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.

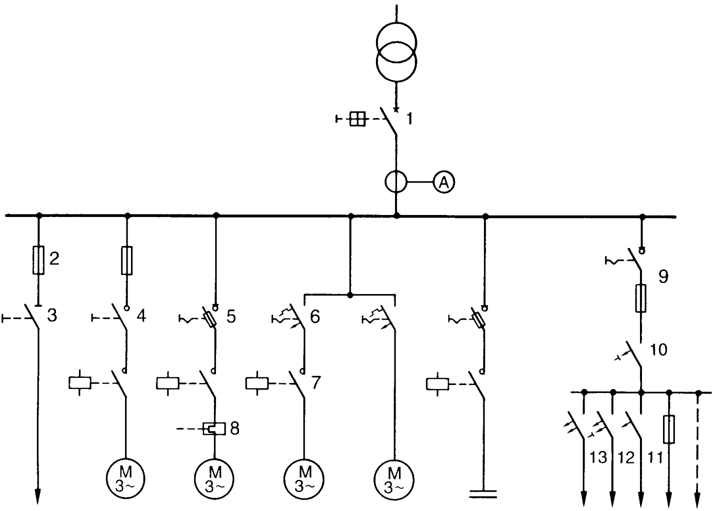


Fig. 7-1

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

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}	Utilization category B % of I_{CU}
25	–
50	50
75	75
100	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 ≤ 6	0.7	1.5
6 < I ≤ 10	0.5	1.7
10 < I ≤ 20	0.3	2.0
20 < I ≤ 50	0.25	2.1
50 < I	0.2	2.2

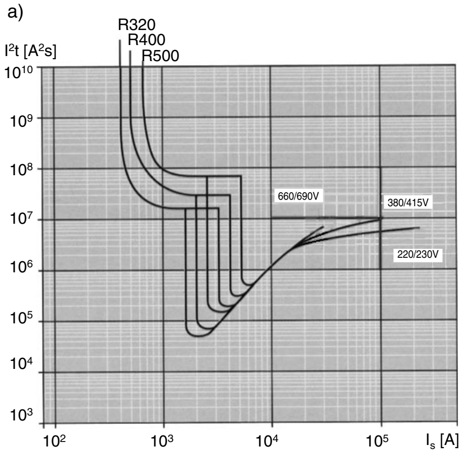


Fig. 7-2a

Limitation of let-through power $I^2 \bullet t$ 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

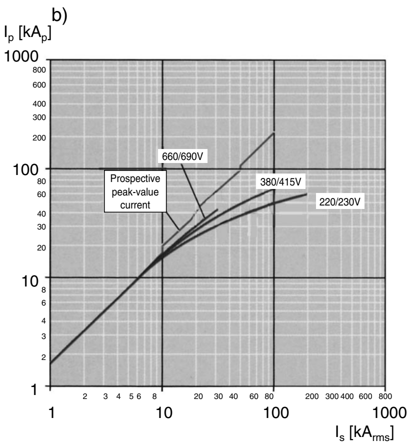


Fig. 7-2b

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 φ	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 φ	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 φ	Test-circuit power factor
L/R	Test-circuit time constant

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

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

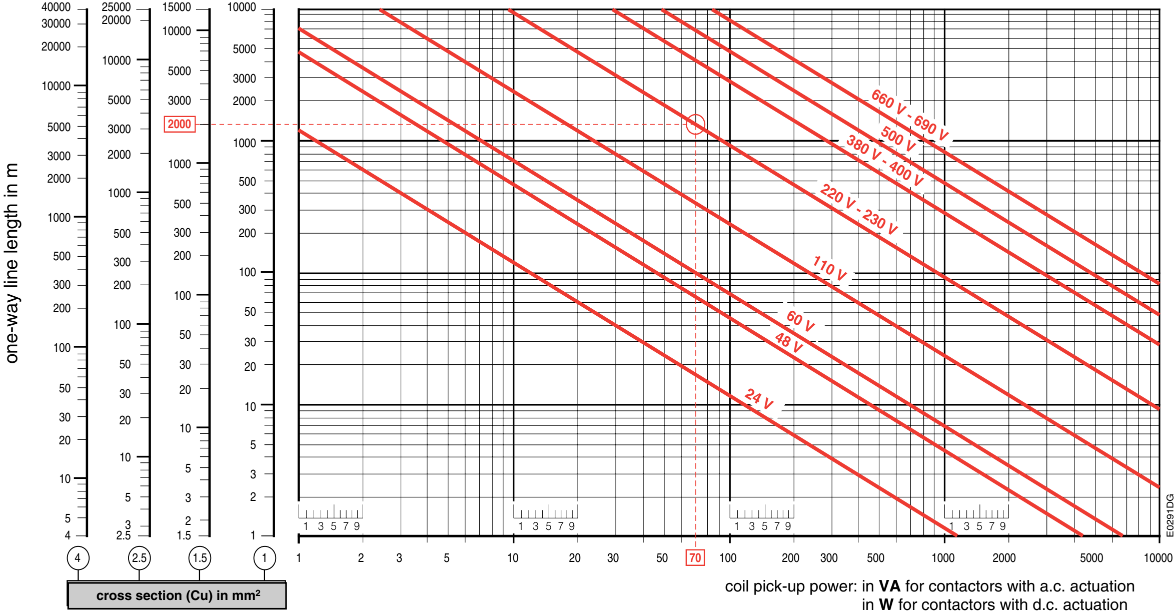


Fig. 7-3

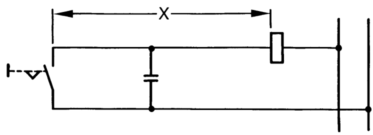
Permissible one-way control line length when closing contactors

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

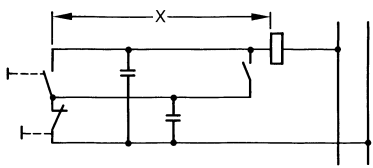


Fig. 7-4

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

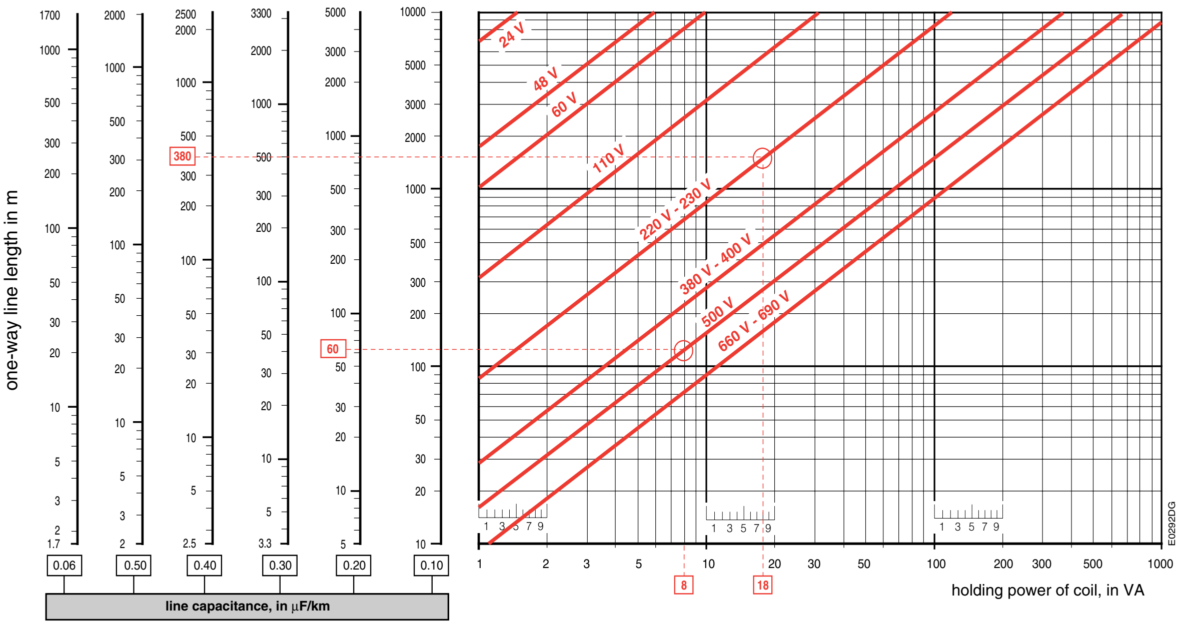


Fig. 7-5

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 

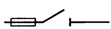
Load-break switch that meets the isolating requirements specified for a disconnector in the open position.

Disconnection (isolating function)

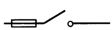
Function for isolating the voltage supply of the entire switchboard or system part, in which the switchboard or system part is disconnected from all energy sources for safety reasons.

Fuse combination unit

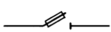
Load-break switch, disconnector or switch-disconnector and one or more fuses in a unit assembled by the manufacturer or in accordance with the manufacturer's directions.

Disconnector with fuses 

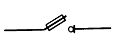
Unit comprising disconnector and fuses, in which one fuse is switched in series with the disconnector in one or more phases.

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)]			Breaking		
			I/I_e	U/U_e	cos φ	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.

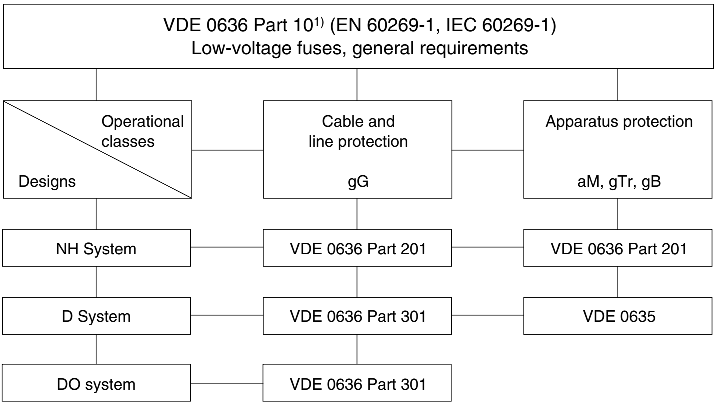
3) However it must be at least 1000 A.

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.



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

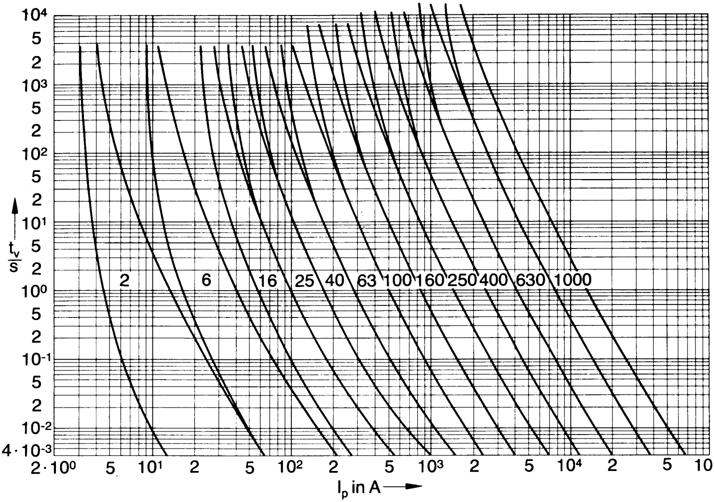
Test periods and currents for gG and gM fuse links as per VDE 0636 Part 10 and VDE 0636 Part 201

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.



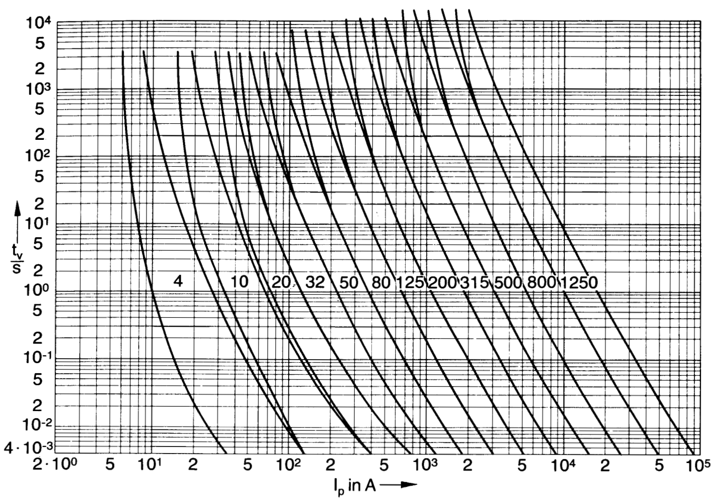


Fig. 7-6

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

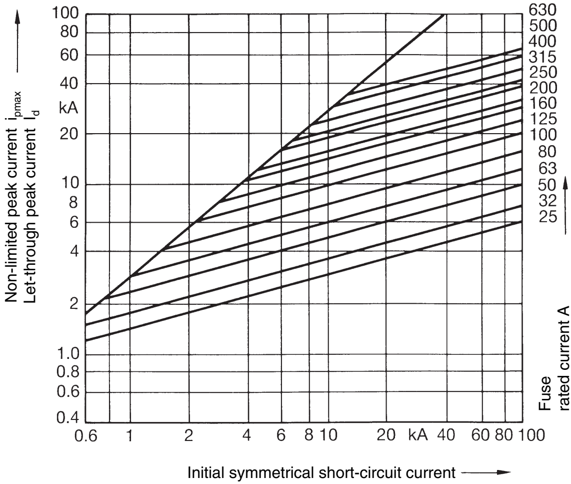


Fig. 7-7

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.

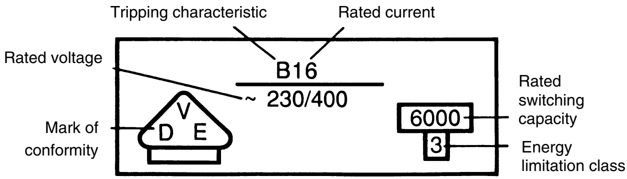


Fig. 7-8

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.

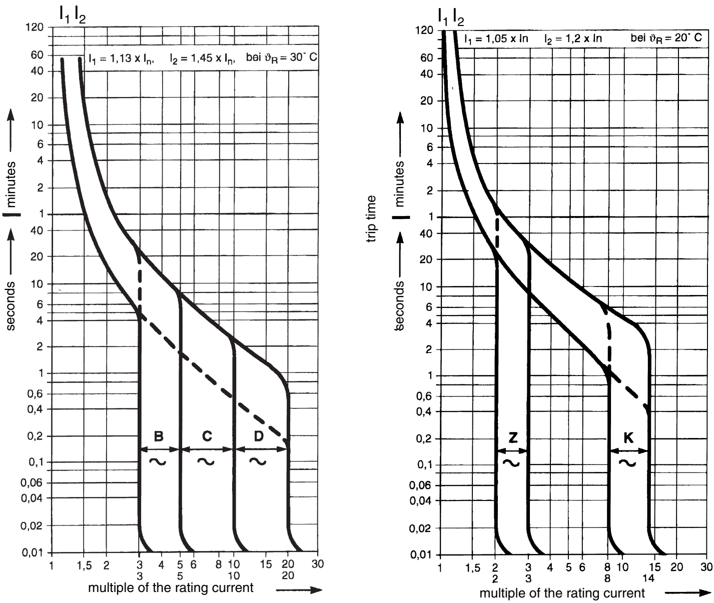


Fig. 7-9

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.

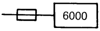
In Germany, only residual current-operated circuit-breakers of Class A for AC and pulsating DC fault currents are approved. In addition they must not be functionally dependent on the system voltage.

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

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.

Selectivity circuit-breaker – circuit-breaker

In general, selectivity by grading the response times of the electromagnetic tripping is not possible. It is only possible with an additional time delay of the short-circuit tripping. Here, the total break time t_A of the downstream circuit-breaker must be less than the minimum command time t_M of the upstream circuit-breaker. The grading times between two circuit-breakers should be a maximum of 100 ms, see Fig. 7-10.

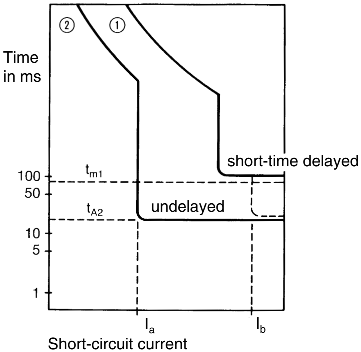


Fig. 7-10

Selectivity of 2 non-current-limiting circuit-breakers connected in series:

1 upstream circuit-breaker with short-time delay short-circuit tripping (e.g. power supply)

2 downstream circuit-breaker (e.g. feeder)

t_m minimum command time

t_A total break time

Selectivity with $t_{A2} < t_{m1}$

If the upstream circuit-breaker has additional instantaneous tripping, this series connection has partial selectivity for short-circuit currents < I_b.

Selectivity fuse – circuit-breaker

So long as the let-through power $I^2 \cdot t$ of the current limiting circuit-breaker on disconnecting is less than the melting energy of the backup fuse, this combination is selective (Fig. 7-11).

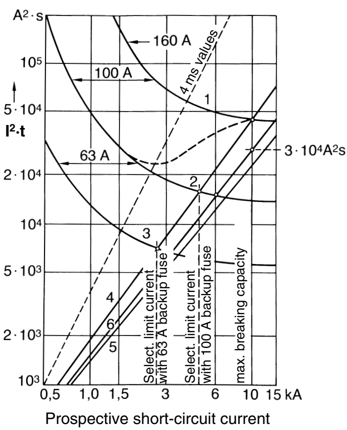


Fig. 7-11

Selectivity of a current-limiting circuit-breaker 25 A to a backup fuse 63 A and 100 A:

1 max. breaking values, 100 A fuse

2 max. melting values, 100 A fuse

3 min. melting values, 63 A fuse

4 max. let-through values, circuit-breaker 25 A

5 min. let-through values, circuit-breaker 25 A

6 max. let-through power values of circuit-breakers 25 A for 90% of all responses at I_k"= 10 kA

7

Selectivity non-current-limiting circuit-breaker – fuse / current-limiting circuit-breaker

Normally the selectivity limit is higher than the response value of the undelayed short-circuit tripping. The short-circuit current up to which this switchgear assembly is selective should be determined experimentally (Fig. 7-12).

Fig. 7-12

Selectivity of non-current-limiting circuit-breakers (undelayed or short-time delay) and current-limiting circuit-breaker/LS switches

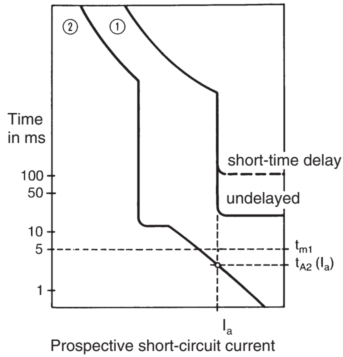
1 *upstream circuit-breaker*

2 *downstream circuit-breaker*

t_m *minimum command time*

t_A *total break time*

Selectivity at $t_{A2}\ (I_a) < t_{m1}$



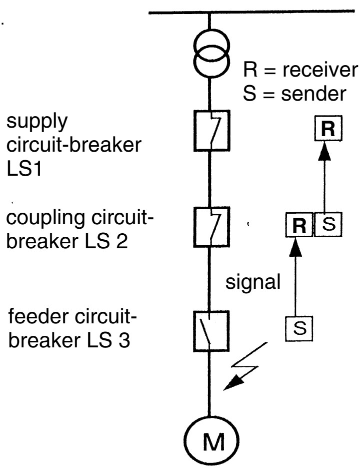
Release selectivity (zone selectivity)

With time selectivity, the grading time required between two circuit-breakers requires that a fault near the power supply is only disconnected with a large delay depending on the number of grading steps. The system of release selectivity avoids this disadvantage (Fig. 7-13).[1]

[1] Used throughout for the first time in the "Schwarze Pumpe" major power-plant project.

Fig. 7-13

Basic principle of release-selective tripping of faulty feeders



In the event of a release selective tripping, the circuit-breaker nearest the fault always reacts first. The fault is detected on the basis of the steepness of the fault current. Then the circuit-breaker nearest the fault position is determined and tripped by correspondence via communication modules from breaker to breaker, signal exchange within maximum 3 ms, thereby achieving a fault current duration of less than 100 ms.

If the fault current exceeds the switching capacity of a circuit-breaker, the nearest suitable circuit-breaker can be tripped by a corresponding signal. This enables selectivity even with backup protection.

Targeted preset delays can suppress spurious tripping caused by high motor-startup currents or also downstream fuses can be assured sufficient time for the current interruption.

Selectivity residual current-operated circuit-breaker - residual current-operated circuit- breaker

If selectivity is required for residual current-operated circuit-breakers connected in series, a selective master RCCB, identified by [S], must be used, Fig. 7-10. Master RCCBs with rated residual current $I_{\Delta n}$ = 300 mA at rated currents of 40 and 63 A are available.

These selective RCCBs are time-delayed in comparison to the standard RCCBs.

7.1.5 Backup protection

The arrangement of two overcurrent protection devices connected in series, which provides protection with or without the second protection device and prevents excessive stress on the second protection device, is referred to as backup protection.

Current-limiting circuit-breakers and fuses are best suited for backup protection. The let-through power value $I^2 \cdot t$ of the upstream short-circuit protection device must be less than the $I^2 \cdot t$ value of the protected device at its rated breaking capacity.

In contrast to the selectivity, the backup protection should always be experimentally confirmed.

Selectivity and backup protection are normally mutually exclusive. However, there are switching devices that can have both functions: The contact system opens dynamically when a high short-circuit current occurs without releasing the locking system of the the breaker mechanism, and it limits the short-circuit current; the short-circuit currents release trips with a delay if the downstream circuit-breaker does not interrupt the current.

7.2 Low-voltage switchgear installations and distribution boards

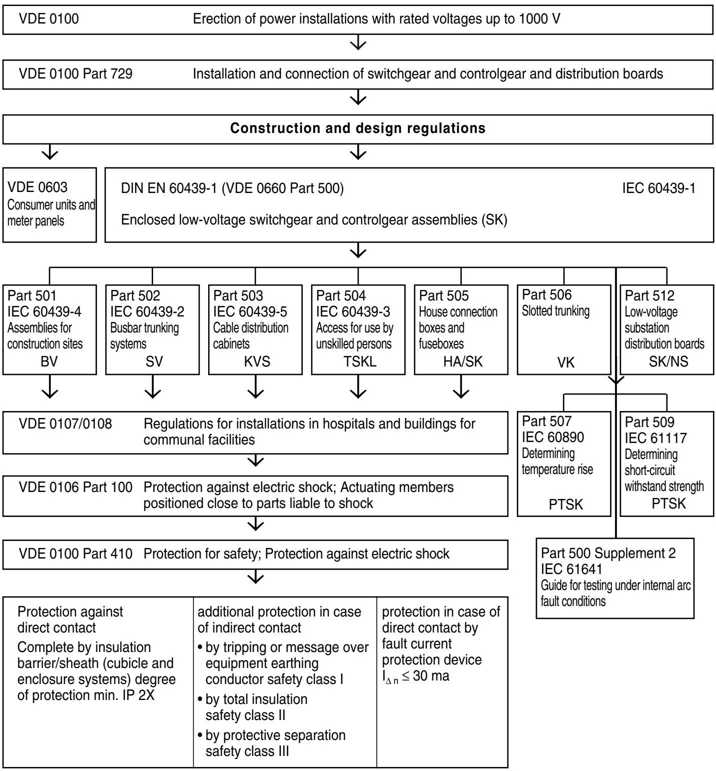
7.2.1 Basics

Low-voltage switchgear installations and distribution boards are used for power distribution, motor power supply and to supply building services.

Depending on the application, they include equipment for switching, protecting, conversion, control, regulation, monitoring and measurement. Because of the extremely varied applications and requirements – from operation of the distribution boards by untrained personnel to operation by trained electrical specialists in electrically seperated control rooms – different enclosure designs and equipment combinations tailored for the specific requirements are required. These applications are described in numerous standards and design regulations (Table 7-17).

Table 7-17

Construction and design regulations for low-voltage switchgear installations and distribution boards



Apart from the small distribution boards, all other low-voltage switchgear installations and distribution boards are considered under the heading low-voltage switchgear assemblies in the standard DIN EN 60439-1 (VDE 0660 Part 500) and the provisions in its subheadings. The base standard specifies the terms, the subdivision and the manufacturer's instructions for the designation of switchgear assemblies and also the operating and environmental conditions, the specified requirements and the testing (type and routine tests).

In recent years, the dimensions of switchgear assemblies have a basic grid of 25 mm (as per DIN 43 660) for flexible internal structure and for modular design. This technology provides the prerequisite for economical planning and manufacture of systems and simplifies later conversion in the event of changes and extensions. The preferred external dimensions are specified in the DIN 41485 standard.

7.2.2 Standardized terms

Only the most basic terms of the many specified in the DIN EN 60 439-1 (VDE 0660 Part 500) standard are listed below.

– *Switchgear assembly (SK)* Combination of one or more low-voltage switching devices with associated equipment for control, measurement, monitoring and the protection and process control units etc., fully assembled under the manufacturer's supervision, with all internal electrical and mechanical connections and design parts.

Note The manufacturer of the complete switchgear assembly has full responsibility also in case of the installation of purchased type-tested units/functional modules.

– *Type-tested low-voltage switchgear assembly (TSK//TTA = type tested assembly):* low-voltage switchgear assembly not substantially different from the original type or system of the switchgear assembly that was type-tested according to the standard.

Note This allows specified assembly work to be done outside the production premises of the manufacturer of the assembly for shipping and manufacturing reasons.

– Partially type-tested low-voltage switchgear assembly (PTSK//PTTA = partially type-tested assembly): low-voltage switchgear assembly (SK) consisting of type-tested and not type-tested modules derived from type-tested modules that have passed the relevant test.

Note Instead of the derivation from type-tested modules, the retention of the temperature rise limit as per VDE 0660 Part 507 and the short-circuit current capability as per VDE 0660 Part 509 may both be confirmed by calculation. A module can comprise one single switching device with the associated electrical and mechanical connections or one single enclosure.

The distinction between TSK and PTSK by the standard does not mean a subdivision into two classes of different quality. Both designs are equal.

The following configurations are among those standardized as units of switchgear assemblies:

– *Section:* unit of a switchgear assembly between two sequential vertical limit levels.
– *Sub-section:* unit of a switchgear assembly between two horizontal limit levels positioned one above the other in a section.
– *Compartment:* section or sub-section that is fully enclosed, except for the openings required for connections, control or ventilation.
– *Functional unit:* part of a switchgear assembly with all electrical and mechanical components required to meet the same function.
– *Fixed part:* a rack of equipment assembled and wired on a common support for fixed installation.

Note: cannot be removed under voltage, even if the rack is designed to be inserted on the supply side.

– *Removable part:* unit that can be removed from the switchgear assembly and replaced as a whole, even when the current circuit to which it is connected is live.
– *Withdrawable part:* removable part that can be placed in a position where an isolating distance is open while it is still mechanically connected to the switchgear assembly.
– *Type tests:* type tests are used to confirm compliance with requirements specified in the standards. Type tests are conducted on an example of a switchgear assembly or on those parts of switchgear assemblies that are repeatedly manufactured in the same or similar type. The tests must be conducted or commissioned by the manufacturer. The testing laboratory prepares a test certificate.
– *Routine testing:* routine testing is used to detect any material and manufacturing defects. Routine testing is conducted on every new switchgear assembly after assembly or on every transport unit. A second round of routine testing at the set-up area is not required. Conducting routine testing at the manufacturing plant does not release the installer of the switchgear assembly from the obligation of a visual inspection of the switchgear assembly after transportation and after erection.

7.2.3 Classification of switchgear assemblies

The variety of applications results in many different designs of low-voltage switchgear assemblies. They can be classified under different criteria. These criteria must be used to select a switchgear assembly suitable for the basic requirements of the specific application (Table 7-18).

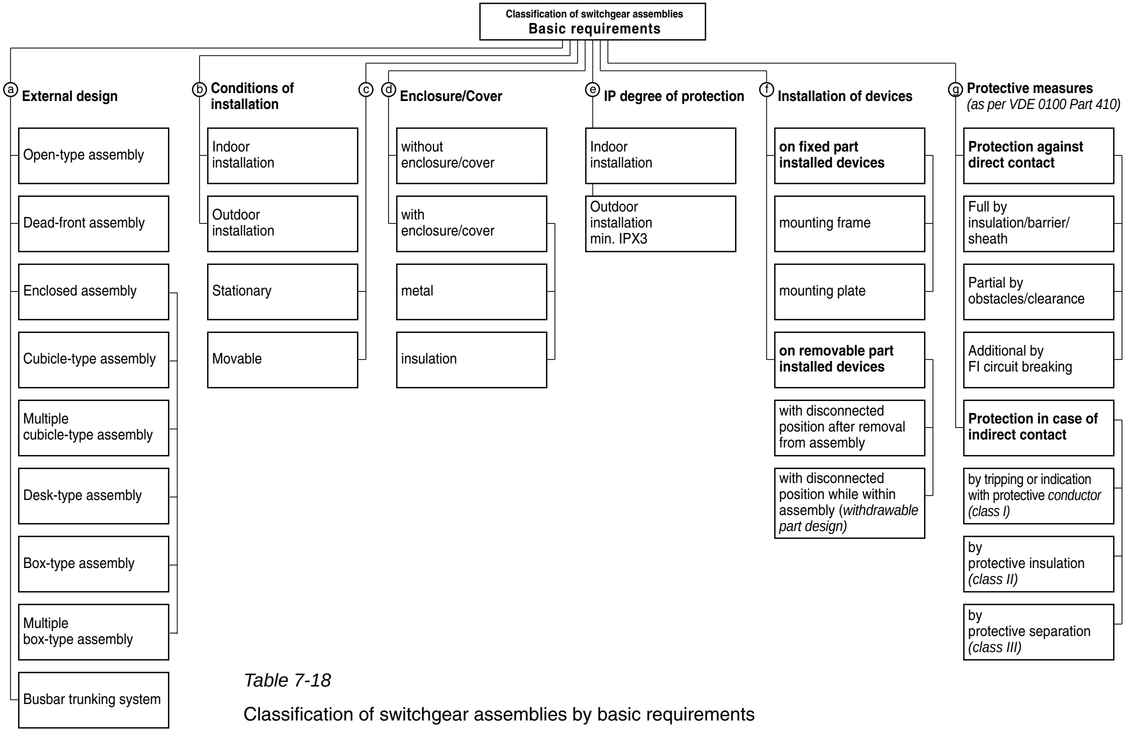


Table 7-18

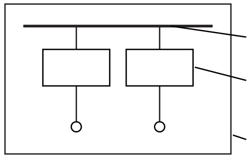
Classification of switchgear assemblies by basic requirements

7.2.4 Internal subdivision by barriers and partitions

A systematic nomenclature for the various options of internal subdivision as adapted to the changing market requirements, particularly as influenced by other European countries, was introduced with the recent edition of DIN EN 60439-1 (VDE 0660 Part 500) (Table 7-19).

Form 1

No internal subdivision



Key to symbols:

Busbars, including multiterminal busbars

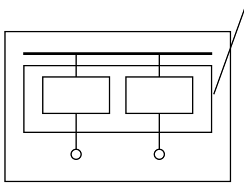
Functional unit(s) including terminals for connecting external conductors

Enclosure

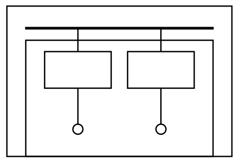
internal subdivision

Form 2

Subdivision between busbars and functional units



Form 2a
No subdivision between terminals and busbars



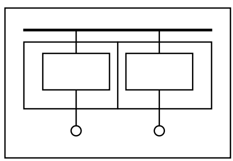
Form 2b
Subdivision between terminals and busbars

Form 3

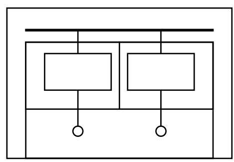
Subdivision between busbars and functional units

Subdivision between functional units

Subdivision between terminals and functional units



Form 3a
No subdivision between terminals and busbars



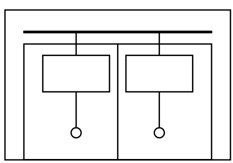
Form 3b
Subdivision between terminals and busbars

Form 4

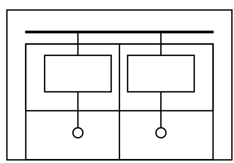
Subdivision between busbars and functional units

Subdivision between functional units

Subdivision between terminals and functional units



Form 4a
Terminals in the same subdivision as the connected functional unit



Form 4b
Terminals not in the same subdivision as the connected functional unit

Table 7-19

Forms of internal subdivision
according to DIN EN 60439-1 (VDE 0660 Part 500)

7.2.5 Electrical connections in switchgear assemblies

A classification with three letters for identifying the connection technology on fixed parts, removable parts and withdrawable parts is in preparation as Ammendment 12 (draft May 1993) to DIN EN 60439-1 (VDE 0660 Part 500). It works as follows

– the first letter refers to the connection point of the supply side of the main circuits,

– the second letter refers to the connection point of the feeder side of the main circuit,

– the third letter refers to the type of connection of the auxiliary circuits.

The following letters are used:

– the letter F for fixed connections (can only be connected or disconnected with tools)

– the letter D means connections that can be released by manual action (without tool), e.g. plug connectors

– the letter W means withdrawable part connections that are automatically connected or disconnected during insertion or withdrawal.

This means that three items are required to determine terminal connections precisely:

– example 1: FFF = fixed-part design

– example 2: WWW = withdrawable-part design

– example 3: WFD = removable-part design

– example 4: DFF = fixed-part design

7

7.2.6 Verification of identification data of switchgear assemblies

The high degree of safety of a switchgear assembly must be assured by verification of type tests and routine testing by the manufacturer. Table 7-20 shows the verifications and tests required for a type-tested switchgear assembly or partially type-tested switchgear assembly. In general, the user includes the requirements in the request for proposals. The manufacturer may select the type of verification depending on manufacturing technology or economical criteria.

Table 7-20

Verifications that the technical requirements for type-tested low-voltage switchgear assemblies (TTA) and partially type-tested l.v. switchgear assemblies (PTTA) are met

Seq. no.	Requirements to be tested	Section[1]		TSK		PTSK
1	Temperature rise limit	8.2.1	Type tests	Verification of non-exceeding of temperature rise limits by testing	Tests	Verification that temperature rise limits are not exceeded by testing, extrapolation of TSK or as per VDE 0660 Part 507
2	Dielectric withstand	8.2.2		Verification of dielectric withstand by testing		Verification of dielectric withstand as in section 8.2.2 or verification by dielectric test as in section 8.3.2 or verification of insulation resistance as in section 8.3.4 (see seq. no. 11)
3	Short-circuit current withstand strength	8.2.3		Verification of short-circuit current withstand strength by testing		Verification of short-circuit current withstand strength by testing, extrapolation of similar type-tested configurations or as per VDE 0660 Part 509
4	Effectiveness of the protective conductor	8.2.4		Verification of intact connection between		Verification of intact connection between
	Proper connection between exposed conductive parts of the switchgear assembly and protective conductor	8.2.4.1		exposed conductive parts of switchgear assembly and protective conductor by checking or resistance test		exposed conductive parts of switchgear assembly and protective conductor by checking or resistance test
	Short-circuit current withstand strength of the protective conductor	8.2.4.2		Verification of short-circuit current withstand strength of the protective conductor by testing		Verification of short-circuit current withstand strength of protective conductor by testing or corresponding design and configuration of the protective conductor (see section 7.4.3.1.1. last paragraph[1]
5	Creepage distance and clearances	8.2.5		Verification of creepage distance and clearances		Verification of creepage distance and clearances
6	Mechanical function	8.2.6		Verification of mechanical function		Verification of mechanical function
7	IP degree of protection	8.2.7		Verification of IP degree of protection		Verification of IP degree of protection
8	Wiring, electrical function	8.3.1	Routine testing	Visual inspection of switchgear assembly incl. wiring and if applicable electrical function test		Visual inspection of switchgear assembly incl. wiring and if applicable electrical function test
9	Dielectric withstand	8.3.2		Dielectric withstand test		Dielectric withstand test or verification of insulating resistance as in section 8.3.4 (see seq. no. 11)[1]
10	Protective measures	8.3.3		Checking protective measures and visual inspection of electrical continuity of the electrical protective conductor connection		Checking protective measures
11	Insulation resistance	8.3.4		–		Verification of insulation resistance if not tested as in section 8.2.2 or 8.3.2 (see seq. no. 2 & 9)[1]

1) DIN EN 60439-1 (VDE 0660 Part 500)

7.2.7 Switchgear assemblies for operation by untrained personnel

The special requirements for switchgear assemblies to which untrained personnel have access for control purposes, also referred to as “distribution boards”, are covered by DIN VDE 0660-504 (VDE 0660 Part 504) in connection with Ammendment DIN EN 60 439-3/A1 (VDE 0660 Part 504/A1).

Rated voltages of up to 300 V (AC against earth) and rated currents of up to 250 A are approved for these applications. There are some additional requirements in the context of type testing and verifications, such as:

– shock resistance of enclosure
– rust resistance
– resistance of insulation materials against heat and
– resistance of insulation materials against excessive heat and fire.

7.2.8 Retrofitting, changing and maintaining low-voltage switchgear assemblies

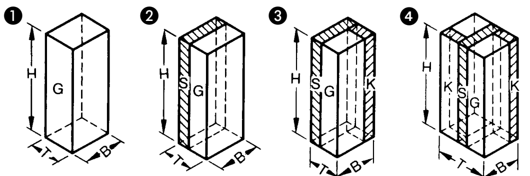
As per DIN EN 60439-1 (VDE 0660 Part 500), older switchgear assemblies manufactured before the beginning of the validity of the standard in its current version do not require retrofitting.

If a switchgear assembly is changed or retrofitted, the requirement for a test depends on the nature and scope of the intervention and must be decided on a case by case basis. Fundamentally, anyone who makes a change or retrofit takes over the manufacturer’s responsibility.

The manufacturer must always set maintenance and service schedules. If the switchgear assembly is not continuously monitored by a qualified electrician, VBG 4 (accident prevention regulations of the German professional association of precision mechanical and electrical technology, April 1996) in Table 1 “Testing electrical systems and stationary equipment” requires a test at least every 4 years. The test must be conducted by an electrical technician.

7.2.9 Modular low-voltage switchgear system (MNS system)

Cost-effective, compact switchgear systems require design and production documentation for functional units in the form of modules that can be combined as necessary (combination modules). The basis for the design is a basic grid dimension E of 25 mm (DIN 43660) in all three dimensions (height, width, depth). Fig. 7-14 gives an overview of the modular arrangement options and the usable bay dimensions of the MNS system.



B	T	H
400		
600	400	2200
800	600	
1000	800	
1200	1000	
	1200	

Dimensions in mm

Fig. 7-14

The most common dimensions of sections of the MNS system
1 to 3 = single control, 4 = double control (duplex),
G = equipment compartment, K = cable terminal compartment, S = busbar compartment (preferred dimensions underlined)

The standardized subdivision of a section into various functional compartments, i.e. equipment compartment, busbar compartment and cable terminal compartment, offers advantages not just for design but also in operation, maintenance, change and also safety.

The basic design of a section with the configuration of the busbars and the distribution busbars for supplying power to fixed, removable or withdrawable parts is shown in Fig. 7-15. A particular advantage of the MNS system is the configuration of the busbars at the rear of the section (in contrast to the formerly common configuration above in the section). It offers supplementary safety for personnel in the event of an accidental arc on the busbar, provides space for two busbar systems if required, enables an advantageous back-to-back configuration with only one busbar system and allows cables to be fed in through cable racks from above.

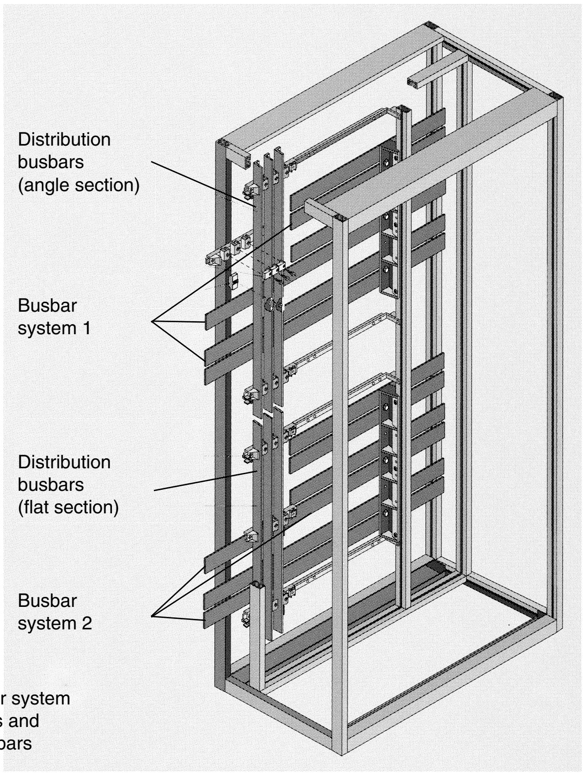


Fig. 7-15

MNS switchgear system
Busbar systems and
distribution busbars

The configuration of the function wall with the access openings for the plug-in contacts is shown in Fig. 7-16. The function wall of the MNS system, as the most important internal subdivision, provides the electric shock protection (IP20) and the arc barrier between equipment compartment and busbar compartment. This is achieved with form-design features only without automatically actuated protective shutters.

When the fixed parts and the withdrawable parts are inserted, labyrinthine insulation configurations are formed around the plug-in contacts, safely preventing flashovers between the conductors.

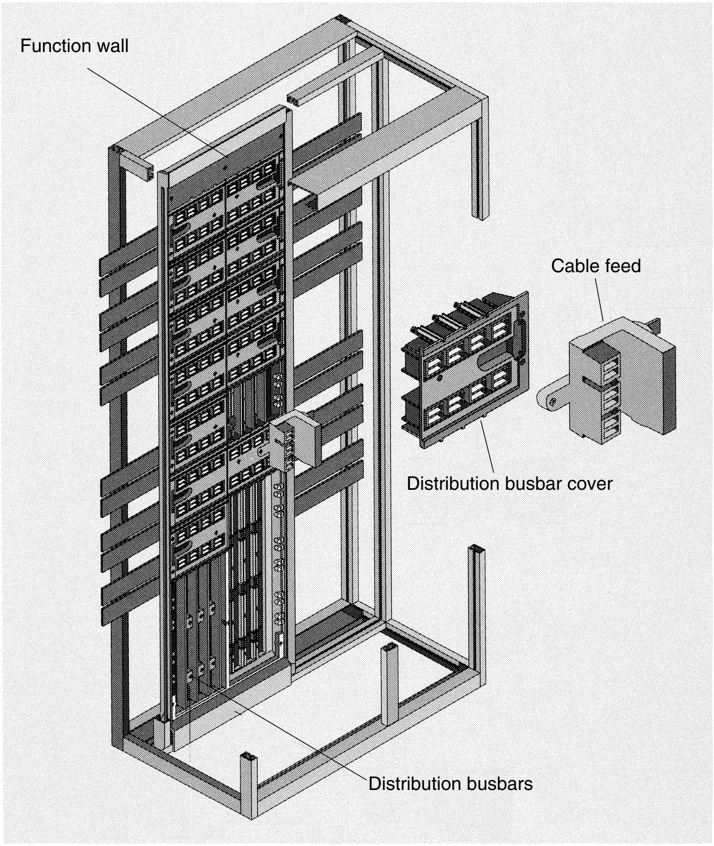
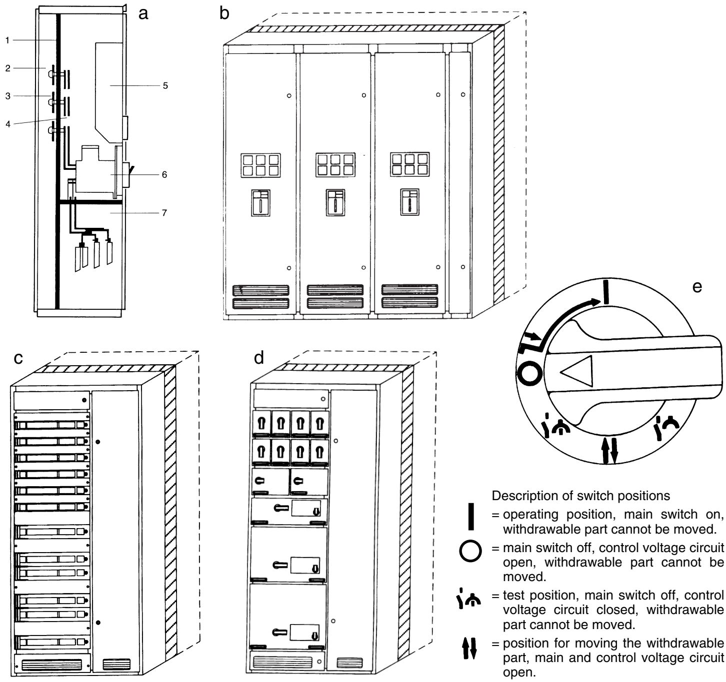


Fig. 7-16

MNS switchgear system
configuration of function wall

Fixed and withdrawable parts basically have plug-in contacts as busbar-side terminals. In fixed parts the equipment is arranged two-dimensionally on the functional units, while it has a three-dimensional design in withdrawable parts with maximum usage of the cabinet depth. With a majority of smaller modules (<7.5 kW), the demands on switch cabinet volume are around 40 % less with the withdrawable part design. The withdrawable part sizes are adjusted to one another to enable small and large modules to be economically combined in one bay (Fig. 7-17). Later changes of the components can be made without accessing the bay function wall. Reliable mechanical and electrical interlocking of the switchgear prevents operating errors when moving the withdrawable parts.



Description of switch positions

I = operating position, main switch on, withdrawable part cannot be moved.

O = main switch off, control voltage circuit open, withdrawable part cannot be moved.

= test position, main switch off, control voltage circuit closed, withdrawable part cannot be moved.

= position for moving the withdrawable part, main and control voltage circuit open.

= isolated position, withdrawable part withdrawn by 30 mm (to stop), main and control contact open, withdrawable part mechanically locked.

Fig. 7-17

Bay types of the MNS system

a) and b) cutaway view and view of MNS sections with circuit-breakers
1 arc partition, 2 busbar compartment, 3 primary busbar, 4 distribution busbar, 5 instrument recess, 6 circuit-breaker and 7 cable terminal compartment

c) MNS section with power output modules in strip form

d) MNS section with withdrawable units

e) Control switch for withdrawable unit

The circuit diagrams of typical motor starters, which can be obtained as fixed or withdrawable parts, are shown in Fig. 7-18. Tables 7-21 and 7-22 have an initial selection of the associated module sizes. MNS assemblies can be supplied as arc-resistant, shock-resistant, vibration-resistant and earthquake-resistant as required for specific quality demands. Table 7-23 shows an overview of the breadth of application of the system.

a b c

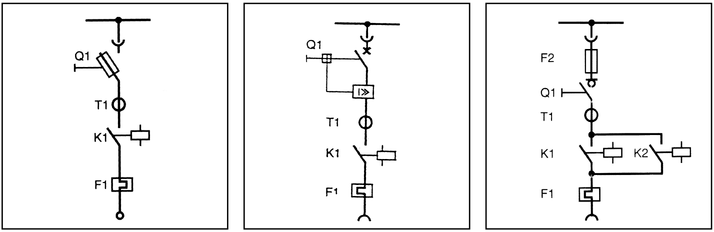


Fig. 7-18

Examples of standard modules with circuit diagrams for motor starter
a) with fuse switch-disconnector and thermal relay (fixed-part technique)
b) with circuit-breaker and thermal relay (withdrawable-part design)
c) with load-break switch, fuse, thermal relay and reversing (withdrawable-part design)

Table 7-21

Standard type program motor starter with HRC fuses, with thermal relay

Rated current I_e (AC3/400 V~) A	Motor ratings under AC3 (occasional jog mode 0.5% under AC4 permissible) at 400 V~ kW	500 V~ kW	690 V~ kW	Module dimensions Height One direction of rotation	With reversing
11.5	5.5	5.5	5.5	5 E	5 E
15.5	7.5	7.5	7.5	5 E	5 E
30	15	15	15	5 E	7 E
44	22	30	30	7 E	9 E
60	30	37	37	7 E	9 E
72	37	45	40	7 E	9 E
85	45	59	–	11 E	11 E
105	55	75	110	17 E	17 E
140	75	90	110	17 E	17 E
205	110	132	160	23 E	23 E
295	160	200	250	29 E	37 E
370	200	250	355	31 E	39 E
460	250	355	355	31 E	–

Basic grid dimension E = 25 mm

Table 7-22

Standard type program motor starter with circuit-breaker, with thermal relay

Rated current I_e (AC3/400 V~) A	Motor ratings under AC3 (occasional jog mode 0.5% under AC4 permissible) at 400 V~ kW	500 V~ kW	690 V~ kW	Module size Height One direction of rotation	With reversing
3.5	1.5	1.5	–	8E/4	8E/4
5	2.2	2.2	–	8E/4	8E/4
11.5	5.5	5.5	–	8E/4	8E/4
15.5	7.5	7.5	–	8E/4	8E/4
30	15	15	–	8E/4	8E/4
44	22	30	–	8E/4	8E/4
60	30	37	–	8E/2	8E/2
72	37	45	40	8E	8E
85	45	59	75	8E	8E
105	55	75	110	16E	16E
140	75	90	110	16E	16E
205	110	132	160	16E	16E
295	160	200	250	24E	24E
370	200	250	355	24E	–
460	250	355	355	24E	–

Basic grid dimension E = 25 mm

Table 7-23

Type-tested switchgear assembly MNS
System characteristic data

Electrical parameters

Rated voltages	rated insulation voltage U_i	1000 V 3~, 1500 V
	rated operational voltage U_a	690 V 3~, 750 V–
	rated impulse withstand voltage U_{imp}	8 kV
	overvoltage category	III
	pollution severity	3
	rated frequency	to 60 Hz
Rated currents	**busbars:**	
	rated current I_e	to 6300 A
	rate peak withstand current I_{pk}	to 250 kA
	rated short-time withstand current I_{cw}	to 100 kA
	distribution busbars:	
	rated current I_e	to 2000 A
	rate peak withstand current I_{pk}	to 165 kA
	rated short-time withstand current I_{cw}	to 86 kA

(continued)

Table 7-23 (continued)

Mechanical parameters

Dimensions	cubicles and supporting structure preferred module sizes, height preferred module sizes, width preferred module sizes, depth basic grid dimension hinged frame for installation of electronics tiers	DIN 41488 **2200** mm 400, **600,** 800, **1000**, 1200 mm 400, **600,** 800, **1000**, 1200 mm E = 25 mm as per DIN 43660 DIN 41494, Sheet 1, ASA C 83.9
Surface protection	supporting structure internal subdivision cross section enclosure	Al-Zn coating Al-Zn coating galvanised paint RAL 7032, pebble grey
Degrees of protection	as per IEC 60529 or DIN 40050	IP 00 to IP 54
Plastic parts	CFC and halogen-free, flame-retardant, self-extinguishing	DIN VDE 0304 Part 3
Internal subdivision	section - section busbar compartment-cable terminal compartment busbar compartment-equipment compartment equipment compartment-cable terminal compartment sub-section - sub-section	
Specifications	IEC 60439-1, EN 60439-1, VDE 0660 Part 500, BS5486, UTE63-410	
Special qualification	German Lloyd, Hamburg (shipping) Pehla Test Laboratory, Ratingen (internal arcing as per IEC 60298, Appendix AA and VDE 0660 Part 500 Supplement 2) KEMA, Arnheim NL (internal arcing) Federal Ministry for Regional Planning, Building and Urban Development, Bonn (shelters) ABB testing laboratory, Mannheim (induced vibrations, KTA 2201.1 and 2201.4, DIN IEC 60068 Part 2)	

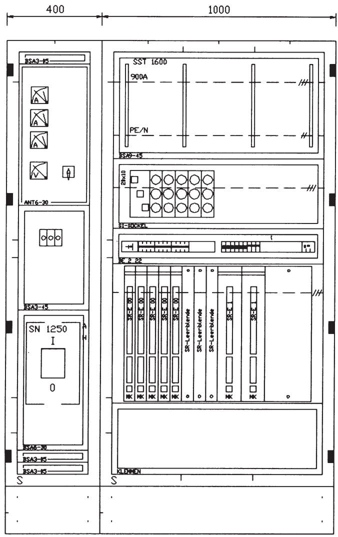
For particularly demanding control tasks in industrial plants with a large number of smaller mechanisms with high switching frequency, such as is found in power plants, ProMNS system withdrawable parts can be used in MNS low-voltage substations. These have thyristor power controllers as primary switching device for power of up to 5.5 kW. This makes them maintenance-free and suitable for virtually unlimited switching frequency. The heat produced by the semiconductor modules is dissipated to the ambient air primarily via cooling fins at the front of the withdrawable part. The withdrawable part also includes fuses as additional short-circuit protection and a switch-disconnector for isolation. For higher outputs, there are also ProMNS withdrawable parts with power contactors instead of the thyristor controllers.

7.2.10 Low-voltage distribution boards in cubicle-type assembly

For smaller distributors with busbar currents to 1600 A, there are specially designed cabinet solutions with sheet steel enclosures (protective earthing, safety class I, Fig. 7-19) and also with insulated enclosures (protective insulation, safety class II, Fig. 7-20). The cabinet and enclosure sizes are modular in design, enabling the elements to be combined economically with one another.

Fig. 7-19

Sheet steel distribution board KNS-S with power output modules in strip form (vertical)



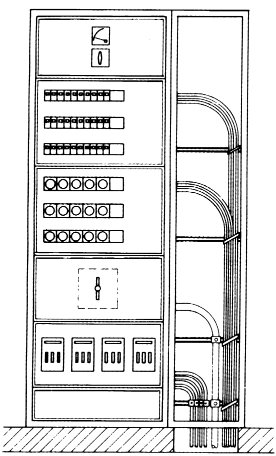


Fig. 7-20

Insulated distribution board KNS-I with cable compartment

Table 7-24 Technical data of KNS-S and KNS-I distribution boards in cubicle-type assembly

		KNS-S	**KNS-I**
Electrical parameters	rated operational voltage rated insulation voltage rated frequency	690 V 3 ~ 1000 V 3 ~, 1200 V– to 60 Hz	690 V 3 ~ 1000 V 3 ~, 1200 V– to 60 Hz
	rated current of the busbars rated peak-withstand current of the busbars rated short-time-withstand current (1s) of the busbars	to 1600 A to 90 kA to 45 kA	to 1250 A to 90 Ka to 45 kA
Dimensions	cubicles height width depth	1300, 1900 mm 400, 700, 1000 mm 300, 400, 600 mm	500, 1000, 2000 mm 350, 650, 950 mm 200, 400 mm
	basic grid dimension	E = 25 mm as per DIN 43660	E = 25 mm as per DIN 43660
Dimensions	– enclosure – device coverings – rear walls – base	sheet steel RAL 7035, light grey fibre glass reinforced polyester RAL 7035, light grey sheet steel AIZn (Al-Zn) sheet steel RAL 7035, light grey	insulation* RAL 9011, black fibre glass reinforced polyester RAL 7035, light grey Resopal RAL 7032, pebble grey sheet steel RAL 7035, light grey sheet steel, aluminium RAL 7035, light grey
Protective measures		safety class I	safety class II
Degrees of protection	as per IEC 60529, DIN 40050	IP 30, IP 40, IP 55	IP 30, IP 40, IP 54
Specifications	type-tested switchgear assembly (TSK) and partially type-tested switchgear assembly (PTSK)	IEC 60439-1, EN 60439-1 VDE 0660 Part 500	IEC 60439-1, EN 60439-1 VDE 0660 Part 500
	fire behaviour		VDE 0304 Part 3, Level BH 2
Shock safety			Application for civil defence shelters to control class RK0.63/6.3 Degree of safety B

* Polyurethane hard integral foam, without CFC component and chlorine-free

7.2.11 Low-voltage distribution boards in multiple box-type assembly

The INS box system has housings of high-quality plastic (polycarbonate), placing it in safety class II. It can be used with busbar currents of up to 1000 A. Fig. 7-21 shows examples of the structure of housings with flange mountings, Table 7-25 shows how the INS system can be used.

1 Wedge
2 Cotter way
3 Self-adhesive gasket
4 Flange mounting

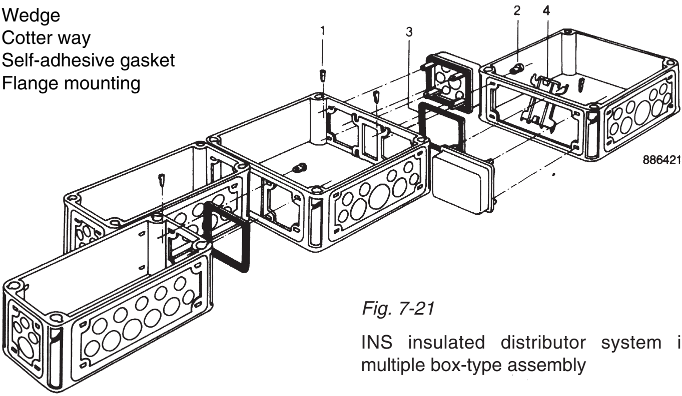


Fig. 7-21

INS insulated distributor system in multiple box-type assembly

Table 7-25

Technical data of the INS insulated distribution board system

Electrical parameters	
Rated insulation voltage	1000 V 3~, 1200 V-
Rated operational voltage	690 V 3~, 800 V–
Rated current of busbars	200 A, 400 A, 630 A, 1000 A
Rated current of incoming units	1000 A
Rated peak withstand current (peak value)	60 kA
Rated short-time-withstand current (1 s)	29 kA
Mechanical parameters	Modular enclosure sizes:
Enclosures (external dimensions)	150 x 300 mm 300 x 300 mm 450 x 300 mm 600 x 300 mm 600 x 600 mm
Basic grid dimension	25 mm
Enclosure	
Box, cover, insertion flange, cable socket etc.	Thermoplast (maintenance-free)
Resistance against:	Inorganic acids, organic acids, oxidation and reduction agents, salt solutions and many fats, waxes and oils.
Colour of housing parts	RAL 7032, pebble grey
Device covering	RAL 2003, pastel orange
Protective measures	Safety class II
Degrees of protection as per IEC 60529/DIN 40050	IP 65: full electric-shock protection, Protection against dust entry (dustproof), Protection against water from all directions (spray water)
Specificatons	
Type-tested	IEC 60439-1, EN 60439-1
Switchgear assembly (TSK)	VDE 0660, Part 500 VDE 0110 as per Group C
Fireproof as per	VDE 0304, Part 3, Level II b
Shock safety	RK 0.63/6.3

The heat generated in the built-in devices (Section 7.3.1) and the heat sources in the surroundings are particularly important with the distribution board in box-type assemblies. For this reason, when operating distribution boards in the open, even under a roof, it should be considered that temperature variations greater than 50 °C may occur. If the distribution board is subject to direct sunlight during the day and cooling at night, condensation is likely to form. This may be a serious danger to the functioning of the equipment and may result in arcing. To prevent such problems, installation of ventilation openings or ventilation inserts is recommended, with due regard to the degree of protection required. This should be considered in the design of the distribution board.

7.2.12 Systems for reactive power compensation

The reactive power modules for the MNS system are designed to conform to the installation dimensions of the system, i.e. they are designed for a 600 mm wide and 400 mm deep equipment compartment. Four or five modules and one controller unit fit into one switchgear cubicle. The direct association of the compensation modules with the electrical equipment (motor feeder modules) enables a very compact design. On the supply side, the plug-in contacts allow the fixed-part modules to be replaced quickly by electrical technicians when necessary. However, the modules are also available in withdrawable part design.

Table 7-26

Technical data of modules for reactive power compensation with dry capacitors

Rated system voltage	Provision with harmonic filter coil	Module output
400 V ~	0%	4 x 10 kvar, 4 x 12.5 kvar, 3 x 20 kvar, 3 x 25 kvar
	5.67%, 7%	2 x 10 kvar, 2 x 12.5 kvar, 2 x 20 kvar, 2 x 25 kvar, 1 x 40 kvar, 1 x 50 kvar
	12.5%, 14%, 15%	2 x 10 kvar, 2 x 20 kvar, 1 x 40 kvar
	5/12.5%, 5.67%/12.5%	1 x 20 kvar, 1 x 40 kvar
500 V ~	0%	4 x 10 kvar, 3 x 20 kvar
	5.67%, 7%	2 x 10 kvar, 2 x 20 kvar, 1 x 40 kvar
	12.5%, 14%, 15%	2 x 10 kvar, 2 x 20 kvar, 1 x 40 kvar
	5/12.5%, 5.67%/12.5%	1 x 20 kvar, 1 x 40 kvar
690 V ~	0%	4 x 10 kvar, 4 x 12.5 kvar, 3 x 20 kvar, 3 x 25 kvar
	5.67%, 7%	2 x 10 kvar, 2 x 12.5 kvar, 2 x 20 kvar, 2 x 25 kvar, 1 x 40 kvar, 1 x 50 kvar
	12.5%, 14%, 15%	2 x 10 kvar, 2 x 20 kvar, 1 x 40 kvar
	5/12.5%, 5.67%/12.5%	1 x 20 kvar, 1 x 40 kvar

7.2.13 Control systems for low-voltage switchgear assemblies

Today's automated, advanced designs for operation of low-voltage systems for power distribution, supply of power for motors and connection to the controls of higher-order control systems require control components based on microprocessors even for low-voltage switchgear installations. ABB supplies the INSUM system as such a control system (Fig. 7-22). The versatile protection and control functions of every single motor starter are controlled by Motor Control Units (MCU) in the INSUM system. The operator at the switchgear assembly can access and read out measured values on a simple menu-controlled operation and display device (Human Machine Interface HMI) to control up to 128 MCUs, i.e. motors. INSUM offers the following functions, which can be used as required:

Protection tasks such as:
- overload protection/automatic restart
- low-load indicator
- off-load protection
- blocking protection
- phase failure monitoring
- autoreclosure blocking
- safety interlocking
- thermal overload protection by thermistor
- loss of supply monitoring/sequential starting of motors after voltage recovery
- earth-fault detector
- cyclic bus monitoring/fault protection

Control functions:
- control of the motor starter/circuit-breaker via the MMI, the local control panel, with the integrated INSUM OS monitor workstation or the higher-order process control system
- test function

Measured and metered value recording, such as:
- phase currents
- voltages
- power outputs
- earth-fault current
- switching cycle counter
- operating hours

Signalling functions:
- status messages and signals
- warning and fault messages in plain text in the local language

Communications functions:
- use of the LON open intersection bus (Local Operating Network)
- direct integration into ABB ADVANT OCS process control system and Freelance 2000 using LON
- protocol converters (gateways) such as for PROFIBUS DP, MODBUS RTU or ETHERNET TCP/IP are available for serial connection to all PLT systems of other manufacturers.
- parameter setting and event logging with trending function with INSUM OS PC control station, monitor workstation or laptop.

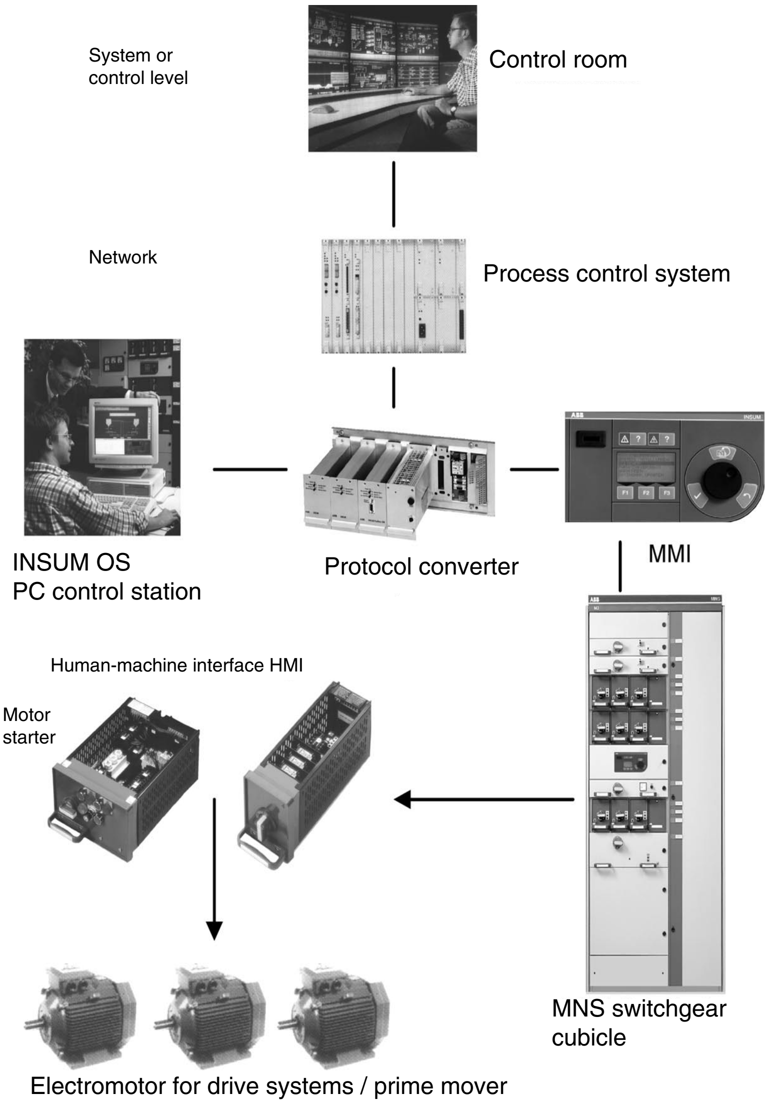


Fig. 7-22

Structure of INSUM control system

Control variants are available for the various types of drive systems such as direct starters, reversible starters, star-delta starting, Dahlander starters, pole-changing switches, servo-motor starting (with or without inching service), soft starters (with or without easy gradient) or latch-locked switches. They are selected in the MCU by the drive-type parameter. The MMI allows the user easy access to the INSUM system. The desired measured values and status can be read out here and switching operations can be conducted. The parameter setting can also be queried or parameters can be set by yourself. Setting parameters means that the characteristic values (e.g. drive-type and motor data of the equipment) are saved in the control system.

INSUM allows the Motor Control Centres to be linked to the higher-order process control system over intersection bus connections (Fig. 7-22). The protocol converters (gateways) adapt to the specific hardware and software requirements of the control system as required.

Implementation of INSUM, integrated over intersection bus connections into the process control system (PCS), has been shown to reduce investment costs significantly. In addition, INSUM makes it easier for the user to operate the system and make any changes and maintenance required. Full monitoring and implementation of maintenance work as required and not to a set period allows significant reduction of operating expenses.

INSUM has already proven itself in mechanical engineering, in the chemical industry, in paper and pulp manufacture, with power supply companies, in balance of powerplant, in sewage treatment systems and even on offshore drill rigs and ships.

In more complex power network systems, there are separate control systems for medium voltage and low voltage and for building services (e.g. AREADAT from ABB). This requires different workstations with different operational philosophies. The ABB INScontrol system enables these subsystems to be integrated. The operator has an overview of the entire structure in one single display and has access to all levels of the network through the system. INScontrol shows the user displays of systems, event lists and alarm lists and prompts the operator when switching operations are required.

INScontrol shows the system structure organized on one bay level and one system level, and also a common control level. At section level, autonomously operating equipment is used, which can be adapted to the specific protection, control, regulation and monitoring tasks with the aid of programmable functions. The system level above the section units in the system hierarchy independently controls and monitors communications, enables system-based process data query and is the link to the next level of the hierarchy. All data from the individual processes is bundled at the control level, allowing the operator to fully monitor and control the entire system (see also Section 14.4).

7.3 Design aids

Some suggestions for the design of low-voltage switchgear assemblies are given below. In every case, they will need to be adapted for the actual system conditions.

7.3.1 Keeping to the temperature rise limit

The limit temperatures that must be maintained for a TTA are listed in Table 2 (DIN EN 60439-1 (VDE 0660 Part 500). An ambient temperature of max. 40 °C or 35 °C in 24-hour equipment is specified as a base. For example, this means that:

– Conductor terminals: 35 °C + 70 K (conductor) = max. 105 °C
– Operating parts: 35 °C + 15 K (metal) or + 25 K (plastic) = max. 50 °C or 65 °C
– Enclosures: 35 °C + 30 K (metal) or + 40 K (plastic) = max. 65 °C or 75 °C

If the system has to be subjected to higher ambient temperatures (export = 55 °C), the same limit temperature must be maintained in the substation design. This is preferably achieved by using a lower component density for the switchgear or by improved ventilation of the cubicles (including forced ventilation).

Table 7-26

Examples of typical power dissipation sources in a section, MNS system, protection class IP40, I_B = rated current,
I_M = load current,
P_V = rated power loss (load current).

Equipment	Dimensions	I_B	I_M	P_V
Motor starter 2 kW	8 E/4	15 A	9 A	9 W
Motor starter 7.5 kW	8 E/4	15 A	10 A	12 W
Motor starter 55 kW	8 E	100 A	80 A	50 W
Moulded case circuit-breaker 400 A	8 E	400 A	400 A	60 W
Load-break switch with fuse 63 A	4 E	63 A	50 A	8 W
Load-break switch with fuse 125 A	4 E	125 A	100 A	25 W
Load-break switch with fuse 250 A	4 E	250 A	200 A	70 W
Load-break switch with fuse 400 A	6 E	400 A	320 A	160 W

Exact values for all installed switchgear, busbar trunking and wiring arrangements must be supplied by the manufacturers/suppliers.

Fig. 7-23 shows the connection between the degree of protection, the heat load of a switchgear cubicle and the influence of the ambient temperature. If the power dissipation generated in a switchgear cubicle reaches the permissible value according to the corresponding curve, an air temperature of 60°C appears in the area of the upper sub-section. The temperature gradients from top to bottom are taken into account by the general rule of installing the functional units for the heavier drives at the bottom and those for the lighter at the top.

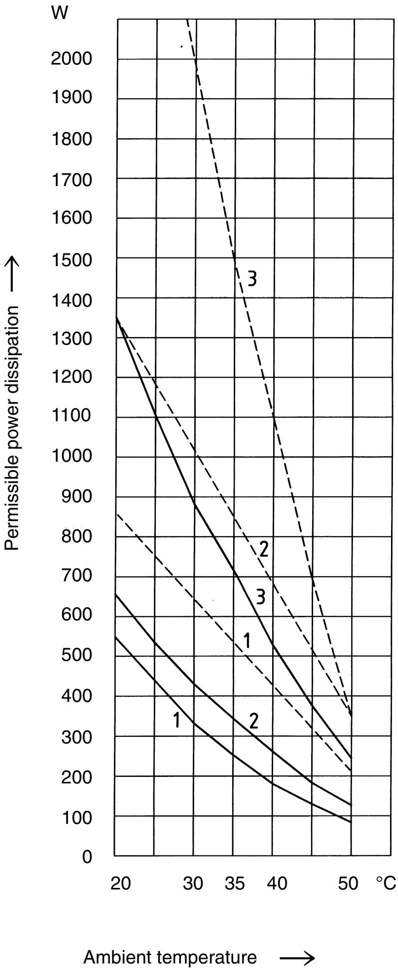


Fig. 7-23

Typical values for the maximum permissible effective power dissipation in an MNS switchgear cubicle

Dimensions of the switchgear cubicle(middle cubicle)
height 2200 mm
width 1000 mm
depth 600 mm

Equipment compartment
width 600 mm

Clearance from wall
8 cm

Legend
______ degree of protection IP52 to IP54
---------- degree of protection IP32 to IP42

1 = Withdrawable-part design
2 = Fixed-part design
3 = Switchgear cubicle with open-type circuit-breakers

7

7.3.2 Internal arc test

When developing switchgear assembly designs, the primary goal must be to avoid faults that could result in internal arcing.

With this in mind, the design of the electrical and mechanical interlocking (withdrawable-part versus subsection) must be considered with respect to withdrawable-part design. Another important point is the requirement for high availability. This means that even if accidental arcing does occur, the entire assembly should not fail and be damaged but at worst one section – or even better – only the affected withdrawable part will be destroyed. In addition, if such a malfunction occurs, the operating staff should not be endangered.

The occurrence of internal arcing can be greatly restricted with suitable design, such as with internal subdivision of a switchgear cubicle. The effects of accidental arcing can be limited primarily by reducing the duration of arcing.

This can be achieved with the aid of suitable sensors that will react to light, temperature or pressure and trip the backup feeder circuit-breaker, in general the incoming feeder circuit-breaker. This will result in arcing periods of 40 to 80 ms. Three-pole shorting links operating in connection with the incoming feeder circuit-breaker will enable even shorter arcing periods. Both methods have the disadvantage of leaving the entire low-voltage switchgear assembly without power when the incoming feeder circuit-breaker is tripped, with the result that a large part of the system fails.

The better technical solution is to use suitable design measures to ensure that the arc quenches itself after a few milliseconds in the event of such a fault, so only the faulty functional unit will fail. The remainder of the substation will remain in operation. This can be done by selecting suitable layout, configuration and material for the walls comprising the internal subdivisions.

Testing the response of switchgear assemblies to internal arcing – specified for medium voltage assemblies already for many years by a test directive (Section 8.2.3) – is now also regulated for low-voltage assemblies. The new test directive is available as Supplement 2 to DIN EN 60439-1 (VDE 0660 Part 500) or as IEC 61641. The preferred arc duration in the test should be 100 ms. As a maximum, arcing times of up to 500 ms should be considered. The response of the switchgear assembly is assessed by the following criteria:

- Properly secured doors or barriers shall not open.
- Parts that could cause a hazard shall not come loose.
- Arcing must not burn any holes in freely accessible, external parts of the enclosure.
- The vertically installed indicators (black cotton cloth = cretonne) must not ignite.
- The protective-conductor function for the exposed conductive parts of the enclosure must be retained.

7.3.3 Verification of the short-circuit current capability of busbar systems

The most certain way to verify the short-circuit current capability of the busbar systems of a TTA or PTTA is to test them with the rated short-time withstand current. The compact design of the busbar supports would demand relatively complicated and extensive calculations. For this reason, it is recommended that the basic (standard) design of the busbar system be subjected to a type test, ensuring that the TTA is tested for the standard rated currents and standard rated short-circuit withstand current. Special solutions and interim values can then be very easily considered by resorting to an extrapolation procedure in accordance with DIN IEC 61117 (VDE 0660 Part 509). This technical report describes an extrapolation procedure for determining the short-circuit current capability of non type-tested busbar systems (NTS), derived from type-tested busbar systems (TS).

7.3.4 Calculation programs for planning and design of low-voltage substations

Many companies offer calculation programs for the PC for planners. DOC by ABB – Version 020C – is described here as an example. It is designed for IBM-compatible computers. The program is supplied on 3.5" diskettes. They contain the individual program modules, the database and the texts in compressed and encrypted form. The program is currently available in seven languages (German, English, Italian, French, Spanish, Portuguese, Danish).

The required operating system is MS-DOS/PC-DOS 5.0 or higher and code page 437 is necessary. Version 020C was also developed for use in a local area network.

This version includes the following features:

- Rating of cables of low-voltage systems
- Thermal verification of conductors and busbars
- Calculation of short-circuit currents
- Examination of dynamic load on busbars and their supports
- Selection of circuit-breakers
- Starting of motors
- Assignment of circuit-breakers and fuses, contactors and thermal relays
- Assignment of circuit-breakers: selectivity and protective functions
- Examination of outgoing feeder-cable protection
- Calculation and drawing of time-current characteristics
- Power factor correction
- Selective assignment of protection equipment on the low-voltage and medium-voltage side of transformers
- Calculation of overtemperature in switchgear assemblies
- Drawing of general circuit diagrams
- Printing a summary of all completed project planning and engineering
- Data output in special file formats for dialogue with the programs of CAD, CIM
- Individually designed configuration based on the connected hardware (monitor, printer, etc.), the referenced standards and the database of the devices in use

7.4 Rated voltage 690 V

Publications in the 1970s frequently referred to the technical and economic advantages of a higher rated voltage. As early as 1967 IEC Publication 38 listed the voltage level of 660 V as a preferred voltage in comparison to the 500 V level. Particularly in the area of device development, great efforts were made to upgrade them generally for 660 V. Today it can be assumed that almost all switchgear is suitable for this voltage. The higher voltage has become firmly established in the power distribution sector, e.g. in power plants, many industrial plants and for the power supply of high-output motors instead of 3 kV or 6 kV.

The supplementary benefits of the 690 V voltage level for the user is in many cases quite significant, but it needs to be evaluated with reference to the actual implementation. In general, implementation of the 690 V offers the following advantages in comparison to 400 V (and with lower values in comparison to 500 V):

- Reduction of the rated currents
- Reduction of the short-circuit currents
- Reduction of the conductor cross sections for current transmission by 1 to 3 times
- Lower power losses
- Larger cable limit length with reference to voltage drop
- Use of motors of up to 630 kW, i.e. elimination of the 6 kV for this output
- More economical usage of reactive current compensation modules by greater reactive power at 690 V
- Increase in transformer rated power to 3150 kVA
- Operation of 400 V motors (delta) also for 690 V (star)

The 690 V rated voltage today has a fixed position in low-voltage engineering. It has reached a share of as high as 15%. It will soon have replaced the 500 V level completely.

7.5 Selected areas of application

7.5.1 Design of low-voltage substations to withstand induced vibrations

The highest demands for functional safety under the influence of induced vibrations are placed on important switchgear assemblies in particularly stressed buildings or at sites subject to seismic disturbances.

The verification and testing of low-voltage substations under these conditions covers the following loading cases: >earthquake<, >explosive shock wave< and >aircraft impact<. The verification targets are stability, integrity and functional safety of the switchgear cubicles and functional units.

The loading case >earthquake< is a low frequency waveform, which may have an effect for some seconds, thereby distinguishing it from the loading cases of >explosive shockwave< and >aircraft impact<. Both of these loading cases are high-frequency square wave pulses; the oscillations are excited in the millisecond range. To ensure that the loading cases of >explosive shock wave< and >aircraft impact< are covered by the loading case of earthquake, the switchgear assemblies are installed in rooms equipped with resilient floors. These resilient floors sit on suitable schock insulators. They absorb the square wave pulse and balance the waveform of an earthquake. This enables all types of loads, both computed and experimental, to be treated equally. The verifications for the supporting structures and base frames of the switchgear assemblies are generally calculated in accordance with the German nuclear KTA 2201 regulation.

7.5.2 Low-voltage substations in internal arc-proof design for offshore applications

Offshore systems place very high demands on the quality of the technical equipment, because the fixed or floating offshore drill rigs operate autonomously and technical failures can have serious consequences. Repeated faults and personal injuries make particular demands on the user. The low-voltage switchgear assemblies are also included in these demands, because they must continue to function under the severest weather conditions. In addition to the general basic conditions listed below, offshore systems have stringent requirements for internal arc-proof design of the incoming feeder, coupling feeder and also for the switchgear cubicles for the motor control centre (MCC) in withdrawable-part design.

Examples of the general conditions for substation design are listed below:

- All plastic components must be halogen-free
- Plastic support components for live parts must be designed to be creepage-proof in accordance with CTI 300 and must have self-extinguishing properties
- All steel parts must be galvanized
- Substations must be delivered in accordance with IEC 60439-1
- The requirements of IEC 60092 must be met
- The busbars must be isolated
- The switchgear cubicle must be subdivided into separate functional compartments (busbar compartment, equipment compartment, cable terminal compartment)
- The substation must have a minimum weight (busbar, e.g. Cu-Al)

The MNS system corresponds to these general requirements even in its standard design. ABB has supplied electrical equipment and components for more than 1000 ships and offshore units. The request for internal arc-proof design has been taken into account in separate tests. The results from the comprehensive tests confirm the suitability of the equipment. The internal arc-proof capability of the MNS systems has been successfully confirmed in the test. In addition to compliance with the test criteria as specified in the regulations, the following results are important:

- The internal arc self-extinguishes after 1.5 to 100 ms.
- The effects of the internal arc remain restricted to the place where it occurred.
- Neighbouring withdrawable parts remain fully functional.
- Additional equipment enables incoming feeder cubicles to withstand a 50 kA internal arc for 300 ms.
- Additional tests were passed with 40 kA at 720 V.

7.5.3 Substations for shelter

Application approval certification is required for electrical equipment and assemblies intended for installation in shelters. This confirms that the requirements of the relevant technical directives for civil defence construction have been met and that approval for installation in a shelter has been granted. The inspecting authority requires the application approval certification as verification for all protection construction supported by federal funding. The application approval certification is issued by the federal civil defence office (BZS, Bonn) on behalf of the federal ministry for regional planning, building and urban development (BMBAU, Bonn). The BZS is also responsible for testing and verifying the shock safety of equipment installed in shelters. ABB has been awarded the application approval certification for medium-voltage substations, low-voltage substations, INS switchboxes and various switchgear and installed material.

The shock test is conducted on factory-new test samples. The test centre specifies the scope of testing required and the details of the shock test, such as special rigging, number of test objects and testing schedule. Test centres are the German army proving ground in Meppen and the federal office for civil defence experimental establishment at Ahrbrück. The exact testing conditions are specified by the BMBAU and are described in the appendix to the general basic construction standards for shelters, “Verification of Shock Safety of Installed Parts in Shelters”. There are specific control classes for classifying the shock safety, which are defined by recording the main characteristics of the test. The main characteristics are the test parameters of velocity and acceleration of the shock polygon. For example, control class 0.63 / 6.3 refers to a test velocity of 0.63 m/s at an acceleration of 6.3 g.

The shock safety is assessed with degrees of safety A, B and C.

- A: unrestricted shock safety. This means that the installed part must be guaranteed to retain unrestricted function even during the shock effect.
- B: restricted shock safety. This means that the installed part function may only be affected for the duration of the shock effect.
- C: minimum safety. This means that only safety against subsequent damage in the personal and technical environment of the installed parts must be guaranteed.

The INS, KNS and MNS low-voltage substation systems have been subjected to shock testing and have passed the test. The BMBAU has issued an application approval certification for the substations. The certifications are valid for operation in civil shelters up to and including control class RK 0.63/6.3, degree of safety B. Only the wall plugs approved for civil defence shall be used for securing the switchgear cubicles to the building.