8. Switchgear and switchgear installations for high voltage up to and including 52 kV (medium voltage)

8.1 Switchgear apparatus (≤ 52 kv)

This voltage range is generally referred to as “medium voltage”, even though the term has not been standardized anywhere.

The principal terms relating to switchgear are defined in Section 10.1.

8.1.1 Disconnectors

The classic design of the disconnector is the knife-contact disconnector (Fig. 8-1). It has become less common with the increasing use of withdrawable circuit-breakers and switch-disconnectors. This functional principle is now again becoming more frequent in gas-insulated switchboard technology.

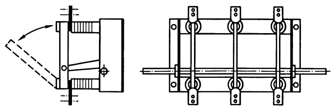


Fig. 8-1
Medium-voltage knife-contact disconnectors

The blades of knife-contact disconnectors installed in an upright or hanging position must be prevented from moving by their own weight.

Disconnectors can be actuated manually and, in remotely operated installations, by motor or compressed-air drives.

8.1.2 Switch-disconnectors

Switch-disconnectors are increasingly being used in distribution networks for switching cables and overhead lines. Switch-disconnectors in connection with HV fuses are used for protection of smaller transformers.

Switch-disconnectors are switches that in their open position meet the conditions specified for isolating distances. General purpose switches can make and break all types of operating currents in fault-free operation and in the event of earth fault. They can also make and conduct short-circuit currents.

a) b)

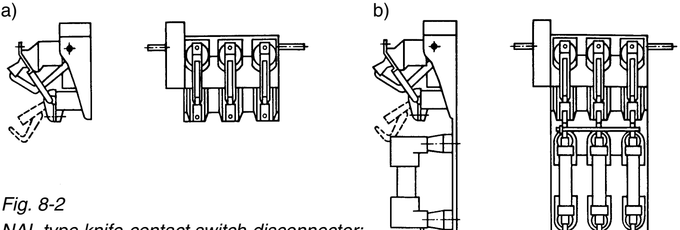


Fig. 8-2
NAL type knife-contact switch-disconnector:
a) without and b) with fuse assembly

a) b)

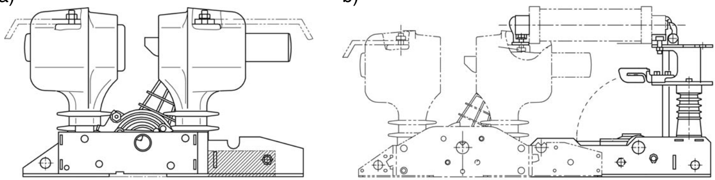


Fig. 8-3
C4 rod-type switch-disconnector: a) without and b) with fuse assembly

Knife-contact switch-disconnectors (Fig. 8-2) and rod-type switch-disconnectors (Fig. 8-3) are actuated in two ways:

a) “Snap-action mechanism”, also referred to as toggle-spring mechanism. With this type of operating mechanism, a spring is tensioned and released shortly before the operating angle is completed and its release force actuates the main contact systems. This is used for both closing and opening.

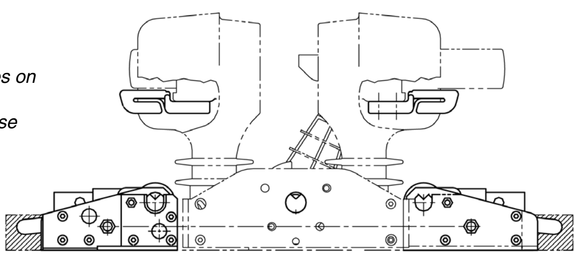
b) “Stored-energy mechanism”. This mechanism has one spring for closing and a second spring for opening. During the closing operation, the opening spring is simultaneously tensioned and latched. The stored energy for the opening operation is released by magnetic trips or the striker pin of the HV fuse.

The rod-type switch-disconnector is particularly suitable for the design of compact switchbays, because the knife-contact switch-disconnector requires a greater depth for the switching zone because of the projecting contact blade in its open state. The rod-type switch-disconnectors also enable very small phase spacings without phase barriers.

8.1.3 Earthing switches

Earthing switches are installed in switchbays primarily near cable boxes, i. e. before the main switching device. However, earthing switches are often specified also for busbar earthing, for example in metering panels. If the main switching device is a switch-disconnector, the earthing switch and the switch-disconnector will often be on a common base frame (Fig. 8-4).

Fig. 8-4
Configuration of earthing switches on the switch-disconnector base frame



Every earthing switch must be capable of conducting its rated short-time current without damage. “Make-proof” earthing switches are also capable of making the associated peak current at rated voltage. For safety reasons, make-proof earthing switches are recommended with air-insulated switchboards because of possible faulty actuations (DIN VDE 0101, Section 4.4). In gas-insulated switchboards, the earthing of a feeder is often prepared by the earthing switch and completed by closing the circuit-breaker. In this case, a make-proof earthing switch is not required.

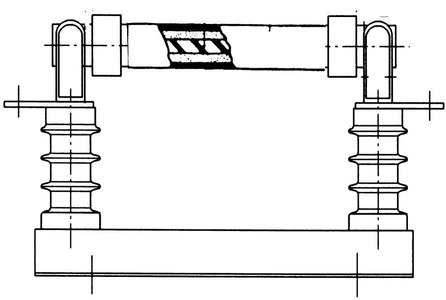
8.1.4 Position indication

Because disconnectors, switch-disconnectors and earthing switches are very important to the safety of the isolation of cables, lines and station components, there are special requirements for their position indication. It is true that the switch contacts themselves no longer need to be visible, but actuation of indicators or control switches must be picked up directly at the switch contacts or at a connecting point downstream of any operating spring on the power kinematic chain. (DIN EN 60 129 (VDE 0670 Part 2 Appendix 4)).

8.1.5 HV fuse links (DIN EN 60 282-1 (VDE 0670 Part 4))

The load current flows in fuse links through narrow silver conductor bands, which are arranged spirally in a sealed dry quartz sand filling in the interior of an extremely thermally resistant ceramic pipe. The conductor bands are designed with a narrower cross-section at many points to ensure that in the event of an overcurrent or short-circuit current, a defined melting will occur at many points simultaneously. The resulting arc voltage ensures current limiting interruption in case of high short-circuit currents.

Fig. 8-5
Fuse base with fuse link



The cap-shaped end contacts of the HV fuse link are picked up by the terminal contacts of the fuse base. HV fuse links can be fitted with indicators or striker pins, which respond when the band-shaped conductors melt through. The striker pin is required for mechanical tripping of the switching device when used in the switch/fuse combination (DIN EN 60 420 (VDE 0670 Part 303)).

Characteristic current values for HV fuse links:

Rated current

The majority of fuse links in operation have a rated current ≤ 100 A. For special applications with smaller service voltages (e.g. 12 kV), fuse links up to 315 A are available. The associated melt-through times of the fusible conductors are found from the melting characteristics (manufacturer information for the range of the interrupting currents) (Fig. 8-6).

Rated breaking current

This value must be provided by the manufacturer of the fuse link. It is influenced by the design for a specified rated current. When selecting fuse links for transformer protection in distribution systems, the maximum breaking current is not a critical quantity.

Rated minimum breaking current

Classification of fuse links into three categories

- *Back-up fuses*
  Smallest breaking current (manufacturer information) in general at 2.5 to 3.5 times rated current. Suited for application in switch/fuse combinations. Very common!
- *General purpose fuses*
  The minimum breaking current is that which results in melt-thRough after 1 hour or more of exposure time (generally twice the rated current).
- *Full-range fuses*
  Every current that results in a melt-through can be interrupted.

Cut-off current characteristic

The maximum value of the current let-through by the fuse depends on its rated current and the prospective short-circuit current of the system. Fig. 8-7 shows a characteristic field.

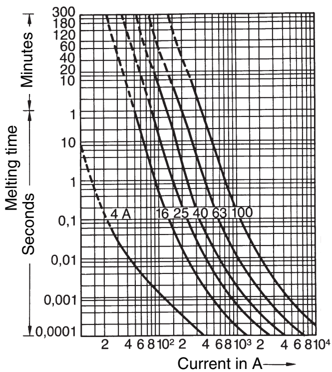


Fig. 8-6

The melting time depending on the overcurrent/short-circuit current

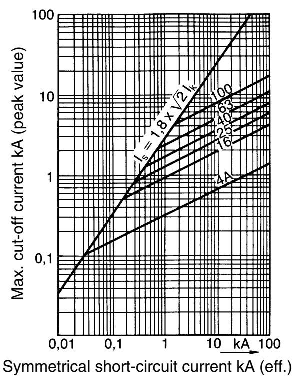


Fig. 8-7

The cut-off current depending on the prospective short-circuit current

Selecting fuse links for specific conditions

When protecting transformers (Table 8-1) and capacitors with fuses, the inrush currents must be taken into account. When protecting transformers, selectivity by making the melting times match of low-voltage fuses and HV fuses is required to ensure that the low-voltage fuses respond first. This is taken into consideration in Table 8-1.

Table 8-1

Approved protection of transformers on the medium-voltage side (fuse-links type CEF) and on the low-voltage side.[1)]

Rated voltage (kV)	Rated transformer output (kVA)																
	50	75	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500
	High-voltage fuses I_n (A)																
3	25	25	40	40	63	63	63	80	100	100	160	200	200	250[2)]	315[2)]		
5	16	25	25	25	40	40	63	63	63	80	100	100	160	200	200	250[2)]	315[2)]
6	16	16	25	25	25	40	40	63	63	63	80	100	100	160	200	200	250[2)]
10	10	16	16	16	25	25	25	40	40	63	63	63	80	100	100	160	200
12	10	16	16	16	16	25	25	25	40	40	63	63	80	100	100	160	160
15	10	10	16	16	16	16	25	25	25	40	40	63	63	63	100	100	125
20	10	10	10	16	16	16	16	25	25	25	40	40	63	63	63	80	100
24	10	10	10	10	16	16	16	16	25	25	25	40	40	63	63	63	80
30	10	10	10	10	10	16	16	16	16	25	25	25	40	40	40	2x40	2x40
36	10	10	10	10	10	10	16	16	16	16	25	25	25	40	40	2x40	2x40
Rated voltage (V)	Low-voltage fuses I_n (A)																
220	80	100	125	160	200	250	250	315	400	500	630						
380	50	63	100	100	125	125	200	250	250	350	400	400	500	630			
500	40	50	80	80	100	100	160	160	200	250	350	350	400	500	630		

[1)] Maximum rated current of the low-voltage protection that yields selectivity with the high-voltage fuse.

[2)] CMF-type fuse link

In capacitor banks the rated current of the HV fuse links should be at least 1.6 times the rated current of the capacitors. Experience has demonstrated that this covers also the influences of possible system harmonics and increased voltage.

When selecting fuse links for protection of high-voltage motors, the starting current and the starting time of the motors must be taken into account. The frequency of startups must also not be neglected if this is frequent enough to prevent the fuses from cooling down between starts.

8.1.6 I_s-limiter – fastest switching device in the world

The increasing requirements for energy throughout the world demand higher rated or supplementary transformers and generators and tighter integration of the supply systems. This can also result in the permissible short-circuit currents of the equipment being exceeded and the equipment being dynamically or thermally destroyed.

It is often not technically possible or not economical for the user to replace switchboards and cable connections with new equipment with increased short-circuit current capability. The implementation of I_s-limiters when expanding existing installations and constructing new installations reduces short-circuit currents and costs.

A circuit-breaker does not provide protection against impermissibly high peak short-circuit currents, because it is too slow. Only the I_s-limiter is capable of detecting and limiting a short-circuit current in the initial rise, i.e. in less than one millisecond. The maximum instantaneous current value that occurs remains well below the peak value of the short-circuit current of the system.

Typical I_s-limiter applications (Fig. 8-10):

- in couplings,
- in coupling the public system with a private supply,
- parallel to reactor coils,
  (avoids copper losses and voltage drop at the reactor coils)
- in transformer or generator feeders,
- in outgoing feeders.

The I_s-limiter is a current-limiting switching device, which detects and limits the short-cicuit current in the initial rise. The short-cicuit current through the I_s-limiter is limited so quickly that it does not contribute in any way to the peak value of the short-cicuit current at the fault site.

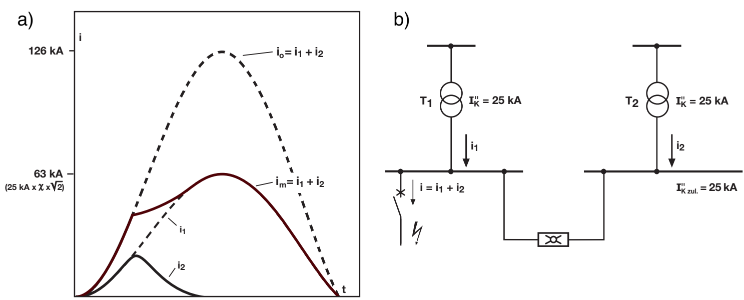


Fig. 8-8
Short-circuit breaking with I_s limiters
a) Current path
i_o Total current without I_s limiter
i_m Total current with I_s limiter
b) Basic layout

In principle, the I_s-limiter consists of an extremely fast switching device that can conduct a high rated current, but has a low switching capacity and a parallel configured fuse with high breaking capacity. To achieve the desired short switching delay, a small charge is used as energy storage for opening the switching device (main current path). Once the main current path has been opened, the current still flows through the parallel fuse, where it is limited within 0.5 ms and then is finally interrupted in the next voltage zero.

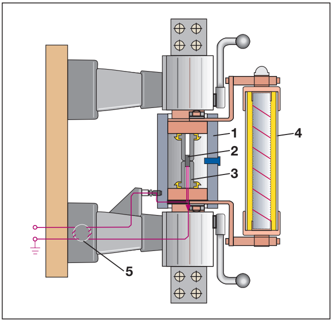


Fig. 8-9

Holder and insert of an I_s-limiter

1 Insulating tube
2 Charge
3 Bursting bridge (main current path)
4 Fuse
5 Insulator with pulse transformer

8

Table 8-2

Rated voltages and currents for I_s-limiter

Rated voltage kV	Rated current A
0.75	.... 4.500
12.0	.... 4.000
17.5	.... 4.000
24.0	.... 2.500
36.0 (40.5)	.... 2.500

I_s-limiter inserts are parallel connected for higher currents

The I_s-limiter is from all points of view the ideal switching device for solving short-circuit problems in switchboards in power plants, in heavy industry and for power supply companies.

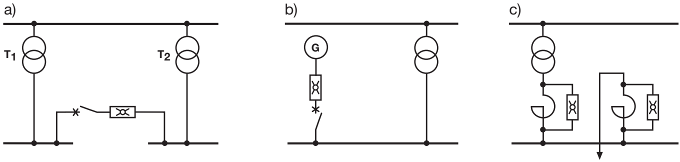


Fig. 8-10

The most common applications for I_s-limiters are:
a) couplings, b) in power supplies, c) parallel to reactors in power supplies and in outgoing feeders.

8.1.7 Circuit-breakers

There are still a number of “small-oil-volume” circuit-breakers in use for rated voltages to 52 kV in systems, but for new installations only vacuum or SF_6 circuit-breakers are used.

Circuit-breakers can be fix-mounted or integrated into the switchbay with appropriate interlocking mechanisms in withdrawable unit design.

Circuit-breakers must be capable of making and breaking all short-circuit and service currents occurring at the operational site. See 10.4.3 for details. The testing conditions for the corresponding verifications can be found in DIN VDE 0670 Part 102 and Part 104.

Vacuum circuit-breakers

Vacuum circuit-breakers of the VD4 type are available from the ABB Calor Emag production range for short-circuit breaking currents up to 63 kA with rated currents from 400 to 3150 A. The VD4 range covers the voltage ranges of 12 kV, 17.5 kV, 24 kV and 36/40 kV.

Fig. 8-11 shows a vacuum circuit-breaker of the VD4 type in column design.

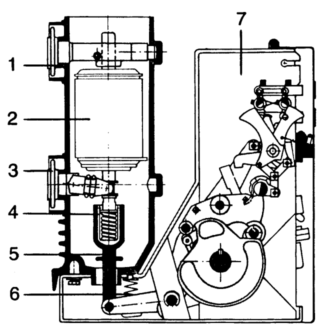


Fig. 8-11

Section through breaker type VD4
1 Upper connection
2 Vacuum interrupter
3 Lower connection
4 Contact pressure spring
5 Insulated coupling rod
6 Opening spring
7 Spring stored-energy operating mechanism

The components of the main circuit are covered by tubular epoxy resin insulators. The VD4 circuit-breaker is therefore particularly suitable for use with compact switchbays of small dimensions.

Fig. 8-12

VD4 circuit-breaker for 12 kV as a withdrawable unit

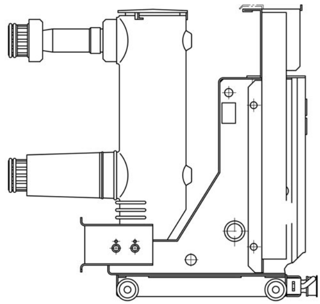


Fig. 8-12 shows the VD4 circuit-breaker with isolating contact arms on the withdrawable module frame for use in air-insulated switchboards, e.g. of type ZS1.

Fig. 8-13

Vacuum interrupter in sectional view, simplified overview

1 Insulator
2 Fixed contact
3 Movable contact
4 Metal bellows
5 Shielding
6 Contact stem
7 Cover
8 Protection guide
9 Central shield

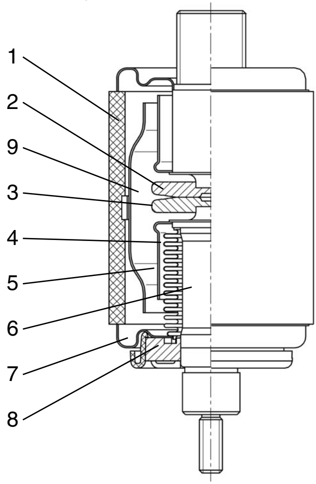


Fig. 8-12 shows the most important components of a vacuum interrupter of the ABB range in sectional view. All joints of the conducting path and of the enclosure are manufactured by brazing in vacuum furnaces with inserted brazing material rings. This results in an extremely reliable and long-lasting seal.

The contacts are a copper/chrome compound material, a copper base containing evenly distributed fine-grained chrome particles, which has a good extinguishing and arc-resistant response when switching short-circuit currents, and is also distinguished by low-chopping current values when breaking small currents.

Switching overvoltages

Switching overvoltages when switching inductive loads with vacuum circuit-breakers have long been a subject of discussion. The introduction of copper/chrome as contact material has significantly reduced the occurence of hazardous overvoltage values. To cover the residual risk, surge arresters based on metal oxide (MO) are recommended for specified applications. Examples of such applications are:

– small motors (with starting current below about 600 A),
– small generators,
– reactor coils for power factor compensation,
– dry-type transformers in industrial application.

Only in special cases (e.g. furnace transformers) are supplementary RC circuits required, preferably in the form of ZO-R-C combinations (zinc oxide+R+C).

Actuating systems

The travel of movable contacts between open and closed position in the vacuum circuit-breaker is between 8 and 14 mm depending on the rated voltage. At the end of the closing stroke, the energy for tensioning the contact pressure springs is required. The relatively low total energy requirement for vacuum circuit-breakers is generally provided by mechanical spring stored energy operating mechanisms, as with the VD4 type. Tripping is initiated by magnetic trips or manually. The mechanical operating mechanism of the VD4 circuit-breaker is always suitable for autoreclosing (0 – t – CO).

Fig. 8-14 shows a new actuating system for the VM1 type circuit-breaker. The movable contacts here are actuated by a permanent magnet mechanism with two stable end stops. The contact movements are initiated by current pulses (approx. 100 Watt / 45 ms), generated by discharge of a capacitor with a charged voltage of 80 V, i.e. with less tripping energy than with magnetic trips of the mechanical mechanism.

1 Upper connection
2 Vacuum interrupter
3 Epoxy resin enclosure
4 Lower connection
5 Flexible connector
6 Contact pressure spring
7 Insulated coupling rod
8 Lever shaft
9 Stroke setting
10 Sensors for position indication
11 ON coil
12 Permanent magnets
13 Magnet armature
14 OFF coil
15 Manual emergency trip
16 Actuator housing

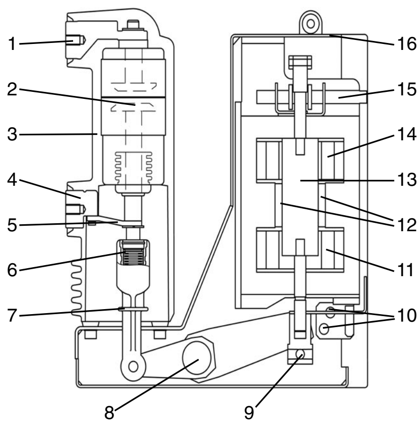


Fig. 8-14
Vacuum circuit-breaker VM1 (dimensions fully compatible to type VD4)

The trip currents are controlled by thyristors and transistors, i.e. exclusively by electronic components. A fixed-programmed logic circuit coordinates the processes and interlock conditions. The contact position is detected by magnetic proximity sensors. The interface to the control system is through binary inputs and outputs.

Because of the extremely small number of individual parts, this actuating system offers significant advantages in reliability, durability (100,000 switching cycles) and manufacturing costs.

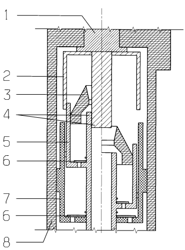
The pole section (Fig. 8-14) with the vacuum switching chamber moulded in epoxy resin has optimum dielectric properties, permanent protection against external influences of all types and because of the small number of parts, very little likelihood of faults occurring. This eliminates the requirement for maintenance of this switching device under standard operating conditions.

SF_6 circuit-breakers

After its successful implementation in the range of transmission voltages (cf. Section 10 and 11!), SF_6 has also become established in the medium-voltage range. The puffer-type arc-quenching principle, which was introduced first, provides an effective arc-quenching gas flow by a mechanically driven piston. However, this requires high-energy driving systems. Hence self-blast arc-quenching systems of different types were developed, where the relative movement between the gas and the arc is provided by the arc itself, either by continuous movement of the arc in a circular route or by pressure built up in a temporarily enclosed volume.

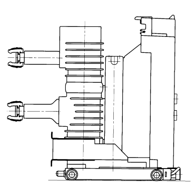
The newest generation of ABB SF_6 circuit-breakers for medium-voltage - type HD4 - makes use of a combination of these two-different arc-quenching principles („Autopuffer“). Circuit-breakers of this type are available for service currents from 630 A to 4000 A and for short-circuit currents up to 50 kA. The arc-quenching system (Fig. 8-15) applies the gas compressed in the lower chamber to interrupt small currents with overvoltage factors < 2.5 p.u. even in case of small inductive currents. High short-circuit currents are interrupted by the self-blast effect applying the pressure built up in the moving chamber by the arc energy.

Fig. 8-15: SF_6 circuit-breaker type HD4



1 Upper terminal
2 Main contact
3 Nozzle
4 Arcing contact
5 Moving chamber
6 Valves
7 Lower chamber
8 Insulating housing
left: closed
right: open

“Autopuffer“-arc quenching system



Circuit-breaker on switch truck, side view

8.1.8 Vacuum contactors

Vacuum contactors, in connection with HV fuses, are particularly suitable for operational switching of motors with very high switching frequency, e.g. medium-voltage motors for pumps, fans, compensators and capacitors. HV fuses provide protection for cables and circuit components in case of a short circuit.

Vacuum contactors have a life expectancy (electrical) of $1 \cdot 10^6$ switching cycles, and can handle a switching frequency up to 1200 on/off operations per hour. The V-contact type vacuum contactors (Fig. 8-16) have the performance data listed in Table 8-3. However, the table does not note whether suitable fuses are available to take advantage of the listed performance ranges.

Table 8-3

Performance data of type V-contact vacuum contactors

Rated voltage	kV	3,6	7.2	12
Rated current	A	400	400	400
Suited for				
– Motors of up to	kW	1 500	3 000	5 000
– Capacitors of up to	kVAr	1 500	3 000	4 800

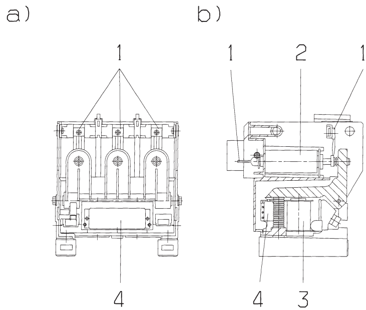


Fig. 8-16

Vacuum contactor, type V-Contact

a) front view
a) section view

1 connection terminals
2 vacuum interrupter
3 contactor coil
4 auxiliary contacts

8.2 Switchgear installations (≤ 52 kv)

8.2.1 Specifications covering HV switchgear installations

This voltage range – generally referred to as medium voltage – covers switchbays in use and on the market that can be classified as per one of the two following specifications:

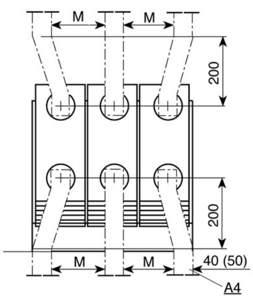
DIN VDE 0101 or
DIN EN 60298 (VDE 0670 Part 6)

8.2.2 Switchgear as per DIN VDE 0101

Switchgear installations as per DIN VDE 0101 are designed to comply with fixed minimum clearances of live components from one another, from earth potential and from protecting barriers. They can basically be manufactured at the site where they will be operated. Current-carrying capacity for service and short-circuit currents must be verified by calculation (cf. Section 4. also). Type testing is not required.

When setting up these installations in electrical equipment rooms with restricted accessibility, protection against accidental contact with live components, e.g. screens or rails, is sufficient. The bays can also be designed with sheetmetal walls and doors (minimum height 180 cm) (cf. Section 4.5; 4.6 and 5.2). Reinforced wallboard is also frequently encountered as a wall material. The bays can also be completely enclosed for full protection for operation outside locked premises.

The use of insulating materials and intelligent design will allow smaller clearances, particularly in the terminal zone of circuit-breakers and switch-disconnectors, than the specified minimum clearances as per DIN VDE 0101 (cf. Table 4-12:). A device of this kind must be tested with connected conductors in the zone in which the permissible minimum clearances are not met. This zone is referred to as the “tested terminal zone” (see DIN VDE 0101). It must be included in the user manual for the switching devices with the main dimensions (Fig. 8-17).



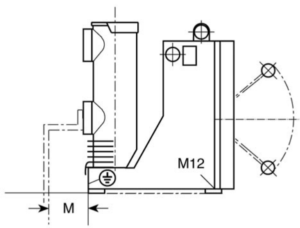


Fig. 8-17

Tested terminal zone as per DIN VDE 0101
M = minimum clearance as per DIN VDE 0101
here: tested terminal zone = 200 mm
A4 = connecting bar as per DIN 46433

Today, switchbays as per DIN VDE 0101 are mainly encountered in individual installation design on site or are manufactured by smaller companies without in-house test laboratories.

DIN VDE 0101 also includes basic specifications for the general design of a substation, including the structural requirements. They are also applicable for the installation of type-tested switchgear as per DIN EN 60298 (VDE 0670 Part 6).

8.2.3 Metal-enclosed switchgear as per DIN EN 60298 (VDE 0670 Part 6)

Metal-enclosed switchboards are generally assembled from type-tested panels these days. As per DIN EN 60298 (VDE 0670 Part 6) metal-enclosed switchgear installations must be designed so that their insulation capacity, degree of protection, current-carrying capacity, switching capacity and mechanical function conform to the requirements set by the testing provisions. This is verified by a type test on a prototype unit. In addition, a routine test is made on every completed panel or every transport unit.

Note: As well as DIN EN 60298 (VDE 0670 Part 6), the higher-order specification DIN EN 60694 (VDE 0670 Part 1000) must also be observed.
Type-tested switchgear installations with insulated enclosures are subject to IEC 60466. However, there is no longer a corresponding European or German standard.

Rated voltage

The rated values for the insulation level of a switchgear installation must be selected on the basis of the requirements of the system at the installation site from the selection tables in DIN EN 60 694 (VDE 0670 Part 1000).

Table 10-1 (Section 10) shows the selection values for the range of rated voltages up to 52 kV. The voltage values “over the isolating distance” only apply for switching devices with which the safety requirements for the open contacts of disconnectors must be met.

Table 10-1 lists two value pairs that can be selected for the rated lightning impulse voltage level for almost all rated voltages. The options correspond to the former subdivision in list 1 and list 2.

When making the selection, the degree of danger from lightning and switching overvoltages, the type of neutral treatment and, if applicable, the type of overvoltage protection should be considered. The higher value pairs in each case are the ones to be selected for installations and equipment exposed to atmospheric overvoltages, e.g. by direct connection to overhead lines. The lower value pairs can be used for installations that are not exposed to atmospheric overvoltages or are protected from these overvoltages by arresters.

Gaseous insulating materials

DIN EN 60298 covers switchgear in which atmospheric air acts as the gaseous insulation within the enclosures and also those in which a gas other than the atmospheric air is used (e.g. SF_6)(air-insulated/gas-insulated).

Degree of protection for metal-enclosed switchgear

The metallic and earthed enclosure protects personnel against approach to live components and against contact with moving parts. It also protects the installation against the penetration of foreign bodies. One of three different degrees of protection may be selected for switchgear as per DIN EN 60298. The difference is whether the enclosure is suitable for repelling fingers or similar objects (IP 2X), rigid wires more than 2.5 mm in diameter (IP 3X) or rigid wires more than 1 mm in diameter (IP 4X).

Compartmentalization

The general term “metal-enclosed” is used in DIN EN 60298 for three different categories depending on the design of the internal compartmentalization

– “metal-clad” switchgear has separate compartments for the main switching device and the two adjacent zones, i.e. in general three compartments (for circuit-breaker, busbar system and cable terminal zone). The compartment walls are metal and are earthed.

– “compartmented” switchgear has the same degree of bay subdivision as “metal-clad” switchgear, but the compartment walls are of insulating material.

– “cubicle” switchgear is defined as all switchgear whose compartmentalization does not meet the requirements of the two above categories (e.g. only two compartments), but this also includes all switchgear that does not have internal compartmentalization.

The decision on which of these installation categories is to be used in any specific case is up to the user, with most attention paid to safety of personnel during maintenance and cable work inside the switchbay. Restricting the effects of faults is important only when the resistance of the compartment walls to arcing has been verified and when the compartmentalization forms a true potential separation.

Internal arcing

All specialists are in basic agreement that manufacturers and users must make every effort to prevent under all circumstances faults in switchgear installations in which internal arcing occurs. However, it is also acknowledged that such faults cannot be completely prevented in all cases. For this reason, it is expected that current switchgear designs have been tested for response to internal arcing.

Internal short-circuit arcs during operation can occur by overvoltage, faulty insulation or improper control. The test consists of inducing the arc with an ignition wire connected over all three phases. The arc has temperatures of around 4000 K in the area of its footing points and around 10 000 K or more in the area of the arc column. Immediately after the arc has been ignited, the gas in in the immediate vicinity of the arc heats up instantly, causing a very steep rise in pressure in the compartment concerned. This pressure increase would continue to the load limit of the enclosure if pressure relief vents were not built into it. The sealing covers or membranes of these vents respond in ca. 5 to 15 ms and open the path to allow the heated gases to vent (Fig. 8-18). This characteristic process is not determined only by the response time of the pressure relief valves but it also results from the mechanical inertia of the heated gas mass.

The maximum pressure reached is dependent on the volume of the compartment where the fault occurs and on the magnitude of the short-circuit current. The greatest quantity of heated gases is given off into the area around the switchboard during the expansion phase. The pressure stress on the panel exceeds its high point as early as about 15 ms, that of the building has reached its maximum stress after 40 ms at the latest. A powerful ejection of still heated gases of low density and glowing particles occurs in the subsequent emission phase and in the thermal phase.

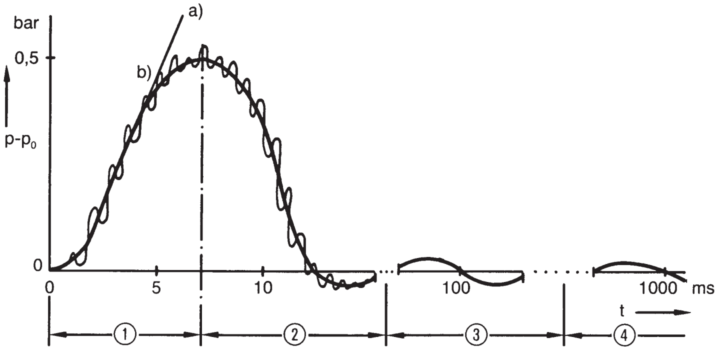


Fig. 8-18

Pressure development in the faulty panel caused by internal arcing, 1 Compression phase (pressure build-up), 2 Expansion phase (pressure relief), 3 Emission phase (hot gases released), 4 Thermal phase (ejection of glowing particles). a) isochorous pressure rise, b) opening of pressure relief valves.

Guidelines for testing metal-enclosed switchgear for their response to internal arcing can be found in Appendix AA of DIN EN 60298 (VDE 0670 Part 6). PEHLA Guide no. 4 contains relevant supplementary provisions.

The specified test sequence requires the internal arcing to be ignited with a thin ignition wire in the test compartment of a switchbay. The short-circuit test plant supplying the test object must have sufficient power to allow a short-circuit current as high as the short-time withstand current to flow in three phases over the internal arcing during the agreed duration of the test. The test generally lasts 1 second. This will cover the longest protection grading times that can be still expected in practice – at full short-circuit current. The test with a short-circuit duration of 0.1 second may be of interest for special protection concepts. With this short-circuit duration, the test result is restricted to the question of whether the tested compartment withstands the stress caused by the internal overpressure.

During the test, fabric indicators (black, cretonne or cotton-wool batiste) are stretched vertically at a defined spacing on metal frames in front of the accessible walls of the switchboards and horizontally at 2 m height above the zone where personnel would be when operating the installation (Fig. 8-19).

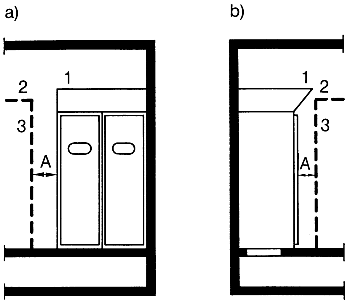


Fig. 8-19

Test structure: thermal effects

a) Front view; b) Side view; 1 Discharge plate; 2 Horizontal indicators at 2.0 m height; 3 Vertical indicators at distance A from test object; A = 300 mm for electrical equipment rooms with restricted accessibility; A = 100 mm for generally accessible rooms.

8

After the short-circuit test, the test engineer records the response of the switchbay(s) tested based on six criteria. The following points are recorded:

1. doors and screens have not opened,
2. no hazardous parts were ejected,
3. arcing did not cause any holes,
4. none of the vertical fabric indicators in front of walls and doors ignited,
5. none of the horizontal fabric indicators at a height of 2 m above the control zone ignited,
6. all earth connections are still effective.

High-speed film or video cameras can also provide additional information on what occurs during the test. They are therefore strongly recommended.

The test objects are not assessed with “pass/fail”. This allows the user to approve switchbays for one application, even though a positive observation was not registered for every one of the above criteria.

This freedom to interpret the results is particularly significant with reference to criteria 4 and 5, because in the event of ejection of hot gases, the switchbay itself is not primarily relevant for the effects. Reflection from the ceilings and walls in the emission phase and the thermal phase (Fig. 8-18) can divert the hot gases coming from the pressure relief vents into zones accessible for personnel and cause hazardous conditions there. The highest degree of damage also occurs during this period inside the switchbay. The ejection of very hot gas reaches its most hazardous amount under the condition when caused by the direction of supply (from below) the electromagnetic forces compel the arc to persist in the immediate vicinity of the pressure relief vent. A switchbay type may be considered fully tested only after this case has been considered.

Countermeasures for protection of personnel against these effects can be as simple as installing screens or discharge plates. At high short-circuit currents, hotgas conduits with blow-out facilities using absorbers discharging into the switchgear installation room are the perfect solution. However, even better results without additional installations can be achieved if it is possible to limit the arc duration to approximately 100 ms by appropriate trip times. Because the grading times of the system protection do not generally allow such a short-term tripping of the feeder circuit-breaker, additional sensors are required, such as the I_{th}-limiter. When one of the pressure relief valves opens and there is simultaneous persistent short-circuit current, it initiates an undelayed trip command to the feeder circuit-breaker. This quenches the internal arc in less then 100 ms.

The pressure load on walls, ceilings, doors and windows of the switchgear installation room is the result of the gas ejection during the expansion phase (Fig. 8-18). The withstand can generally not be verified by testing. All major manufacturers provide calculation programs for determining the pressure development in the switchgear installation compartment to find out whether pressure relief vents are required for the installation room.

8.2.4 Metal-enclosed air-insulated switchgear as per DIN EN 60298 (VDE 0670 Part 6)

Switchgear of this design have the largest market share throughout the world.

Metal-clad switchgear

Fig. 8-20 shows an example of metal-enclosed and metal-clad switchgear of type ZS1.

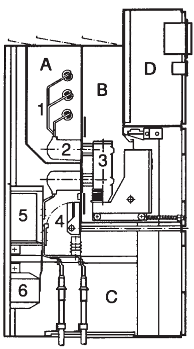


Fig. 8-20

Type ZS1 switchbgear
A busbar compartment; B main switching device compartment; C cable terminal compartment; D low-voltage compartment; 1 busbar; 2 isolating contacts; 3 circuit-breaker; 4 earthing switch; 5 current transformer; 6 voltage transformer

The circuit-breaker of this type of switchgear can be moved when the door is closed between the operating position and test position. Because vacuum circuit-breakers under normal operating conditions are maintenance-free, the door to the circuit-breaker compartment can remain permanently closed. However, if it should be necessary to remove the switch from the switchbay, this can be done without problems on a service truck that can be adjusted for height to the exact position.

Access to the cable boxes can be made much easier by removing the circuit-breaker and also removing the partition between compartments B and C.

Compartment C has room for the cable boxes of several parallel cables. Metallic oxide arresters for overvoltage protection of inductive consumers can also be installed here.

When the circuit-breaker is in test position and the switchbay doors are closed, the cables can be earthed via the permanently installed earthing switch (with short-circuit making capacity). In order to check that the cables are dead voltage indicator plugs can be inserted into test sockets at the front of the switchboards. The test sockets are connected to the terminals of capacitive deviders, which are integrated into the current transformer.

Instead of the vacuum circuit-breaker, an SF_6 circuit-breaker of the HD4 type with identical main dimensions can be installed in this switchgear type.

The ZS-1 switchgear shown in Fig. 8-20 is available with the technical data and bay dimensions shown in Table 8-4.

Table 8-4

Technical limit data and associated minimum bay dimensions of the ZS1 metal-enclosed metal-clad switchgear design series

Rated voltage	kV	12	17.5	24
Rated short-duration power-frequency withstand voltage	kV	28	38	50
Rated lightning impulse withstand voltage	kV	75	95	125
Rated current				
– of the busbars	A	... 4 000	... 4 000	... 4 000
– of the feeders	A	1250/ ... 4 000	1250/ ... 4 000	1250/ ... 2 500
Rated short-time withstand current (3 s)	kA	31.5/... 50	25/... 40	... 25/... 25
Minimum bay dimensions				
– width	mm	650/1 000	650/1 000	800/1 000
– depth	mm	1 300/1 350	1 300/1 350	1 500/1 500
– height	mm	2 200	2 200	2 200

In addition to the standard switchgear panel with draw-out circuit-breaker, there are variations for sectionaliers, metering panels and bays with permanently installed switch-disconnectors for substation power supply transformers. Double busbar installations are designed in accordance with the two circuit-breaker methods in back-to-back or front-to-front configurations (Fig. 8-21).

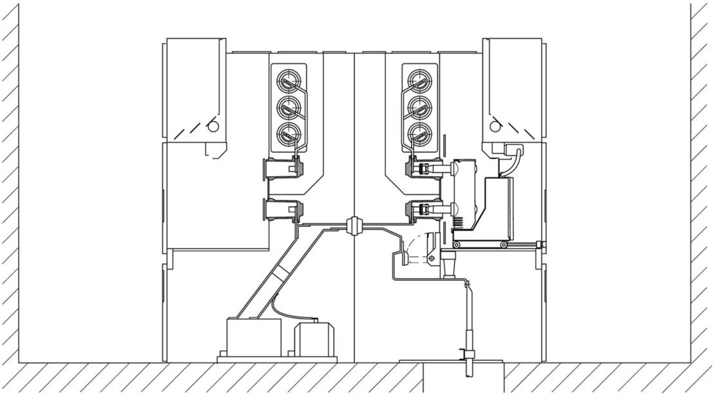


Fig. 8-21

Double busbar switchgear installation ZS1, switchbays in back-to-back configuration

Cubicle switchgear

Fig. 8-22 shows metal-enclosed cubicle switchgear of type ZS8. Below are switchbays with permanently installed switch-disconnectors for switching cables and overhead lines and with HV fuses for protection of distribution transformers. The switch-disconnectors can be remote-controlled with the motor-operated mechanism. In the circuit-breaker bays, the VD4 and VM1 vacuum circuit-breakers are withdrawable units that can be moved when the panel door is closed.

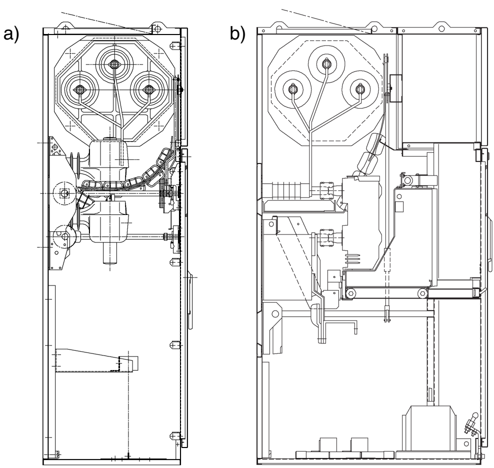


Fig. 8-22

ZS8
metal-enclosed
cubicle switchgear:

a) switch-disconnector panel

b) circuit-breaker panel

All bay types of the ZS8 design series can be queued up in spite of varying dimensions. The switch-disconnector bay can also be supplied in the same depth as the circuit-breaker bay. The most important dimensions of these bays and their rating data are shown in Table 8-5.

Table 8-5

Technical limit data and associated minimum bay dimensions of the ZS8 cubicle switchgear

Rated voltage	kV	12	17.5	24
Rated short-duration power frequency withstand voltage	kV	28	38	50
Rated lightning impulse withstand voltage	kV	75	95	125
Rated current				
– of the busbars	A	... 1 250	... 1 250	... 1 250
– of the switch-disconnector feeders	A	... 630	... 630	... 630
– of the circuit-breaker feeders	A	... 1 250	... 1 250	... 1 250
Rated short-time withstand current (3 s)	kA	... 25	... 20	16[1)]/... 25
Minimum bay dimensions				
– width of switch-disconnector bay	mm	600	650	600
– depth of switch-disconnector bay without/with branch compartmentalization	mm	600/1 200	1 000/–	800/1 200
– width of circuit-breaker bay	mm	650	650	800
– depth of circuit-breaker bay without/with branch compartmentalization	mm	1 000/1 200	1 000/1 200	1 200/1 200
– height	mm	1 900	1 900	1 900

1) switch-disconnector bay for 24 kV only up to 16 kA

ZS8 switchbays are not subdivided by metallic earthed compartment walls, as required for the “metal-clad” category. For this reason, they must be classified in the “cubicle” category.

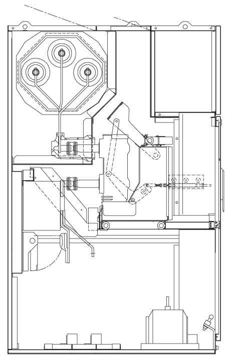
ZS8 switchbays are equipped with earthing switches (with short-circuit making capacity) for feeder earthing. The earthing switches can only be closed when the switch-disconnector is open or the circuit-breaker withdrawable unit is in isolated position. There is an insulating plate integrated in every switchbay, which slides into the open break of the switch-disconnector or in front of the busbar-side slide-in contacts of the circuit-breaker compartment. This assures protection against accidental approach to live components during work in the bay, e.g. at the cable terminals. There are also ZS8 panels with “tee-off partitions” (Fig. 8-23). These bays have earthed metallic partition, which separate the busbar system from the areas of switching devices and cable terminals. The electric protection against approach to the slide-in contacts installed in epoxy resin spouts is provided by earthed metallic shutters that swings in front of the epoxy resin spouts in these bays. The panel doors can only be opened after closing the protection shutter in all ZS8 type switchgear.

Checking that the cables are dead can be made with conventional voltage indicators or by using voltage indicator plugs at externally accessible test sockets. Measurements using sockets require installation of capacitive divider devices in the epoxy resin insulators of the switch-disconnector or in the current transformer of the circuit-breaker panels.

Panel variations of the ZS8 series in addition to the panels with switch-disconnectors or circuit-breakers include sectionalizers, busbar risers and metering panels.

Fig. 8-23

ZS8 switchgear with tee-off partition



8.2.5 Metal-enclosed gas-insulated switchgear
as per DIN EN 60298 (VDE 0670 Part 6)

The same standard as for the air-insulated switchgear described in Section 8.2.4 also applies to the gas-insulated switchgear of the medium-voltage area. The term “gas-insulated” refers to the fact that atmospheric air is not used as the gaseous insulating material inside the switchbays, i.e. the enclosure of the installation must be gas-tight against the environment.

The gas currently used in most gas-insulated designs is a synthetic electronegative gas, SF_6, with almost three times the dielectric resistance of air. See also Section 16.3! The insulating gas can also be nitrogen, helium or even air dried for the purpose and at a higher pressure level.

The decisive advantage of a gas-insulated switchgear compared to an air-insulated installation is its independence from environmental influences such as moisture, salt fog and pollution. This results in less maintenance, increased operational safety and high availability. The smaller dimensions due to compact design and increased dielectric resistance of the gaseous insulating material are also advantages. Gas-insulated switchgear technology in the medium-voltage area has become increasingly significant over the last 15 years.

The numerous designs available on the market can be generally classified into three different application groups:
– switchgear with circuit-breakers
– switchgear with switch-disconnectors and circuit-breakers
– ring-main units

One technical solution for each of these application groups is described below as an example.

Gas-insulated switchgear with circuit-breakers

Fig. 8-24 shows switchgear type ZX1 (for 12, 17.5 and 24 kV) with the versatile options offered by the advanced technology of these new switchgear designs.

The principles used for the application are:

High-precision housing

– The gas-tight housing of the live components is manufactured of stainless steel using laser technology for high-precision cutting and welding. This not only ensures that the housing is gas-tight but also allows the bays to be queued up on site without problems.

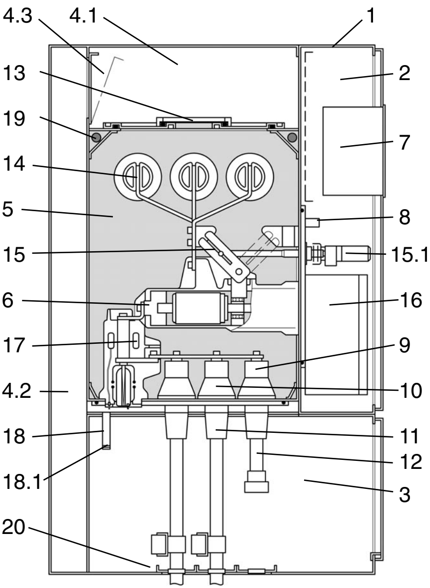


Fig. 8-24 Metal-enclosed gas-insulated switchgear type ZX1 with single busbar system

1 Panel enclosure, complete
2 Secondary compartment
3 Cable terminal compartment
4.1 Integrated pressure release duct
4.2 Pressure release duct, cable terminal compartment
4.3 Pressure relief flap
5 Core module
6 Circuit breaker pole
7 Bay control and protection unit REF542
8 Pressure sensor
9 Cable and test socket
10 Cable socket
11 Cable plug
12 Surge arrester (as example)
13 Pressure release plate
14 Busbar
15 Transfer switch
15.1 Transfer switch mechanism
16 Circuit-breaker mechanism
17 Combined current/voltage sensor with capacitive tap
18 Main earthing conductor
18.1 Bay/bay earthing connection strap
19 Bag of desiccating agent
20 Base plate, divided
▒ Insulation gas in core module and inside c.-b. pole tube

Vacuum switching technology

– The application of vacuum switching technology as the quenching principle of the circuit-breaker meets a primary requirement for gas-insulated switchgear: the interruptor unit must be maintenance-free. So far, this requirement is really only met by vacuum interrupters, because of their low contact wear and their high electrical durability. Gas-insulated switchgear for this voltage range with SF_6 circuit-breakers is also available.

Plug connector technology

– The application of plug-in technology is essential for ensuring short assembly times when setting up installations. Several parallel cables can be connected to the commercially available internal conical sockets in the baseplate of the core module. The plug-in technology in the area of the busbar bushings is new but based on the same technology as the cable connectors. These bushings designed as plug connectors are the most important requirement for easy installation of the completed panels. There are additional plug connectors in the supply lines for auxiliary power and in the fibre-optic connections to the higher-order control system, if present.

Sensors for measured quantities and states

– The combined current/voltage sensor has three functions. For current measurement, it has a Rogowski coil, which gives a voltage signal that has a linear dependency on the current and therefore can be used in a very broad current range (e.g. to 1250 A in one type). This not only simplifies planning but also increases the flexibility when modifying installations that are already operating.

  A high-resistance (200 MΩ) voltage divider is used as a voltage sensor. Two bell-shaped screening electrodes ensure equal distribution of the electric field along the resistance. The voltage signal captured at the subresistance of the devider is fed to the bay control unit.

  The earth side of the two screening electrodes is simultaneously used as a capacitive tap to the voltage indicator plugs. It is connected with test sockets on the front of the switchboard to allow checking that the cables are dead independently of the functional availability of the bay control unit.

  The positions of the two switching devices and the ‘ready for switching’ indication of the circuit-breaker mechanism are detected by inductive proximity sensors. A temperature-compensated pressure sensor signals three pressure/density levels, i.e. fill pressure at 20°C, lower operational pressure limit and pressure with internal arcing. All sensor information goes directly to the bay control unit and is displayed and processed there.

Digital bay control and protection unit

– The digital REF542 bay control and protection unit is the base of the intelligence and communications interface of the new switchgear (see also Section 14!)

It has the following functions:

- on site and remote actuation
- display of positions, measured values, protective parameters
- interlocking, internal and external
- protection (all protective functions except for cable differential protection)
- storage of events
- information transmission to a higher-order control system
- monitoring its own functions and the tripping circuits

Faults in the sequence of actuation of circuit-breaker and disconnector/earth switch function of the transfer switch are prevented by interlocking in the REF542. The earthing process can be automatically run by the REF542 as a programmed sequence while retaining the “five rules of safety”. Any required protective functions can be programmed in as software before delivery. Software changes can be made on site at any time with a laptop computer. Parameter changes can be made by pressing buttons on the device itself.

Personnel safety design

A switchgear design such as that of the ZX1 makes the occurrence of faults with internal arcing unlikely from the start. However, the ZX1 offers complete personnel protection in the event of internal arcing. In the case of a fault in the area of the insulating gas, the housing is relieved from excessive stress by the response of the pressure release plate in the pressure release duct, which runs horizontally through all bays and at the end of the installation releases the gas into the open air through an outside wall or into the switchgear installation room via an absorber. The response of the pressure sensor at 0.6 bar overpressure can be used to trip the feeder circuit-breaker immediately without requiring additional components, thereby reducing the arcing time to less than 100 ms. In the event of a fault in the cable terminal area, the pressure is relieved through the back channel into the horizontal pressure release duct.

Double busbar switchgear installations can be designed with the panel type ZX1, in accordance with the two-circuit-breaker method in back-to-back or front-to-front arrangement. Bay variations such as sectionalizer, busbar riser and metering panel are also available.

The most important rating data and the main dimensions of the ZX1 switchgear are shown in Table 8-6.

Table 8-6

Technical limit data and associated minimum panel dimensions of ZX1 type metal-enclosed gas-insulated switchgear

Rated voltage	kV	12	17.5	24
Rated short-duration power-frequency withstand voltage	kV	28	38	50
Rated lightning impulse withstand voltage	kV	75	95	125
Insulating gas	–	N_2	SF_6	SF_6
Rated fill pressure, absolute	bar	1.3	1.3	1.3
Rated current				
– of the busbars	A	... 2000	... 2 000	... 2 000
– of the feeders	A	1 250/2 000	1 250/2 000	1 250/2 000
Rated short-time withstand current (3 s)	kA	... 40	25	25
Minimum panel dimensions				
– width	mm	600/800	600/800	600/800
– depth	mm	1 250/1 300	1 250/1 300	1 250/1 300
– height	mm	1 950	1 950	1 950

As shown in Table 8-6, with 17.5 kV and 24 kV, SF_6 is used as insulating gas while with 12 kV nitrogen (N_2) is used. Nitrogen has the advantage over air that it prevents oxidation of contact surfaces and lubricants.

The switchgear type ZX2 (Fig. 8-25) is suited for "conventional" double busbar substations that have two busbar systems for every switchbay. This switchgear has the same advanced features as described for switchgear type ZX1.

Table 8-7 shows the technical data implemented to date with the associated main dimensions.

Table 8-7

Technical limit data and associated minimum panel dimensions of the ZX2 type metal-clad gas-insulated switchgear

Rated voltage	kV	12	17.5	24	36
Rated short-time power-frequency withstand voltage	kV	28	38	50	70
Rated lightning impulse withstand voltage	kV	75	95	125	170
Insulating gas	–	N_2	SF_6	SF_6	SF_6
Rated fill pressure, absolute	bar	1.3	1.3	1.3	1.3
Rated current					
– of the busbars	A	... 2 500	... 2 500	... 2 500	... 2 500
– of the feeds	A		800/1250/...2500		1250/...2500
Rated short-time withstand current (3 s)	kA	... 40	... 40	... 40	... 40
Minimum panel dimensions					
– width	mm		400/600//800		600/800
– depth	mm	1 710	1 710	1 710	1 710
– height	mm	2 300	2 300	2 300	2 300

Single-busbar switchgear in the ZX2 design can also be manufactured without the rear busbar system to make full use of the advanced technical data.

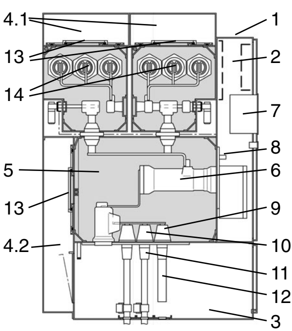


Fig. 8-25 Metal-clad gas-insulated switchgear with double busbar system type ZX2

1 Panel enclosure, complete
2 Secondary compartment
3 Cable terminal compartment
4.1 Integrated pressure release duct
4.2 Integrated pressure release duct
5 Core module
6 Circuit-breaker pole
7 Bay control and protection unit REF542
8 Pressure sensor
9 Cable and test socket
10 Cable socket
11 Cable plug
12 Surge arrester (as example)
13 Pressure release plate
14 Busbar systems ▒ *Insulating gas*

Gas-insulated switchgear with switch-disconnectors and circuit-breakers

Gas-insulated switchgear technology is becoming the subject of increasing interest for distribution systems and smaller industrial consumers. Because the high performance data are not required as with the installations described in the previous section, special switchgear series have been developed for this application. A major characteristic of this application is the use of switch-disconnectors for feeders with cables and overhead lines and in combination with fuses for protection of smaller transformers.

Fig. 8-26 shows cross-sections through variations of the switchgear series ZX0. SF_6 is used as insulating gas and quenching medium for the switch-disconnectors for all rated voltages.

The switch-disconnectors integrated into the panels include the function of the earthing switch for the feeder as a combination device. The contact blades are actuated by the same mechanism for one or the other function depending on the actuation direction. The combination device as switch-disconnector meets the same requirements as a switch-disconnector tested and manufactured as a single unit as per DIN EN 60265-1 (VDE 0670 Part 301). The requirements of DIN EN 60129 (VDE 0670 Part 2) apply for the earthing function (with short-circuit current-making capacity).

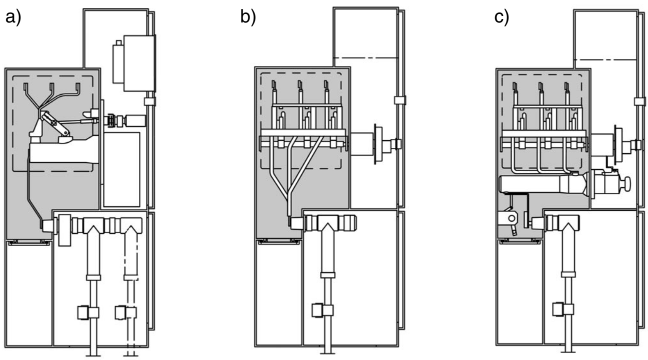


Fig. 8-26

Metal-enclosed gas-insulated switchgear system type ZXO

a) circuit-breaker panel b) switch-disconnector panel c) switch-disconnector panel with fuses

In order to check that the cables are dead before earthing voltage indicator plugs can be inserted into test sockets at the front of the switchboard. These sockets are connected to the taps of field grading electrodes inside the cable-plug bushings.

The circuit-breaker bays of this type of switchgear have vacuum interrupters with a resin coating as arc-quenching systems. This also forms the pivot of the 3-position switch for disconnecting and earthing.

The connected cables are therefore earthed via the circuit-breakers. The REF542 digital bay control and protection unit also controls the actuation, interlocking, display and protection functions in the circuit-breaker panel of the switchgear system ZX0.

Table 8-8 shows limit data and dimensions of the ZX0 type switchgear system.

Table 8-8

Technical limit data and associated minimum panel dimensions of the ZX0 metal-enclosed gas-insulated switchgear system

Rated voltage	kV	12	17.5	24
Rated short-duration power-frequency withstand voltage	kV	28	38	50
Rated lightning impulse withstand voltage	kV	75	95	125
Insulating gas	–	SF_6	SF_6	SF_6
Rated fill pressure, absolute	bar	1.3	1.3	1.3
Rated current				
– of the busbars	A	1 250	1 250	1 250
– of the switch-disconnect. feeder	A	800	800	800
– of the switch-disconnect. feeder with HV fuses	A	200	100	100
– of the circuit-breaker feeder	A	630	630	630
Rated short-time withstand current (3 s)	kA	... 25	... 20	... 20
Panel dimensions				
– width	mm	400	400	400
– depth	mm	850	850	850
– height	mm	1650[1)]/1950[2)]	1650[1)]/1950[2)]	1650[1)]/1950[2)]

1) For switchboards without circuit-breaker panels
2) For all panels of a switchboard with circuit-breaker panels

Ring-main units for distribution systems

There are two basic designs in use for this purpose:
- modular switchboards with the option of later expansions,
- switchboards with a common gas volume inside a common enclosure with a preset number (e.g. 3 or 4) of feeders.

Fig. 8-27 shows such a type CTC switchboard with common enclosure for all three feeders.

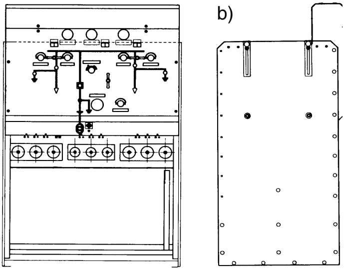


Fig. 8-27

Front view a) and side view b) of the ring-main switchboard type CTC.

SF_6 switch-disconnectors are also used here for switching the connected cables and overhead lines. For protection of transformers, either a vacuum circuit-breaker with electronic protection (type CTC-V, Fig. 8-27) or a switch-disconnector in combination with HV fuses (type CTC-F, same dimensions as CTC-V) can be supplied.

Every switchbay has an earthing switch with specified making capacity to earth the connected cables. In order to check that the cables are dead before earthing voltage indicator plugs can be inserted into test sockets at the front of the switchboard. These sockets are connected to the taps of field grading electrodes inside the cable-plug bushings.

The switch-disconnectors and circuit-breakers of the switchboards can be remotely actuated with motor-operated mechanisms. Table 8-9 shows limit data and dimensions of the CTC gas-insulated ring-main unit.

Table 8-9

Technical limit data and dimensions of the CTC metal-enclosed gas-insulated ring-main unit

Rated voltage	kV	12	17.5	24
Rated short-duration power-frequency withstand voltage	kV	28	38	50
Rated lightning impulse withstand voltage	kV	75	95	125
Insulating gas	–	SF_6	SF_6	SF_6
Rated fill pressure, absolute	bar	1.4	1.4	1.4
Rated current				
– of the cable ring feeder	A	630	400	400
– of the transformer feeder (CTC-F)	A	200	100	100
– of the transformer feeder	A	630	400	400
Rated short-time withstand current (3 s)	kA	20	16	16
Switchboard dimensions				
– width	mm	1 000	1 000	1 000
– depth	mm	760	760	760
– height	mm	1 500	1 500	1 500

8

8.2.6 Control systems for medium-voltage substations

Conventional secondary technology

A wide range of devices for protection, control and monitoring tasks is available for conventional secondary technology in medium-voltage switchgear installations. The planning engineer selects the required single units and combines them into one installation.

The information on measured values, switchgear status and interference messages is transmitted through parallel wiring from the various medium-voltage bays to a main control desk or a telecontrol system. Records, data storage, graphical measured value processing, help information when faults occur and self-monitoring functions are not possible with this technology.

Microprocessor control systems

The implementation of digital system designed for the requirements of medium-voltage networks allows a number of much more powerful solutions at moderate expense. A system of this type is divided into the bay level, the switchboard level and the control room level (see also Section 14.4!).

At the bay level autonomously operating, modular and multifunction devices that can be adapted for the required protection, control and regulating tasks by appropriate software are used. These monitoring devices are installed directly in the secondary compartment of the medium voltage switchbays. Here, all measured values, switch positions and messages from the bays are acquired, processed and sent over a serial (unified) interface. The device, which operates independently of the next hierarchy level, combines the protective functions, the switching position display, the measured value display and the local operation of the switchgear, which is protected against faulty operation, in one single housing. Its modular design makes it adaptable for the bay-specific protection tasks and selectively or in combination controls functions such as motor protection, overcurrent definite-time protection, over and undervoltage protection, earth fault detection, distance protection, differential protection and alarm description. It has comprehensive self-monitoring functions and also allows events to be sorted by time with real-time stamping.

The REF542 bay control and protection unit is a device of this type. It can optionally be implemented autonomously for one switchbay only or integrated into a higher-order automation control system.

8.3 Terminal connections for medium-voltage installations

8.3.1 Fully insulated transformer link with cables

Plastic-insulated cables and fully insulated (plug-in) cable terminals provide a number of operational improvements in substation design when consistently used at the interfaces between cables and station components. The key component for a new type of cable link, Fig. 8-28, between the power transformer and the switchboard is a multiple transformer terminal, Fig. 8-29, for four parallel power cables. The multiple terminal is designed for a rated voltage of up to 36 kV and enables rated currents of up to 3150 A. It can be retrofitted to all power transformers. In addition to the operational advantages, this technology offers savings because the transformer no longer requires a cable rack. For more information on plug connectors for power cables, see Section 13.2.8.

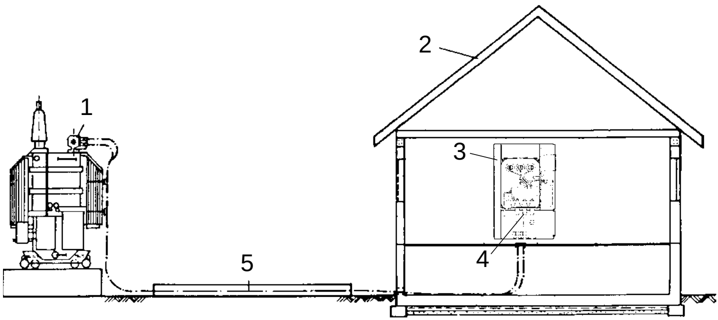


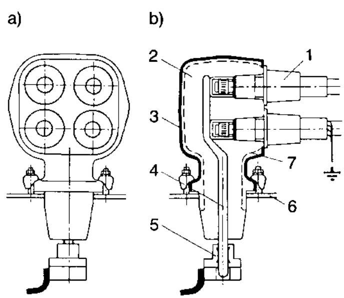
Fig. 8-28

Substation design with fully insulated cable link to the transformer, 1 transformer multiple terminal, 2 substation building, 3 switchboard, 4 cable plug, 5 cable link in protective conduit

Fig. 8-29

View a) and section b) of a transformer multiple terminal

1 Cable connector
2 Moulded resin body with sockets
3 Metal housing
4 Conductor bar
5 Contact system
6 Transformer housing
7 Control shield



8.3.2 SF_6-insulated busbar connection

The busbar shown below in Fig. 8-30 is designed for a rated voltage of up to 36 kV and rated currents of up to 3150 A.

The busbar system consists of several individual parts that can be combined to make all required connections. It is suitable for combining busbars of different sections of switchboards and for making connections to power transformers. Use at 12 kV is also possible with the use of N_2 as insulating gas.

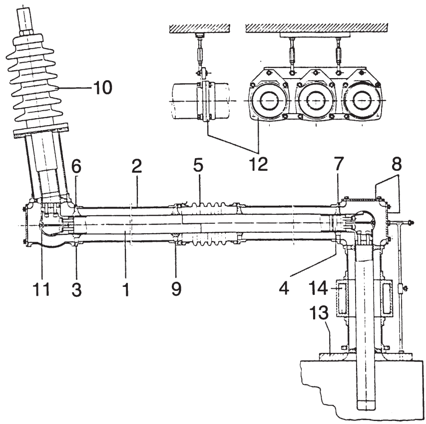


Fig. 8-30

Sectional view of an SF_6-insulated busbar

1 Inner conductor
2 Outer tube
3 Flange joint with insulator
4 Internal expansion joint
5 External expansion joint (metal bellows)
6 T-junction enclosure
7 Cross-junction enclosure
8 Cover with and without connection
9 Insulating flange
10 Outdoor bushing
11 Conductor elbow joint
12 Suspension
13 Mounting flange
14 Current transformer

8.3.3 Solid-insulated busbar connection

Another option for making busbar connections with low space requirements is to use epoxy-resin-insulated capacitor-controlled single-phase conductors. They are available for service voltage of up to 72.5 kV and for operating current of up to 5000 A.

Design of the busbar system

The preferred conductor material is an aluminium alloy with high mechanical strength and low weight. The insulation (Fig. 8-31) is in direct contact with the conductors, with capacitive control provided by conducting layers at the ends. The covering layer at earth potential is fully embedded in the insulation. For outdoor use the bars are also enclosed in a protective tube.

The bar section lengths are up to 12 m. Single or multiple bends are available as required made to fit the assembly and connection dimensions. The bars are connected rigidly or flexibly to the devices with screw or plug-type joints. Individual lengths are joined with an insulating cylinder. The recommended phase clearances, e.g. 200–300 mm at 2500 A, correspond to the phase spacings of the switchgear. Standard support structures and clamps withstand the short-circuit forces. The earth connections comply with the relevant specifications.

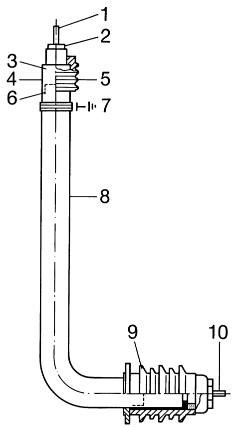


Fig. 8-31

Design of the DURESCA bar for indoor or outdoor use. 1 Indoor connection, 2 Conductor, 3 Insulation, 4 Busbar termination with standard creepage distance, 5 Busbar termination with extended creepage distance, 6 Earth potential layer, 7 Earth connection, 8 Surface finish for indoors: without protective cover, optionally with protective tube or corrugated pipe; for outdoors: with protective tube or corrugated pipe, 9 Porcelain insulating cover, 10 Outdoor connection