing number
- Subject of drawing (title block)
- Modification status
- Filing instructions, if appropriate
- Scale (for layouts, designs)
- Classification

From these indications and by filling out the text panel, it is confirmed that the relevant standards and quality specifications have been observed.

The identifier drawing number at ABB consists of a minimum of three alpha and seven numeric characters, whose position provides varying information.

Key to drawing number:

Sequence of symbols	N	A	A	A	N	N	N	N	N	N
Example:	1	H	D	E	3	3	1	2	3	4

Business Area Code to CS 9 ADA 11 — 1 H

Country code (Germany) — D

Organization unit: dept. etc. — E

Organization unit: group etc. — 3

Paper size: A3 — 3

Identification number: 0 … 9999 — 1234

If a drawing consists of several pages, e.g. circuit documentation manual, additional information is required, see Section 6.2.

6.4.5 Drawings for switchgear installations

The drawings are classified in the following groups, according to their function:

- Civil engineering drawings, architectural diagrams
- Layout drawings
- Design drawings, arrangement drawings, parts lists
- Circuit documentation
- Tables of contents, lists of drawings

Standard paper sizes are available for the different kinds of drawings, depending on their purpose. DIN format A3 with title block conforming to DIN 6771 Part 5 is preferred for circuit documentation and also for related switchboard arrangement drawings, tables etc.

Layout and design drawings have to be drawn to scale. Format and title block are selected in accordance with DIN 6771-1. Preferred scales are specified for the different kinds of installation and voltage levels (Table 6-28).

Table 6-28

Preferred scales

Design Layout	Scale
Outdoor installations	
Up to 525 kV	1 : 500; 1 : 200
Up to 245 kV	1 : 200; 1 : 100
Up to 145 kV	1 : 100; 1 : 50
GIS installations	1 : 50; 1 : 25 (not standardized)
Generator busducts	1 : 50; 1 : 20
Medium-voltage installations	1 : 20
Cubicles, inside arrangement	1 : 10
Other, details	1 : 5; 1 : 2.5; 1 :1
Enlargements	2 : 1; 5 : 1; 10 :1

6.4.6 Drawing production, drafting aids

The following methods are used for economical preparation of documents:

– CAD (Computer-Aided Design and Drafting) with drawings output by plotter, see Section 6.3

– CAE (Computer-Aided Engineering) with documents generated by computer programs and output by plotters, see Section 6.3.3, e.g. terminal diagrams, wiring lists, cable tables, etc.

– Drawing reproduction with photomachines

– Computer-aided microfilming (COM system)

7 Low-voltage Switchgear

7.1 Switchgear apparatus

Low-voltage switchgear is designed for switching and protection of electrical equipment. The selection of switchgear apparatus is based on the specific switching task, e.g. isolation, load switching, short-circuit current breaking, motor switching, protection against overcurrent and personnel hazard. Depending on the type, switchgear apparatus can be used for single or multiple switching tasks. Switching tasks can also be conducted by a combination of several switchgear units. Fig. 7-1 shows some applications for LV switchgear.

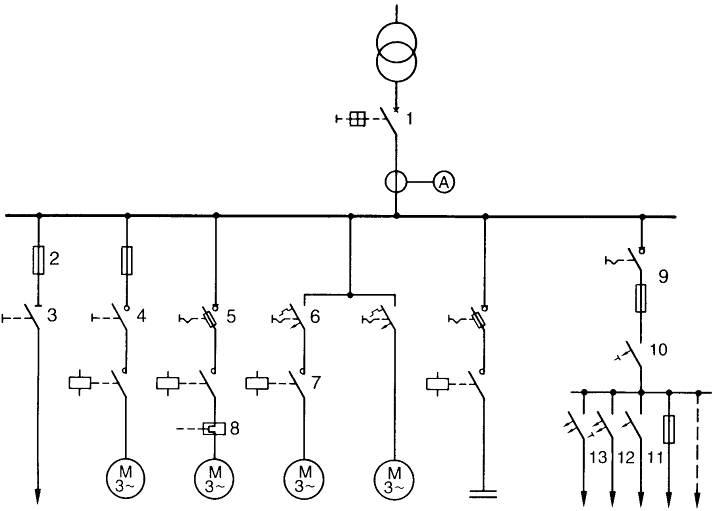


Fig. 7-1

Examples for use of low-voltage switchgear:

1 Circuit-breaker, general 2 Fuse, 3 Disconnector, 4 Loadbreak switch, 5 Fused switch-disconnector, 6 Motor starter (motor protection switch), 7 Contactor, 8 Overload relay, 9 Switch disconnector with fuses, 10 Residual current-operated circuit-breaker (RCCB), 11 Miniature circuit-breaker, 12 Residual current-operated circuit-breaker with overcurrent tripping (RCBO), 13* Residual current-operated miniature circuit-breaker (RCD)*

** Graphic symbols not standardized*

7.1.1 Low-voltage switchgear as per VDE 0660 Part 100 and following parts, EN 60947 – ... and IEC 60947 – ...

Table 7-1 shows a partial overview of the applicable standards for switchgear apparatus.

Table 7-4 of the utilization categories for contactors already corresponds to IEC 60947-4-1, because it has been supplemented with reference DIN VDE. Utilization categories for switchgear as per IEC 60947-3 are shown in Tables 7-6 and 7-7.

In accordance with the regulations, for all devices the rated voltages (formerly referred to as nominal voltages) are specified whose insulation voltages are assigned as test values. For example, devices up to 690 V have a test value of 2 500 V. The rated impulse voltage resistance U_{imp} must be shown on the switch or be included in the manufacturer's documentation. The design of a low-voltage system must ensure that no voltages can occur which are higher than the rated insulation voltages of the devices.

Table 7-1

Partial overview of the most important standards for low-voltage switchgear

	German standard [1]	Classification VDE 0660 [2]	European standard	International standard
General specification	DIN EN 60947-1	Part 100	EN 60947-1	IEC 60947-1
Circuit-breaker	DIN EN 60947-2	Part 101	EN 60947-2	IEC 60947-2
Electromechanical contactors and motor starters	DIN VDE 660-102	Part 102	EN 60947-4-1	IEC 60947-4-1
Switches, disconnectors, switch-disconnectors and fuse combination units	DIN VDE 660-107	Part 107	EN 60947-3	IEC 60947-3
Semiconductor contactors	DIN VDE 660-109	Part 109	–	IEC 60158-2 mod.
Multifunction equipment, automatic transfer switch	DIN VDE 0660-114	Part 114	EN 60947-6-1	IEC 60947-6-1
Multifunction equipment, control and protection switching devices	DIN EN 60947-6-2	Part 115	EN 60947-6-2	IEC 60947-6-2
Contactors and motor starters, semiconductor motor controllers and starters for AC	DIN EN 60947-4-2	Part 117	EN 60947-4-2	IEC 60947-4-2 mod.
Control devices and switching elements, electromechanical control circuit devices	DIN EN 60947-5-1	Part 200	EN 60947-5-1	IEC 60947-5-1

[1] Current valid designation
[2] Classification in VDE specifications system

Circuit-breakers

Circuit-breakers must be capable of making, conducting and switching off currents under operational conditions and under specified extraordinary conditions up to the point of short circuit, making the current, conducting it for a specified period and interrupting it. Circuit-breakers with overload and short-circuit instantaneous tripping are used for operational switching and overcurrent protection of operational equipment and system parts with low switching frequency. Circuit-breakers without overcurrent releases, but with open-circuit shunt release (0,1 to 1,1 Un), are used in meshed systems as „network protectors“ to prevent reverse voltages.

Circuit-breakers are supplied with dependent or independent manual or power actuation or with a stored-energy mechanism. The circuit-breaker is opened by manual actuation, electrical actuation by motor or electromagnet, load current, overcurrent, undervoltage, reverse power or reverse current tripping.

Preferred values of the rated control voltage are listed in Table 7-2.

Table 7-2

Preferred values of the rated supply voltage of control devices and auxiliary circuits as per DIN EN 60947-2 (VDE 0660 Part 101)

U_s DC voltage						AC single-phase voltage					
24	48	110	125	220	250	24	48	110	127	220	230

7

The major classification criteria of circuit-breakers are

– *by utilization categories*

A: without short-time grading of delay tripping for selectivity under short-circuit conditions

B: with intended short-time delay of short-circuit tripping (adjustable or non-adjustable)

– *by type of arc extinction medium*

Air, vacuum, gas

– *by design*

compact design or „moulded case“ type,
open design or „air-break“ type

– *by installation type*

fixed,
draw-out

– *by type of arc extinction*

current-limiting circuit-breaker,
non-current-limiting circuit-breaker

„Moulded case“ circuit-breakers consist of an insulation case that contains the components of the breaker. This type of breaker is designed for rated currents up to about 3 200 A.

“Open type circuit-breakers” or also “air-break circuit-breakers” do not have a compact insulation case. They are designed for rated currents up to 6 300 A.

Non-current-limiting circuit-breakers extinguish the arc at the natural alternating current zero crossing. The conducting paths are so dimensioned that they can conduct the full short-circuit current thermally. All downstream system components are also thermally and dynamically loaded with the unlimited peak short-circuit current.

Current limiting circuit-breakers interrupt the short-circuit current before it reaches the peak value of the first half-cycle. The peak short-circuit current is limited to a value (cut-off current I_D) that significantly reduces the thermal and dynamic stress on the downstream components. Fig. 7-2 shows the energy-limiting and current-limiting characteristics of a current-limiting circuit-breaker.

Current-limiting circuit-breakers, like fuses, are particularly suitable for short-circuit protection of switchgear with lower switching capacity (back-up protection).

Rated short-circuit currents: Rated-operating short-circuit current I_{CS}

Test duty: O – t – CO – t – CO

Rated-limiting short-circuit current I_{CU}

Test duty: O – t – CO

O = open; CO = close-open; t = dead time between operations (3 min)

Table 7-3

a) Recommended percentage values for I_{cs} based on I_{cu} as per DIN EN 60947-2 (VDE 0660 Part 101)

Utilization category A % of I_{CU}
25
50
75
100

Utilization category B % of I_{CU}
–
50
75
100

b) Ratio *n* between short-circuit-making and -breaking capacity and associated power factor (with alternating current circuit-breakers) as per DIN EN 60947-2 (VDE 0660 Part 101)

Short-circuit-breaking capacity I (rms value in kA)	Power factor	Minimum value for n $n = \frac{\text{Short-circuit-making capacity}}{\text{Short-circuit-breaking capacity}}$
$4.5 < I \leq 6$	0.7	1.5
$6 < I \leq 10$	0.5	1.7
$10 < I \leq 20$	0.3	2.0
$20 < I \leq 50$	0.25	2.1
$50 < I$	0.2	2.2

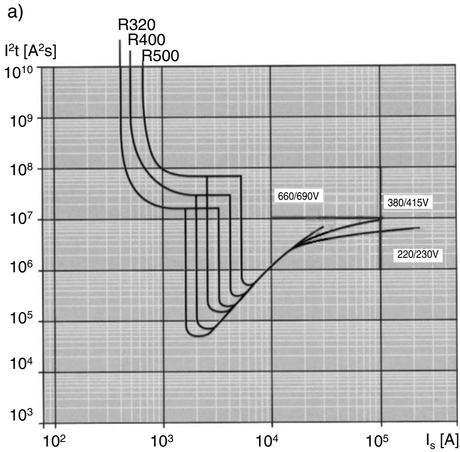


Fig. 7-2a

Limitation of let-through power I^2•t by a current-limiting circuit-breaker for I_n = 630 A with various tripping settings (R 320 to R 500)

I_s = short-circuit current, prospective r.m.s. values

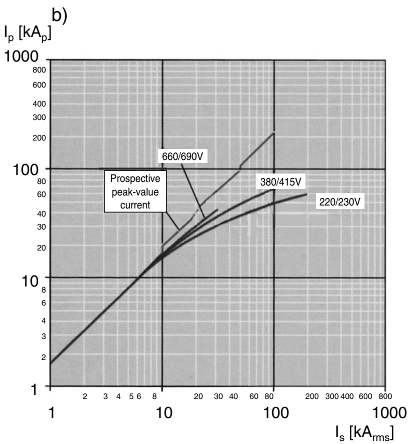


Fig. 7-2b

Limitation of the short-circuit current by a current-limiting circuit-breaker for I_n = 630 A with various service voltages

I_p = let-through current, peak current values
I_s = short-circuit current, prospective r.m.s. values

Contactors

Contactors are remote-control switching devices with restoring force, which are actuated and held by their actuator. They are primarily intended for high-switching frequency for switching currents with equipment in a healthy state, including operational overload. Contactors are suitable for isolation to a limited extent only, and they must be protected against short circuit by upstream protection equipment.

Apart from the electromagnetic actuation most often used, there are also contactors with pneumatic or electropneumatic actuation.

Contactors are selected by utilization categories, Table 7-4.

Table 7-4

Utilization categories for contactors as per VDE 0660 Part 102, EN 60947-4-1

Current type	Utilization category	Typical application
Alternating current	AC-1	Non-inductive or weak inductive load, resistance furnaces
	AC-2	Slip-ring motors: starting, disconnecting
	AC-3	Squirrel-cage motors: starting, disconnecting while running[1)]
	AC-4	Squirrel-cage motors: starting, plug braking, reversing, jogging
	AC-5a	Switching gas-discharge lights
	AC-5b	Switching incandescent lights
	AC-6a	Switching transformers
	AC-6b	Switching capacitor banks
	AC-7a	Weakly inductive load in household appliances and similar applications
	AC-7b	Motor load for household devices
	AC-8a	Switching hermetically sealed refrigerant compressor motors with manual reset of the overload release[2)]
	AC-8b	Switching hermetically sealed refrigerant compressor motors with automatic reset of the overload release[2)]
Direct current	DC-1	Non-inductive or weakly inductive load, resistance furnaces
	DC-3	Shunt motors: starting, plug braking, reversing, jogging, resistance braking
	DC-5	Series motors: starting, plug braking, reversing, jogging, resistance braking
	DC-6	Switching incandescent lights

1) Devices for utilization category AC-3 may be used for occasional jogging or plug-braking for a limited period, such as setting up a machine; the number of actuations in these circumstances shall not exceed five per minute and ten per ten minutes.

2) In the case of hermetically sealed refrigerant compressor motors, compressor and motor are sealed in the same housing without an external shaft or with the shaft sealed, and the motor operates in the refrigerant.

Table 7-5

Making and breaking capacity of contactors

Making and breaking conditions in accordance with the utilization categories[2)]as per DIN EN 60947-4-1 (VDE 0660 Part 102)

Utilization category	Making and breaking conditions			
	I_c/I_e	U_r/U_e	$\cos\varphi$	Number of switching cycles
AC-1	1.5	1.05	0.8	50
AC-2	4.0	1.05	0.65	50
AC-3	8.0	1.05	[1)]	50
AC-4	10.0	1.05	[1)]	50
AC-5a	3.0	1.05	0.45	50
AC-5b	1.5	1.05		50
AC-6a				
AC-6b				
AC-7a	1.5	1.05	0.8	50
AC-7b	8.0	1.05	[1)]	50
AC-8a	6.0	1.05	[1)]	50
AC-8b	6.0	1.05	[1)]	50
			L/R (ms)	
DC-1	1.5	1.05	1.0	50
DC-3	4.0	1.05	2.5	50
DC-5	4.0	1.05	15.0	50
DC-6	1.5	1.05		50

Utilization category	Making conditions for additional operations			
	I_c/I_e	U_r/U_e	$\cos\varphi$	Number of switching cycles
AC-3	10	1.05	[1)]	50
AC-4	12	1.05	[1)]	50

I	Making current. The making current is stated as direct current or symmetrical alternating current r.m.s. value, where with alternating current, the asymmetrical current may be higher.
I_c	Making and breaking current, stated as direct current or symmetrical alternating current r.m.s. value.
I_e	Rated normal current
U	Applied voltage
U_r	Power frequency recovery voltage or DC recovery voltage
U_e	Rated voltage
$\cos\varphi$	Test-circuit power factor
L/R	Test-circuit time constant

[1)] $\cos\varphi = 0.45$ for $I_e \leq 100$ a, $\cos\varphi = 0.35$ for $I_e \geq 100$ A

[2)] More information can be found in the standards listed in Table 7-1

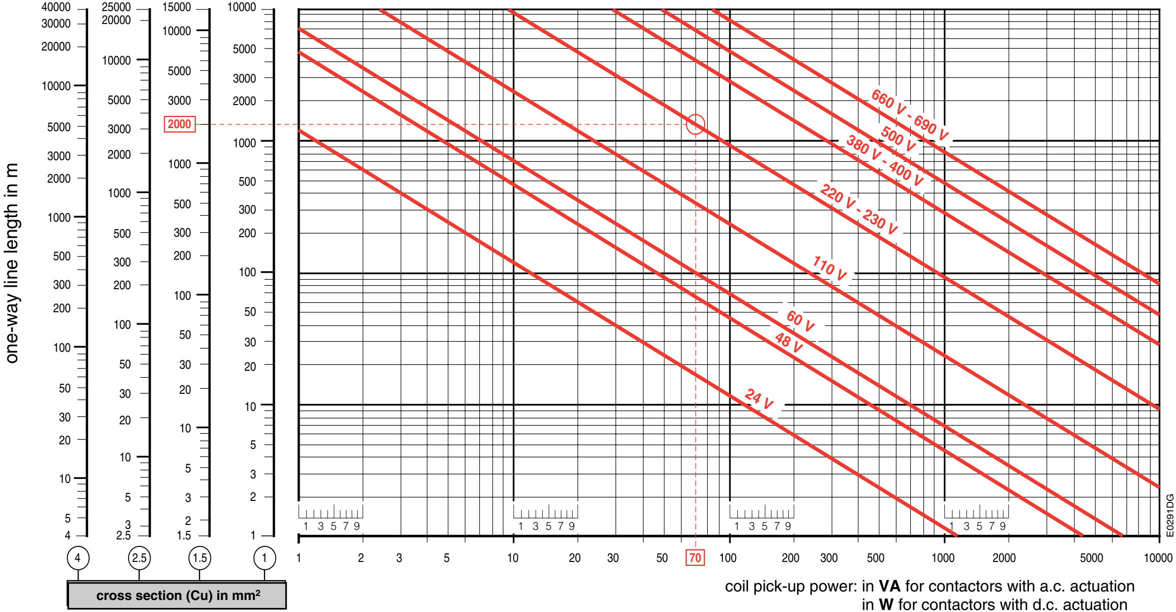


Fig. 7-3

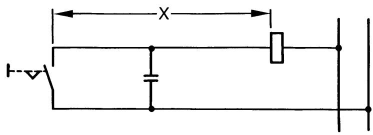
Permissible one-way control line length when closing contactors

Contactors are fitted with current-dependent protection devices to prevent thermal overload of motors. For protection against motor overload or in the event of external conductor failure, e.g. line break or blowing of only one fuse, the overload relays are set to the rated current of the motor. Modern overload relays have a temperature compensation facility to prevent interference from varying ambient temperatures affecting the trip times of the bimetallic contacts. They also have a phase failure protection; manual or automatic reset can be selected.

For preferred values for the rated supply voltage see Table 7-2. Protection must be actuated without problem within the voltage limits of 85 % and 110 % – with control current flowing.

When sending commands over long control lines, the contactor may not react to the command on closing because of excessive voltage drop (AC and DC actuation) or on breaking because of the excessive capacitance on the line (Fig. 7-4). A voltage drop of max. 5 % is permissible for calculating the length of the control line. The permissible line lengths for making and breaking can be determined using Figs. 7-3 to 7-5.

Circuit A:
Sending continuous commands over a two-core cable
(e.g. capacity 0.2 µF/km)
× = one-way line length



Circuit B:
Sending commands by push-button with locking contact,
three-core cable
(e.g. capacity 2 × 0.2 = 0.4 µF/km)
× = one-way line length

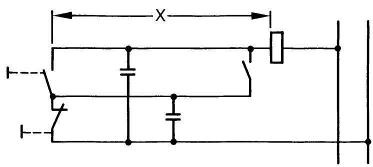


Fig. 7-4

Circuits for actuating contactor coils with line capacities

Example for Fig. 7-3:

Contactor A9, coil 230 V, 50 Hz, power input of coil of the contactor: 70 VA, cross section of the control wiring: Cu 1.5 mm^2,
Permissible line length: 2000 m

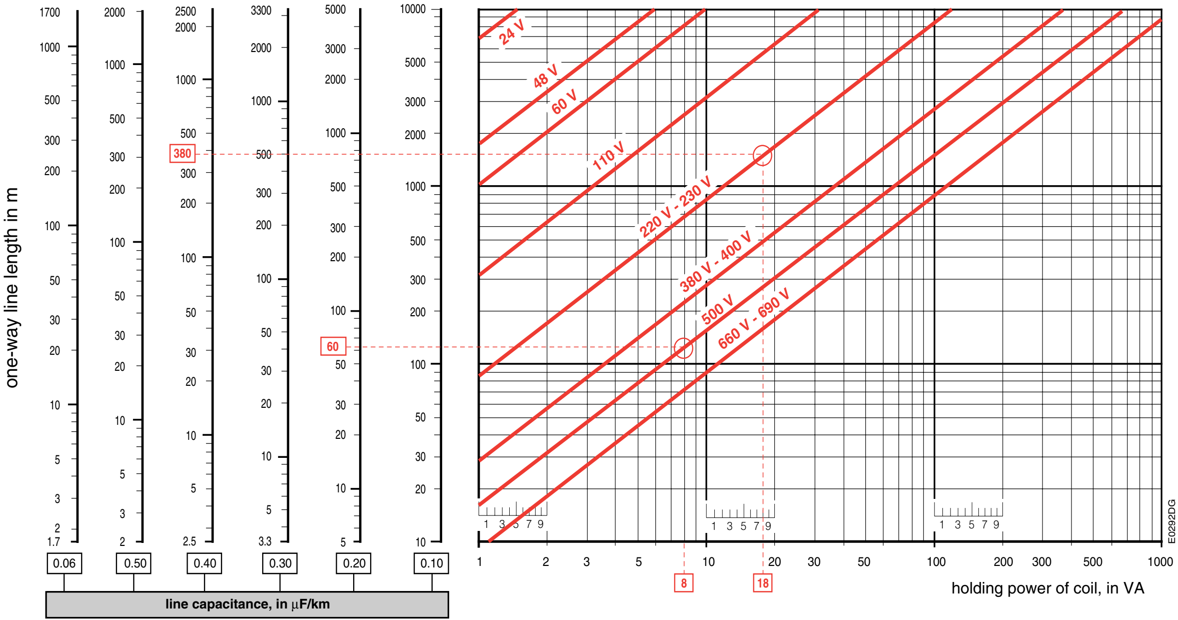


Fig. 7-5

Permissible one-way length for control lines when opening contactors

Example A for Fig. 7-5:

Contactor A 16, coil U_c = 500 V, 50 Hz,
Holding power of coil: 8 VA.

Continuous command via
two-core cable
with a capacity of 0.2 μ F/km
Max. permissible line length: 60 m

Example B for Fig. 7-5:

Contactor A 50, coil U_c = 230 V, 50 Hz
Holding power of coil: 18 VA.
Circuit with push-button
commands and locking contact
three-core cable with a capacity
of 2 x 0.2 μ F/km = 0.4 μ F/km
Max. permissibleble line length: 380 m

Motor starter

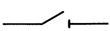
The motor starter is the term for the combination of all devices required for starting and stopping a motor in connection with appropriate overload protection.

Compact, manually operated motor starters, also referred to as motor protection switches, are suitable for switching short-circuit currents if they meet the conditions for circuit-breakers.

Motor starters can be actuated manually, electromagnetically, by motor, pneumatically and electropneumatically. They are suited for operation with open-circuit shunt releases, undervoltage relays or undervoltage tripping releases, delayed overload relays, instantaneous overcurrent relays and other relays or releases.

The rated normal current of a motor starter is dependent on the rated operating voltage, the rated frequency, the rated operating duty, the utilization category (Table 7-4) and the type of housing.

Other switchgear apparatus (DIN VDE 0660 Part 107)

Disconnector 

Switching devices that for safety purposes has isolating distances in the open position in conformity with specific requirements. A disconnector can only open and close a circuit if either a current of negligible quantity is switched off or on, or if there is no significant voltage difference between the two contacts of each pole. It can conduct normal currents under normal conditions and larger currents under abnormal conditions, e. g. short-circuit currents, for a specific period.

Note 1:

Currents of negligible quantity are capacitive currents, which occur at bushings, busbars, very short cables and the currents from voltage transformers and voltage dividers used for measurement purposes.

There is no significant voltage difference in circumstances such as shunting voltage-regulating transformers or circuit-breakers.

Note 2:

Disconnectors can also have a specific making and/or breaking capacity.

Load-break switch 

Switching device that under normal conditions in the current circuit, if applicable with specified overload conditions, can make, conduct and break currents and that under specified abnormal conditions such as short circuit can conduct these currents for a specified period.

Note:

> A load-break switch may have a short-circuit-making capacity, but no short-circuit-breaking capacity.

Switch-disconnector 

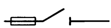
Load-break switch that meets the isolating requirements specified for a disconnector in the open position.

Disconnection (isolating function)

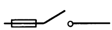
Function for isolating the voltage supply of the entire switchboard or system part, in which the switchboard or system part is disconnected from all energy sources for safety reasons.

Fuse combination unit

Load-break switch, disconnector or switch-disconnector and one or more fuses in a unit assembled by the manufacturer or in accordance with the manufacturer's directions.

Disconnector with fuses 

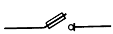
Unit comprising disconnector and fuses, in which one fuse is switched in series with the disconnector in one or more phases.

Load-break switch with fuses 

Unit comprising load-break switch and fuses, in which one fuse is switched in series with the load-break switch in one or more phases.

Fuse-disconnector 

Disconnector in which a fuse link or a fuse holder with fuse link forms the movable contact piece.

Fuse-switch disconnector 

Switch-disconnector in which a fuse link or a fuse holder with fuse link forms the movable contact piece.

Note 1:

The fuse may be located on both sides of the contacts or permanently fixed between the contacts.

Note 2:

All switches must have single break or multiple break operation

Note 3:

The graphic symbols correspond to IEC 60617-7

Various switching mechanisms

Dependent manual actuation

Actuation exclusively by human effort, so speed and power for the switching movement depend on the operator.

Independent manual actuation

Actuation by a stored-energy mechanism, in which the energy applied manually is stored as tension and released during the operating motion, so speed and power for the switching movement are independent of the operator.

Stored-energy operation

Actuation by energy stored in the actuating mechanism, which is sufficient to complete the switching operation under specific conditions. The energy is stored before the actuation begins.

Note:

Stored-energy mechanisms are differentiated by:
1. the type of energy storage (spring, weight etc.);
2. the type of energy source (manual, electrical etc.);
3. the type of energy release (manual, electrical etc.).

Table 7-6

Utilization categories for switchgear as per VDE 0660 Part 107, EN 60947-3 for alternating current

Utilization category		
frequent operation	occasional operation	typical application cases
AC-20A*)	AC-20B*)	close and open without load
AC-21A	AC-21B	switching resistive load including minor overload
AC-22A	AC-22B	switching mixed resistive and inductive load including minor overload
AC-23A	AC-23B	switching motors or other highly inductive load

*) See Table 7-7!

Table 7-7

Utilization categories for switchgear as per VDE 0660 Part 107, EN 60947-3 for direct current

Utilization category		
frequent operation	occasional operation	typical application cases
DC-20A*)	DC-20B*)	close and open without load
DC-21A	DC-21B	switching resistive load including minor overload
DC-22A	DC-22B	switching mixed resistive and inductive load including minor overload (e. g. shunt motors)
DC-23A	DC-23B	switching highly inductive load (e. g. series motors)

*) Application of these utilization categories are not permitted in the USA.
Utilization categories with B apply for devices that are only switched occasionally in accordance with their design or application. Examples are disconnectors that are only operated for disconnection during maintenance work or switching devices in which the contact blades of the fuse links form the movable contact.

Table 7-8

Verification of rated making capacity and rated breaking capacity. Conditions for making and breaking in accordance with utilization categories as per VDE 0660 Part 107, EN 60947-3

Current type	Utilization category	I_e A	Making[1)] I/I_e	U/U_e	cos φ	Breaking Ic/I_e	U_r/U_e	cos φ
Alternating current	AC-20	all values	[2)]	1.1	[2)]	[2)]	1.1	[2)]
	AC-21	all values	1.5	1.1	0.95	1.5	1.1	0.95
	AC-22	all values	3	1.1	0.65	3	1.1	0.65
	AC-23	≤ 17	10	1.1	0.65	8	1.1	0.65
		$17 < I_e \leq 100$	10	1.1	0.35	8	1.1	0.35
		> 100	8[3)]	1.1	0.35	6	1.1	0.35
Current type	Utilization category	I_e A	I/I_e	U/U_e	L/R (ms)	I_c/I_e	U_r/U_e	L/R (ms)
Direct current	DC-20	all values	[2)]	1.1	[2)]	[2)]	1.1	[2)]
	DC-21	all values	1.5	1.1	1	1.5	1.1	1
	DC-22	all values	4	1.1	2.5	4	1.1	2.5
	DC-23	all values	4	1.1	15	4	1.1	15

I making current
I_c breaking current
I_e rated normal current
U voltage before making
U_e rated operating voltage
U_r recovery voltage (between the terminals of the switching device)

1) With alternating current, the making conditions are expressed as rms values, where the peak value of the asymmetrical current can take a higher value depending on the power factor of the current circuit.

2) If the switching device has a making and/or breaking capacity, the values of the current and of the power factor (time constant) must be stated by the manufacturer.

3) However it must be at least 1000 A.

7.1.2 Low-voltage fuses as per VDE 0636 Part 10 and following parts, EN 60269 – ... IEC 60269 – ...

Fuses are protection devices that open a current circuit by the melting of one or more fusible elements and break the current if it exceeds a specific value for a specific period. Low-voltage fuses are classified by their operating classes and designs, Table 7-9.

Table 7-9

Structure of standards of the VDE series 0636 for low-voltage fuses.

VDE 0636 Part 10[1] (EN 60269-1, IEC 60269-1) Low-voltage fuses, general requirements		
Operational classes / Designs	Cable and line protection gG	Apparatus protection aM, gTr, gB
NH System	VDE 0636 Part 201	VDE 0636 Part 201
D System	VDE 0636 Part 301	VDE 0635
DO system	VDE 0636 Part 301	

1) Future title of this standard DIN EN 60269-1 (VDE 0636 Part 10)

The first letters identifies the breaking range:

g – General purpose fuses can continuously conduct currents up to their rated current and can disconnect currents from the smallest fusing current to the rated breaking capacity,

a – Back-up fuses can continuously conduct currents up to their rated current and can disconnect only currents above a specific multiple of their rated current.

The second letter identifies the application; this letter determines the time-current characteristic

G – for general application
M – for the protection of motor current circuits and switchgear
R – for protection of semiconductor components (VDE 0636 Part 40)
Tr – transformer protection (VDE 0636 Part 2011)
B – mine substation protection (VDE 0636 Part 2011)
D – fuse links with delay } North American practice
N – fuse links without delay }

For rated voltages and rated currents see Table 7-10.

The time response of fuse links depending on the breaking current that causes the fuse to melt and interrupt is shown in time/current characteristics, Fig. 7-6.

The ínterrupting behaviour of the fuse links is characterized by the small test current (I_{nf} – no fusing during the test period) and the large test current (I_f – interruption during the test period), Table 7-11.

Table 7-10

Rated voltages and rated currents of fuse links
(DIN VDE 0636 Part 10), standardized values as per IEC 60038 are underlined

AC voltage										
Series I	<u>220/230</u>		<u>380/400</u>		500		<u>660/690</u>	V		
Series II	<u>120</u>	208	240	<u>277</u>	415	<u>480</u>	600	V		
DC voltage	<u>110</u>	<u>125</u>	<u>220</u>	<u>250</u>	<u>440</u>	450	500	<u>600</u>	<u>750</u>	V

Current I_n	2 4 6 10 16 20 25 32 35 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1 000 1 250 A

Table 7-11

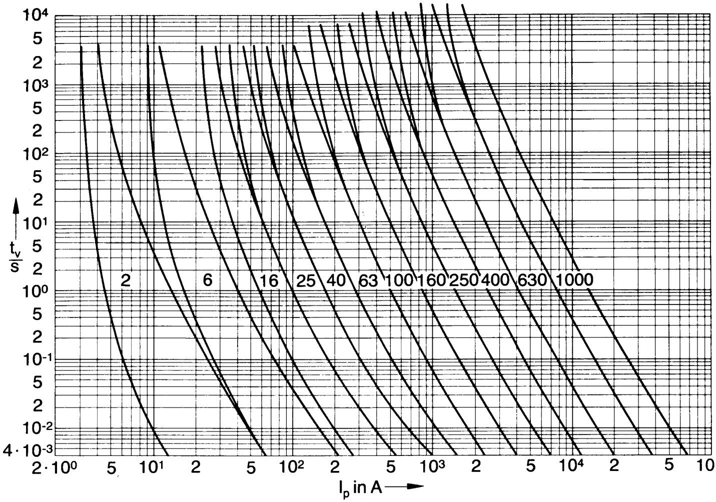
Test periods and currents for gG and gM fuse links
as per VDE 0636 Part 10 and VDE 0636 Part 201

Rated current I_n with gG Characteristic current I_{ch} with gM [1)] A	test period h	test current I_{nf}	 I_f
$I_n \leq 4$	1	1.50 I_n	2.1 I_n
$4 < I_n < 16$	1	1.50 I_n	1.9 I_n
$16 \leq I_n \leq 63$	1	1.25 I_n	1.6 I_n
$63 < I_n \leq 160$	2	1.25 I_n	1.6 I_n
$160 < I_n \leq 400$	3	1.25 I_n	1.6 I_n
$400 < I_n$	4	1.25 I_n	1.6 I_n

[1)] I_{ch}: with gM fuse links the time/current characteristic is specified through gates in Table 3 DIN VDE 0636 Part 10.

With short-circuit current, fuses limit the short-circuit current before the peak value is reached, see current limitation diagram, Fig. 7-7.

Fuse links whose rated currents are in the ratio of 1:1.6 respond selectively up to 690 V rated voltage at rated currents ≥ 16 A.



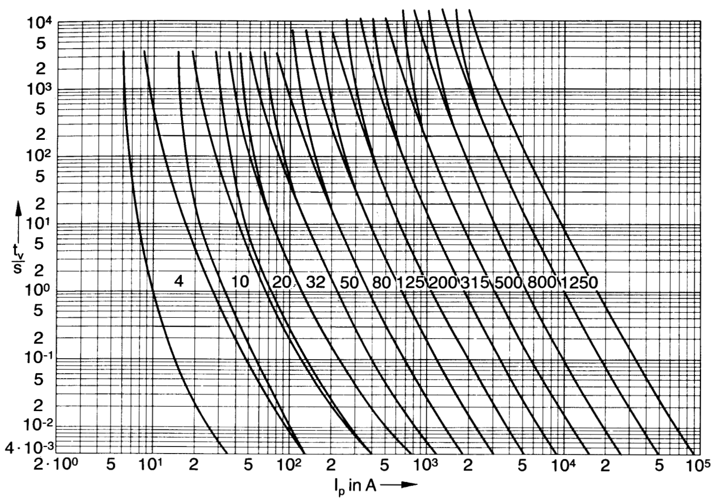


Fig. 7-6

Time/current characteristics for HRC fuse links of duty class gG
a) 2 to 1000 A, b) 4 to 1250 A, as per VDE 0636 Part 201

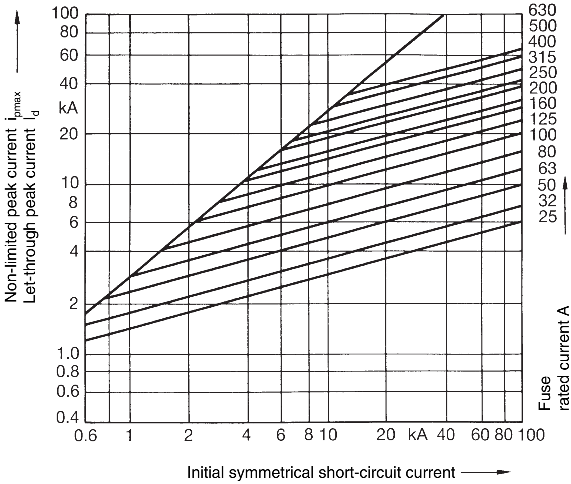


Fig. 7-7

Current limitation diagram

Low-voltage heavy-duty (HRC) fuses

For an overview of the sizes, fuse bases/fuse rails and associated rated currents of the fuse links, see Table 7-12.

The breaking capacity must be at least 50 kA. HRC fuses with a nominal breaking capacity of at least 80 kA to more than 100 kA are available on the market. HRC fuse links must have an indicator to show the status of the fuse.

With HRC fuse links of duty class gTr, the rated power of the three-phase transformer that is to be protected takes the place of the rated current. In kVA: 75, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, Table 7-13.

Table 7-12

Rated currents for HRC fuse bases and fuse rails and also for gG fuse links (VDE 0636 Part 201), values in brackets = deviations for aM usage

Size	HRC fuse bases A	HRC fuse rails A	HRC fuse links ~ 400 V ~ 500 V A	~ 690 V A
00	160	160	6 to 160 (100)	to 100
0	160	160	6 to 160	to 100
1	250	250	80 to 250	to 200 (250)
2	400	400	125 to 400	to 315 (400)
3	630	630	315 to 630	to 500 (630)
4	1000	–	500 to 1000	to 800 (1000)
4a	1600	–	500 to 1600	to 1000 (1250)

The time/current ranges for gTr HRC fuses are adjusted to the time /current ranges for gG HRC fuses so that gG HRC fuses are selective for upstream gTr HRC fuses when the rated currents of the gG HRC fuses are not larger than those in Table 7-14.

Table 7-13

Rated values for HRC fuse links of the gTr operational class, 400 V (VDE 0636 Part 2011)

Duty class	Size	HRC fuse links[1)] S_n in kVA[2)]
gTr	2	50 to 250
	3	250 to 400
	4a	400 to 1 000

1) Links for smaller power ratings are allowable, larger are not included in this standard.

2) With gTr fuses, the rated current of the fuse link corresponds to the rated current of the protected transformer and is calculated with the following formula:

$$I_n = \frac{S_n}{\sqrt{3}\, U_n}$$

with: I_n in A
S_n in kVA
U_n = ~ 0.4 kV

Table 7-14

Rated currents for selectivity of HRC fuses on the transformer low-voltage side (VDE 0636 Part 2011)

Rated apparent power S_n of the transformer kVA	Rated current I_n of the gTr fuse link A	Maximum rated current I_n of the gG fuse link A
50	72	50
75	108	80
100	144	100
125	180	125
160	231	160
200	289	200
250	361	250
315	455	315
400	577	400
500	722	500
630	909	630
800	1 155	800
1000	1 443	1000

Fuses, D and DO system

Table 7-15 shows an overview of the rated voltages and rated currents for these screw-type fuses. The required breaking capacity is 50 kA for alternating current and 8 kA for direct current.

The colour coding of the indicator for the status of the fuse is listed in Table 7-16.

D-fuses E 16 for rated currents of up to 25 A and rated voltages of up to 500 V according to DIN 57635 (VDE 0635) are used for measurement and control equipment. In addition, VDE 0635 is significant with reference to UC 750 V and rated currents up to 100 A for mining applications and in electric railways.

Table 7-15

Rated voltages and rated currents for screw-type fuses
to DIN VDE 0636-301 (VDE 0636 Part 301)

System	Fuse mount Fuse caps Rated current (A)	Fuse links Rated current (A)	Gauge pieces Rated current (A)
D 500 V	25, 63, 100	2, 4, 6, 10, 16, 20, 25, 35, 50, 63, 80, 100	2, 4, 6, 10, 20, 25, 35, 50, 63, 80, 100
D ~ 660 V = 600 V	63	2, 4, 6, 10, 16, 20, 25, 35, 50, 63	2, 4, 6, 10, 16, 20, 25, 35, 50, 63
DO ~ 380 V = 250 V	16, 63, 100	2, 4, 6, 10, 16, 20, 25, 35, 50, 63, 80, 100	2, 4, 6, 10, 20, 25, 35, 50, 80

Table 7- 16

Colour of indicator (DIN VDE 0636-301)

Rated current of fuse link A	Colour of indicator
2	pink
4	brown
6	green
10	red
16	grey
20	blue
25	yellow
35	black
50	white
63	copper
80	silver
100	red

As per VDE 0638, the fuse-combination unit, DO system, is specified as a factory-assembled combination of a switch part and a fuse part. The switching properties of these devices are classified under the utilization categories AC 21 and AC 22 in Tables 7-6 and 7-8.

7.1.3 Protective switchgear for household and similar uses

These switching devices are suitable for protection of lines and cables, apparatus and persons; they are modular built-in devices, which are primarily designed for snap fitting on mounting channels (e.g. to EN 50022) or for fastening with screws. This switchgear is used in building installations and in industry.

Miniature circuit-breakers, DIN VDE 0641-11 (EN 60898, IEC 60898)

Miniature circuit-breakers are manually actuated, primarily current-limiting switches with fixed magnetic and delayed thermal tripping. They disconnect the current circuit from the network independently if a preset current value is exceeded. Miniature circuit-breakers for line protection are supplied as one- to four-pole units and one- and three-pole units with connected neutral conductor. Available accessories are control switches, shunt releases and remote-control mechanism. DIN VDE 0641-11 applies for alternating current miniature circuit-breakers for operation in air at 50 and 60 Hz with a rated voltage not exceeding 440 V, a rated current not exceeding 125 A and a rated breaking capacity not exceeding 25 kA. Miniature circuit-breakers should be labelled in accordance with Fig. 7-8.

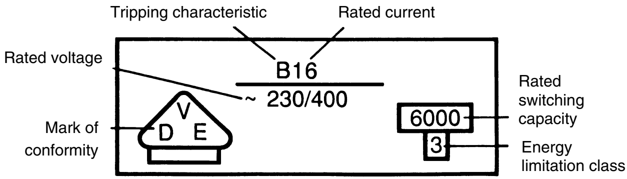


Fig. 7-8

Recommendation for lettering on miniature circuit-breakers according to DIN VDE 0641-11

The energy limitation class – there are 3 classes, 1, 2, 3 – characterises the degree of short-circuit current limitation for circuit-breakers of up to 32 A. There are three tripping characteristics - B, C and D - specified for standard circuit-breakers.

Circuit-breakers with other tripping characteristics such as K for motors, transformers, lamps, etc. or Z for semiconductor protection and line protection of long control lines have a thermal tripping characteristic, which is similar to that in DIN VDE 0660-101. The magnetic tripping range is set corresponding to the starting currents with K at 10 to 14 I_n and with Z, to ensure instantaneous tripping even at low overcurrents, at 2 to 3 I_n. Fig. 7-9 shows the tripping characteristics B, C, D, and K and Z.

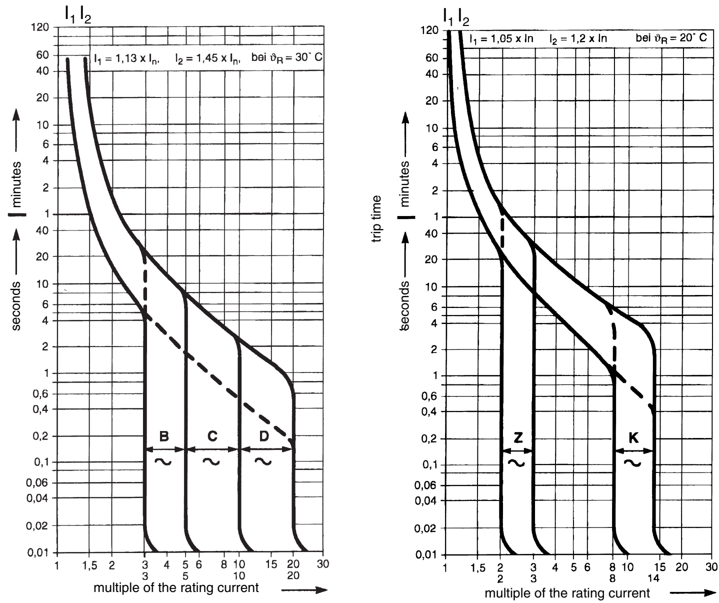


Fig. 7-9

Examples for tripping characteristics of miniature circuit-breakers:
a) tripping characteristics B, C, D,
b) tripping characteristics K, Z.

Residual current-operated protective devices, RCD, general term

Overview of classification:

AC AC fault current

A AC fault current and pulsating DC fault current

B AC fault current, pulsating DC fault current and smooth DC fault current.

Overview of different constructions:

RCCB Residual current-operated circuit-breaker without integral overcurrent protection for household and similar uses.*)

RCBO Residual current-operated circuit-breaker with integral overcurrent protection for household and similar uses.*)

SRCD Residual current device without integral overcurrent protection, incorporated in or associated with fixed socket-outlets.

PRCD Portable residual current devices without integral overcurrent protection for household and similar uses.

*) In Europe, only devices that are functionally independent from the system voltage can have a mark of conformity (exception: GB, IR, NL).

Residual current-operated circuit-breaker, RCCB, DIN EN 61008-1 (VDE 0664 Part 10), IEC 61008-1

RCCB circuit-breakers are switching devices for the protection of persons, pets and farm animals and property (fire protection) against electric shock.

They break when a set value of the rated fault current is exceeded.

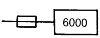
In Germany, only residual current-operated circuit-breakers of Class A for AC and pulsating DC fault currents are approved. In addition they must not be functionally dependent on the system voltage.

In other European countries, residual current-operated circuit-breakers of Class AC for AC fault currents only may be encountered.

Conventional residual current-operated circuit-breakers are tripped within 0.3 s in the event of rated residual currents and within 0.04 s at 5 times rated residual current.

A selective residual current-operated circuit-breaker is tripped selectively in time to downstream residual current-operated protective devices and in this way provides high supply security, because in the event of malfunction only the affected current circuit is initially tripped.

For short-circuit protection, the system must be additionally protected upstream the residual current-operated circuit-breaker by an overcurrent protection device. The designation



means that the residual current-operated circuit-breaker is protected against short-circuit by an upstream primary miniature circuit-breaker or an upstream fuse of 63 A up to a prospective short-circuit current of 6000 A.

If the residual current-operated circuit-breakers have the character , they can be used in a temperature range of – 25 °C to + 40 °C.

Identification of residual current-operated circuit-breakers:

[≈]	Type A for AC and pulsating DC fault currents
[~]	Type AC for AC fault currents
-25	For low temperatures Temperature range – 25 °C to + 40°C
[S]	Selective type (delayed tripping)

Residual current-operated circuit-breaker with integral overcurrent protection, RCBO, DIN EN 61009-1 (VDE 0664 Part 20), IEC 61009-1

RCBOs are combinations that automatically disconnect the current circuit at all poles from the network if the preset values for fault, overload and short-circuit current are exceeded. With rated fault currents of 10 mA and 30 mA, these switching devices are ideal protection devices for socket current circuits.

7.1.4 Selectivity

In most cases, several overcurrent protection devices are connected in series between the current source and the apparatus to be protected in case of a short circuit. These devices must operate selectively to limit a fault to the place of its origin as far as possible. Full selectivity means:

– Operational current spikes must not result in disconnection.

– When functioning properly, only the protection device nearest the fault in the supply direction shall respond.

– If this protection device malfunctions, the next protective device in the series must respond.

Selectivity can generally be determined theoretically by comparison of the breaking characteristics in the overload range and the time-delayed operating characteristics of the upstream circuit-breaker. Selectivity limits between circuit-breakers without time-delayed short-circuit tripping or with fuses should be experimentally confirmed.

Full selectivity is operational between two or more overcurrent protection devices when the protection device nearest to the failure in the supply direction trips selectively up to its rated breaking capacity. *Partial selectivity* means that this protection device will trip selectively only up to a specific short-circuit current.

Selectivity fuse – fuse

Fuses generally respond selectively when their time-current characteristics do not touch. This requirement is usually met when grading the fuse current ratings in the ratio 1:1.6.