

SIEMENS

Medium Voltage Technology **Switchgear Application Guide**



Medium Voltage Technology

Switchgear Application Guide

- A Selection of Switching Devices
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A SELECTION OF THE APPROPRIATE DEVICE

A 1 Selection criteria

The effective selection of devices for a particular switching duty is determined by three main requirements:

- a) the operational current switching capability
- b) the fault current switching capability
- c) the frequency of switching

The section below deals with the criteria for following devices:

- Circuit breakers
- Vacuum switches
- Hard gas (gas evolving) and airbreak switches and switch disconnectors
- Vacuum contactors
- SF₆ switch disconnectors
- HRC fuses

The most important of these is the required switching capability. If more than one device fulfils these requirements a) and b), the frequency of switching might be the critical factor. Individual equipments differ in the number of mechanical and electrical operations for which they are designed, the length of time between maintenance and the cost and inconvenience of that maintenance.

Additional criteria may be:

- the voltage withstand level of the gap;
in switchboards where the switches are not withdrawable, devices which ensure a safe isolation gap are needed. Switch disconnectors fulfil the safety gap requirements, switches, circuit breakers and contactors do not. They need an additional disconnector or similar device in series. In switchboards with withdrawable or truck-mounted equipment this is unimportant, the gap is established by the act of withdrawal.
- the drive mechanism;
for duties such as synchronising and (multiple-) auto-reclose, a drive mechanism with defined, short closing and opening times. Only stored energy systems suffice; springs which have to be charged first are unsuitable.

Circuit breakers can switch on and off (make or break) all values of current within their rated capability, from small inductive or capacitive load currents up to full short circuit currents, and under all the fault conditions like earth fault, phase displacement (out-of-phase switching) etc.

Switches can switch on and off operating currents up to their rated interrupting capability and can close onto existing short circuits up to their rated fault making current. They have very limited fault current breaking capability only.

Switch disconnectors combine the functions of switches and disconnectors or, put another way, they are switches with the specific safety gap required of disconnectors.

Contactors are load switching devices with limited short circuit making and breaking capacity. They are electrically operated and are used for high switching rates, e.g. for motor control.

Fuses (or, more accurately, the fuse link) provides a single interruption of a short circuit current. Fuses are installed in combination with load switching devices.

A 2 Suitability under normal operating conditions

No.	Operating duty	Circuit-breaker	Switch and switch-disconnector			Vacuum contactor
			Vacuum	SF ₆	Air-, Hard gas	
1	Transformer (Star point transformer)	X	X	X	X	X
2	Converter transformer	X				
3	Furnace transformer	X				X
4	Petersen coil	X	X	X		
5	Compensation coil	X				
6	Motor	X	X	(X)		X
7	Generator	X	X	(X)		
8	Cable, Ring mains	X	X	X	X	
9	Overhead lines	X	X	X	X	
10	Single capacitor	X	X	X	(X)	X
11	Paralleling of capacitors	X	X			X
12	Filter circuit	X	X			
13	Ripple control circuit	X	X	X		
14	Synchronising	X				

X = suitable and effective use

(X) = limitedly suitable

Table A-1: Switching capability under normal conditions

A 3 Suitability under fault conditions

Using the following three tables, check the fault currents the device must be able to switch.

No.	Fault duty	Circuit-breaker	Switch and switch-disconnector			Vacuum contactor
			Vacuum	SF ₆	Air-, Hard gas	
1	Closing onto fault	X	X	X	X	(1)
2	Terminal fault	X	(2)	(2)	(2)	(2)
3	Auto-reclose	X				
4	Fault on load side of					
5	- Generator	X				
6	- Reactor	X				
6	- Transformer	X	(2)	(2)	(2)	(2)
7	Locked rotor motor	X	X	(2)		X
8	Double earth fault	X	(2)	(2)	(2)	(2)
9	Phase opposition	X				

(1) Without HRC fuse, only limited fault switching capability.

(2) Only as switch-fuse combination; current interruption by the fuse.

Table A-2: Switching capability under fault conditions

No.	Fault duty	Circuit-breaker	Switch and switch-disconnector			Vacuum contactor
			Vacuum	SF ₆	Air-, Hard gas	
10	Unloaded cable, OHL fault on network side	X	X	X	(1)	X
11	Loaded cable, OHL fault on network side	X	X	X		X
12	Unloaded cable, OHL fault on load side	X	X	X	X	X
13	Loaded cable, OHL fault on load side	X	X	X	(1)	X

(1) for small currents only

Table A-3: Switching under earth fault conditions

No.	Fault duty	Circuit-breaker	Switch and switch-disconnector			Vacuum contactor
			Vacuum	SF ₆	Air-, Hard gas	
14	Safe disconnection (Disconnection under load)			X	X	
15	Rapid changeover	X				
16	Transformer with short-circuited winding	X	X	(1)	(1)	(1)

(1) Only as switch-fuse combination; current interruption by the fuse.

Table A-4: Other fault conditions

A 4 Switching frequency and endurance classes

When a range of devices fulfils the electrical requirements, the frequency of switching in connection with the endurance can be an additional selection criterion. The standards distinguish between mechanical and electrical endurance, which are also applicable to equipment "mixed"; e.g. a switch can mechanically correspond to the class M1 and electrically to the class E3.

The following tables show the endurance classes of the switching devices and give a recommendation about useful use with that.

A 4.1 Circuit-breaker

A 4.1 a Mechanical and electrical endurance – classes M and E

IEC 62271-100 [7] defines the mechanical endurance by a certain number of operating cycles (class M), the electrical endurance, however, merely with the verbal description "normal" and "extended" endurance.

To the orientation, what "normal" and "extended electrical endurance" means, the grey shaded table elements indicate the operating cycles which average modern vacuum circuit-breakers can perform.

The numbers for short circuit operation (I_{sc}) are derived from the operating sequences of the type test. As a rule these are minimum numbers; actually, vacuum circuit-breakers of the class E2 with auto-reclosing capability, which are used in electricity grids with overhead lines, may break the smaller short-circuit currents, usual there, several hundred times.

Furthermore it is worth mentioning, that almost all modern vacuum circuit-breakers can switch the rated normal current with the number of the mechanical operating cycles.

Class		Description		
M	M1	2.000 Operations	normal mechanical endurance	
	M2	10.000 Operations	extended mechanical endurance, limited maintenance	
E	E1	* I_r 2.000 Operations	normal electrical endurance (circuit-breaker, not falling into class E2)	
		* I_{sc} 6 x Open 4 x Close		
	E2	* I_r 10.000 Operations	<u>without</u> auto-reclosing duty	extended electrical endurance without maintenance of interrupting parts
		* I_{sc} 6 x Open 4 x Close	<u>with</u> auto-reclosing duty	
		* I_r 10.000 Operations		
		* I_{sc} 50 x Open 15 x Close		

* Derived numerical values to the orientation => see text.

Table A-5: Classes M and E of circuit-breakers

A 4.1 b Capacitive current switching – class C

Class C defines the capacitive current breaking performance comprising the characteristics of three switching duties, i.e. the closing and switching off of lines, cables and capacitor banks (single and back-to-back capacitor banks).

Class		Performance on breaking of capacitive currents				
C	C1	24 x O 24 x CO	per 10...40% per 10...40%	I_{lc}, I_{cc}, I_{bc} I_{lc}, I_{cc}, I_{bc}	<u>Low</u> probability of restrikes	Restrike-free breaking operations at 2 of 3 test duties
	C2	24 x O 128 x CO	per 10...40% per 10...40%	I_{lc}, I_{cc}, I_{bc} I_{lc}, I_{cc}, I_{bc}	<u>Very low</u> probability of restrikes	

Table A-6: Classes for capacitive current switching

The selection of the class depends on the operating conditions, the switching frequency and the possible effects of restrikes.

- Class C1 is suitable for infrequent switching of transmission lines and cables;
- Class C2 is recommended for capacitor banks as well as for frequent switching of transmission lines and cables.

A 4.1 c Cable or line system – class S

Class S defines the type of the grid where the circuit-breaker is intended to be employed. The switching duties differ in magnitude and rate of rise of the transient recovery voltage (TRV) while breaking short-circuit currents. In line systems the TRV and the associated dielectric stress on the contact gap can be much higher due to the smaller phase-to-earth capacitances.

Circuit-breakers of indoor switchgear are always to be assigned to class S1, i.e. cable system. The same applies to feeders where an overhead line is connected to the switchgear via a cable. Class S2 is virtually not relevant to metal-enclosed medium voltage switchgear. In terms of the standard a circuit-breaker in an overhead line system is, for example, a (outdoor) breaker directly connected to the line without cable.

Class		Description
S	S1	Circuit-breaker intended to be used in a cable system
	S2	Circuit-breaker used in a line-system, or in a cable-system with direct connection (without cable) to overhead lines

Table A-7: Classes for cable or line system system

A 4.2 Switches and switch-disconnectors

IEC 62271-103 [8] specifies classes for so-called general purpose switches. In addition there are „limited purpose“ and „special purpose“ switches¹. General purpose switches – as the name suggests – have to switch different kinds of operating currents: load currents, closed-loop currents, transformer magnetising currents, cable and line charging currents as well as making short-circuit currents. General purpose switches intended for use in isolated neutral point systems or in systems earthed by a high impedance shall be capable of switching under earth fault conditions. This versatility is reflected in the relatively comprehensive definition of the classes, which are applicable for

- Vacuum switches
- SF₆ switches and switch-disconnectors
- Air and hard-gas switches and switch-disconnectors

For switch-disconnectors the table details apply to the function “switch”.

See also section A 4.5 Three-position switching devices.

¹ Limited purpose switches need only cope with a certain range of the performance of a general purpose switch. Special purpose switches are used for selected duties such as switching of single capacitor banks, paralleling of capacitor banks, closed-loop circuits built up by transformers in parallel, or motors (under steady-state and stalled conditions).

Class		Switching cycles	Description	
M	M1	1000	Mechanical endurance	
	M2	5000	Increased mechanical endurance	
E	E1	$10 \times I_{load}$ $10 \times I_{loop}$ $2 \times I_{ma}$	$20 \times 0.05 \cdot I_{load}$ $10 \times I_{cc}$	Test currents: (old) I_{load} active load-breaking current I_1 I_{loop} closed-loop breaking current I_{2a} I_{cc} cable-charging breaking current I_{4a} I_{lc} line-charging breaking current I_{4b} I_{sb} capacitor bank breaking current I_{4c} I_{bb} back-to-back capacitor bank breaking current I_{4d} I_{ef1} earth fault breaking current I_{6a} I_{ef2} cable- and line-charging breaking current under earth fault conditions I_{6b} I_{ma} Short-circuit making current I_{ma}
	E2	$30 \times I_{load}$ $20 \times I_{loop}$ $3 \times I_{ma}$	$10 \times 0.2 \text{ to } 0.4 \cdot I_{cc}$ $10 \times I_{lc}$	
	E3	$100 \times I_{load}$ $20 \times I_{loop}$ $5 \times I_{ma}$	$10 \times I_{ef1}$ $10 \times I_{ef2}$	
C	C1	$10 \times I_{cc}$ $10 \times I_{lc}$ $10 \times I_{sc}$ $10 \times I_{bb}$	Restrikes permitted (number not defined)	
	C2	additionally each 10x $0,1 \dots 0,4 \times I_{cc}, I_{sb}, I_{bb}$	No restrikes	

Table A-8: Classes for switches

A 4.3 Contactors

The standard for contactors has not yet defined endurance classes. Customary designs feature mechanical and electrical endurance in the order of 250,000 and 1,000,000 operation cycles. The can be encountered where extremely high switching rates occur; e.g. $> 1 / \text{hour}$.

However, classes for the suitability of breaking capacitive currents are defined.

Class		Description		
C	C0	$24 \times O$ $24 \times CO$	Not defined	≤ 1 restrike per interruption
	C1	each per 10...40% I_{lc}, I_{cc}, I_{bc}	Low probability of restrikes	≤ 5 cumulated restrikes on test duties BC1 and BC2
	C2	$24 \times O$ per 10...40% I_{lc}, I_{cc}, I_{bc} $128 \times CO$ per 10...40% I_{lc}, I_{cc}, I_{bc}	Very low probability of restrikes	No restrikes ²

Table A-9: Classes for contactors

- Contactors of C2 class are suitable for capacitor banks.

² Class C2 is recommended for capacitor banks.

A 4.4 Disconnectors and earthing-switches

IEC 62271-102 [21] defines the classes for disconnectors and earthing-switches. Since disconnectors have no switching capacity³, only classes for the mechanical endurance are specified.

Class		Operations	Description
M	M0	1000	for general duties
	M1	2000	extended mechanical endurance
	M2	10.000	

Table A-10: Classes for disconnectors

The classes for earthing switches specify the short-circuit making capability (earthing in case of voltage still being present). E0 designates a normal earthing switch, whereas E1 and E2 correspond to earthing switches with short-circuit making capability; so-called make-proof earthing switches.

Class		Operations	Description	
E	E0	$0 \times I_{ma}$	no short-circuit making capability	for general duties
	E1	$2 \times I_{ma}$	short-circuit making capability	reduced maintenance
	E2	$5 \times I_{ma}$		

Table A-11: Classes for earthing-switches

A 4.5 Three-position switching devices

Three-position switching devices combine two or three functions within one device

- Disconnecting
- Earthing and short-circuiting
- Load switching
- Interrupting short-circuits

For three-position switching devices classes are designated for each individual function, i.e. as if there were two or three separate switching devices.

³ Disconnectors up to 52 kV rated voltage can switch off only “negligible” currents up to 500 mA (for example voltage transformers), or higher currents only if no significant change in voltage occurs (for example busbar transfer when bus coupler is closed).

A 4.6 Guidance for use

Table A-12 shows the average lives of switching devices and gives a recommendation for appropriate usage. The table gives only guide values; they can be taken into account when no other criterion is of greater importance.

Device	Mechanical operations		Operations at rated ...			Switching frequency which gives reasonable lifetime
	Nos.	Class	normal current	breaking current	Class	
Circuit-breaker	10 000	M2	10 000	5 - 400	E2	no criterion
Vacuum switch	5 000	M2	5 000	10	E3	1 / week
SF ₆ switch	1 000	M1	30 100	5	E2 E3	≤ 1 / month
Hard-gas switch	1 000	M1	10 30	2	E1 E2	≤ 1 / year
Vacuum contactor	10 ⁶	not defined	10 ⁶	1 000	not defined	> 1 / hour

Table A-12: Endurance of switching devices

The column “breaking current” gives only average numbers of operations. The actual lifetime can be much higher since the full rated value rarely occurs in practice. For circuit-breakers the lower value refers to high short-circuit currents (≥ 50 kA), the upper value to small currents (12.5 kA). For switches the column mentions the transfer current (I_{transfer}) of switch-fuse combinations [30]. With vacuum contactors the value refers to the limit breaking capacity. The class designation refers to the corresponding product standard.

Regarding switching frequency circuit-breakers are an exception: The switching rate is not a deciding factor for the choice because circuit-breakers are used, if short-circuit breaking capacity is required.

A 5 Aspects of selection for disconnectors

For work on switchboard components, it must always be possible to establish a safe disconnection gap. For this, a switching device or an arrangement of equal value is essential, also an interlock between this disconnector and the load, power or earthing switch. With combined devices like switch-disconnectors or three-position devices, an additional disconnector is unnecessary and even separate interlocking may become superfluous.

The average mechanical endurance of disconnectors (truck or withdrawable part) amounts 1000 or 2000 operations, corresponding to the classes M0 or M1. This is completely sufficient for most of the applications.

The life of the disconnector in double busbar switchboards plays an important role: In some networks, for operational reasons, it is necessary to switch frequently from one busbar to the other. Because of the limited life of conventional disconnectors in comparison to the main switching devices, not all switchboards are suitable for this application.

See chapter H 3.3.

B SWITCHING DUTIES IN MEDIUM VOLTAGE NETWORKS

B 1 Overview

The table gives an overview whether special measures have to be taken on selection of switching devices. Details are described in the chapters listed in the right column.

Switching duty	Advice	Section
<i>Distribution transformers</i> ⁴ <i>Power transformers</i>	If the transformer is fed by a switch-fuse combination, the fuses must be selected according to the rules for transformer circuits <u>and</u>, in order to protect the switch, according to the IEC standard for switch-fuse combinations. For circuit-breakers no special requirements apply in this respect.	B 2, D 2 and D 5 - D 7
<i>Unit transformer</i>	See • Motor • Generator • Furnace transformer • Converter transformer	B 8 B 9 B 10 B 11
<i>Petersen coil</i>	Surge arrester or limiter	B 4
<i>Overhead line or cable</i>	Switches and switch-disconnectors are very limited in suitability for earth fault location (by selective switching of circuits): only up to their switching capability under earth fault conditions - with or without load (see manufacturer data)!	B 5
<i>Cable or overhead line with short-circuit limiting reactor</i>	Surge arresters are required at the “short” end of the cable / line	B 6
<i>Compensation coil (shunt reactor)</i>	Overvoltage protection is required generally - RC-circuits - if current < 600 A, additionally surge arresters - protection at the busbar, depending on the network configuration	B 7
<i>Motor</i> <i>(see next page)</i>	Overvoltage protection is required if motor starting current is < 600 A	B 8

⁴ Distribution transformers (rated power up to 2.5 MVA) transform energy from a primary to secondary distribution or industrial network. Equipment connected downstream a distribution transformer have its own switchgear for switching under normal service conditions.

Switching duty	Advice	Section
Motor (continued)	Peak and short-circuit making current: due to reverse power feed with large motors or some motors connected, the peak current rating of the switch-gear may exceed the standardized value of $2.5 I_k$ (or $2.6 I_k$ at 60 Hz). Motor with HRC fuse: select the fuse according to starting current and time of the motor!	D 4 + D 5 to D 7
Generator	Overvoltage protection is necessary, if short-circuit current of generator is $< 600 \text{ A}$ Peak and short-circuit making current: with large machines the peak current may exceed the standardized value of $2.5 I_k$ (or $2.6 I_k$ at 60 Hz) – the critical share is the peak current from the network side. Rated voltage: Consider temporary overvoltage due to the effect of load shedding. Rated short-circuit breaking current: Consider the DC component of the generator current.	B 9
Furnace transformer	Protection by RC-circuits and surge arresters is required, individually matched to the system (in most cases also at the busbar)	B 10
Converter transformer	Surge arresters	B 11
Capacitor bank Back-to-back switching of capacitor banks	Inrush current: consider the maximum permissible closing current of the circuit-breaker; where applicable, use damping measures. Rated normal current: consider additional heating due to harmonic currents. Rated voltage: consider the increased voltage if capacitor bank is fitted with limiting reactors HRC fuses: select rated voltage and rated current 1-2 steps higher	B 12 D 3
Filter circuit	Rated voltage: Consider operating voltage limits at filter capacitor (see capacitor banks)	B 12
Audio frequency ripple control system	— — —	B 13

Table B-1: Planning criteria for switching duties in MV networks

B 2 Distribution transformers

This covers all transformers in industrial and power utility networks, with exception of the special transformers in section B 2.

Duty:	Unloaded transformer	Loaded transformer
Current:	- Magnetising current 1 to 3 % of rated transformer current (I_{RT}) - Inrush current up to 15 I_{RT}	up to 120 % of rated transformer current
$\cos \phi$:	< 0.3 inductive < 0.15 during inrush	0.7 to 1.0 ind.
Remarks:	- Protection relays shall have inrush restraint - Switching device shall have low chopping current	— — —

Table B-2: Switching of distribution transformers

Transformer during inrush: when switching off during the inrush phase, currents up to 15 times the rated current at $\cos \phi = 0.15$ may occur, heavily superimposed by harmonic currents. Air or hard-gas switches are not capable of interrupting those currents. The transformer protection relay must feature an inrush restraint in order to avoid switching off of the transformer during the inrush.

Where HRC fuses are used for short-circuit protection, the selection may be done in accordance with the procedure defined in IEC 60787 [27]; the corresponding German standard VDE 0670-402 [28] presents a table of fuse ratings allocated to transformer ratings – see table 2 therein. Additionally – where applicable – the requirements of switch-fuse combinations to IEC 62271-105 [30] must be taken into account. See section D 5 for the procedure to configure these combinations.

B 3 Unit transformer

Transformers in this arrangement normally feed only one, special load. The switching duty is then determined by the characteristics of that load. For further clarification see:

- Motor (with transformer, starting transformer) → Section B 8
- Generator → Section B 9
- Furnace transformer → Section B 10
- Converter transformer → Section B 11

B 4 Petersen (arc suppression) coil

Petersen coils in earth fault compensated, normally unearthed, networks earth the network at the starpoint of either a transformer or an earthing transformer. When an earth fault occurs, the coil is switched in to produce a purely inductive current which should compensate (equal) the capacitive earth fault current which is flowing into the fault. If the Petersen coil is switched off during the fault, multiple re-ignitions can cause overvoltages. Surge arresters will protect against these.

Switching:	without earth fault in network	with earth fault in network
Current:	approx. 1% of transformer rated current	up to 300 A
$\cos \phi$:	less than 0.15 ind.	less than 0.15 ind.
Remarks:	as unloaded transformer	overvoltages due to multiple re-ignition possible

Table B-3: Switching of arc suppression coil

B 4.1 Overvoltage protection

Arresters at the transformer or neutral point earthing transformer terminals in phase-earth connection, or parallel to Petersen coil; if the coil can be switched directly (left figure), the arrester has to be installed there.

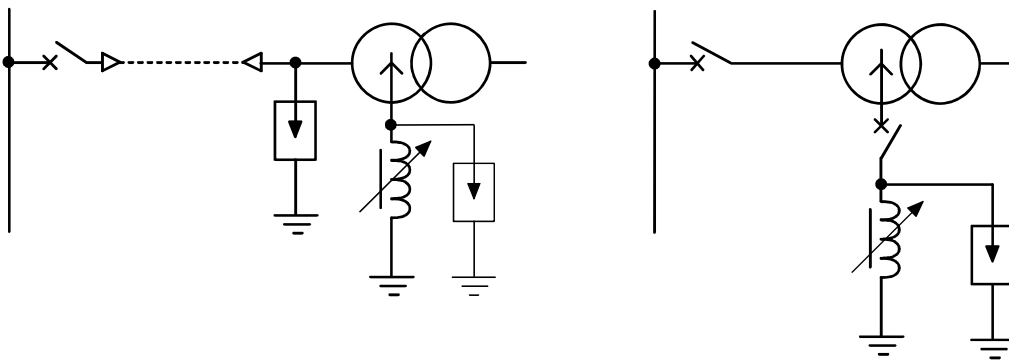


Figure B-1: Protection methods for arc suppression coils

B 4.2 Selection of surge arresters

It is essential that the transformer insulation corresponds to the upper standard value of the rated insulation level in accordance with table 2, IEC 60076-3 [6]; these insulation ratings equal the values in column (4), Table H-3. Otherwise the arrester can be selected as described in section E.

Surge arrester	Rated voltage U_r	Continuous operating voltage U_c
At the primary terminals of the (neutral earthing) transformer	$U_r \geq 1.25 \cdot U_c$	$U_c \geq U_m$
Parallel to Petersen coil	$U_r \geq 0.8 \cdot U_m$	$U_c \geq U_m / \sqrt{3}$

U_{max} Maximum operating voltage of the power system

Table B-4: Selection of surge arresters for an arc-suppression coil

B 5 Cable or overhead line

This refers to unloaded cables and lines. In this case, only the capacitive charging current flows. See section B 6 for cable and lines with short-circuit limiting reactor.

Switching:	Cable	Overhead line
Current:	up to 100 A	up to 10 A
$\cos \phi$:	capacitive	capacitive
Remarks:	Vacuum switches are restrike-free Switches and switch-disconnectors are very limited in suitability for earth fault location (by selective switching of circuits): only up to their switching capability under earth fault conditions - with or without load (see manufacturer data)!	

Table B-5: Switching of cables or overhead lines

Additional measures: None

B 6 Cable or line with short-circuit limiting reactor

If two switchgear installations with different peak and short-time current ratings are connected, a reactor must limit the short-circuit current to the level of the installation with the lower rating.

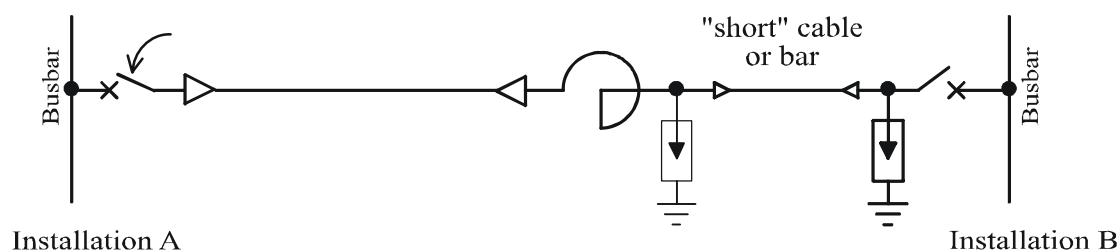
On energising the connection between installation A and B under no-load condition impermissible overvoltages may occur if the circuit-breaker in installation A closes the “long” cable (some hundred metres) while the breaker in installation B is open. The very small line-earth capacitance of the short connection (only a few metres of cable or bar) together with the inductance of the reactor leads to a high-frequency inrush voltage which can reach unduly high amplitudes. Hence in order to avoid disruptive discharges at the reactor terminals or at the open end of the “short” cable or bar connection surge arresters or limiters have to reduce the overvoltage to permissible values.

In contrast to this, when the breaker in installation B closes first, no significant overvoltages occur at the “long” end in installation A, as the closing overvoltage at the open circuit-breaker remains small due to the much higher earth capacitance of the long cable.

Current:	0 A; only on closing under no-load condition
$\cos \varphi$:	---
Remarks:	The energising of the cable at the “long” end can cause overvoltages at the “short”, open end. It is recommended to install surge arresters.

Table B-6: Switching of a line or cable connection with reactor

Surge arresters should be installed in the station with the “short” cable or bar connection between reactor and circuit-breaker (installation B). The arresters can be mounted either at the terminals of the breaker or at the reactor.

**Figure B-2: Surge arresters in line-earth connection at the circuit-breaker (preferably) or at the reactor**

Operating voltage ⁵ of system up to:	Surge arresters for installation at ...	
	circuit-breaker	short-circuit limiting reactor
3.6 kV	3EF1 036-0A	Indoor: type 3EF1, same type as at the circuit-breaker. Outdoor: arresters with equal protection level; selection see chapter E.
4.8 kV	3EF1 048-0A	
7.2 kV	3EF1 072-0A	
12 kV	3EF1 120-0A	
15 kV	3EF1 150-0A	
> 15 kV	Selection see chapter E	

Table B-7: Recommended surge arresters for the reactor

⁵ For other voltages and those above 24 kV any surge arrester can be selected; selection criteria are described in section E.

B 7 Compensation coils (shunt reactors)

These compensate the capacitive charging current on unloaded networks. Compensation coils are switched daily and thus the circuit-breakers reach large numbers of operations. The high rate of rise of the recovery voltage makes this a very difficult duty for conventional units, whereas vacuum breakers master these conditions excellently.

Current:	up to 2000 A
$\cos \phi$:	0.15 ind.
Remarks:	- RC-circuits individually matched to the network are generally required - surge arresters are required if the coil current is ≤ 600 A

Table B-8: Switching of compensation coils

Compensation coils are always equipped with an RC-circuit which prevents resonant harmonics in the coil during switch-off. When the coil current is ≤ 600 A, surge arresters are also fitted to prevent overvoltages.

In case of certain network conditions, where the line-earth capacitance on the feeding side is very small, additional protection at the busbar (x) by RC-circuitry and surge arresters is required.

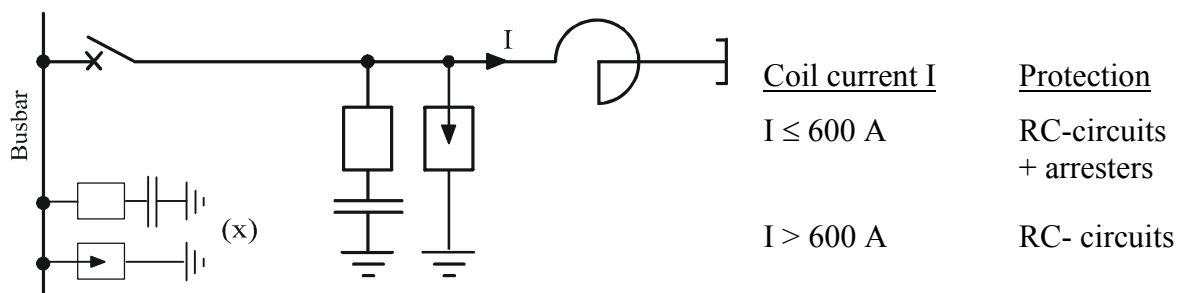


Figure B-3: Surge protection for compensating coils

The protection devices must always be individually matched to the network characteristics and data of the equipment.

B 8 Motors

This area of application covers many types of machines:

- Asynchronous motor: cage rotor, slipring rotor
- Synchronous motor (with asynchronous start)
- Motor with unit transformer
- Motor with starting transformer
- Motor with starting converter ("soft starter")
- Motor with individual power factor compensation
- Variable speed drives (converter motors) → see B 11 Converter transformers

Duty:	Motor during starting Machine with locked rotor	Normal operation, no-load up to full load
Current:	Cage rotor $5 \dots 7 \cdot I_{rM}$ Slip ring rotor $1 \dots 2 \cdot I_{rM}$	$0.1 \dots 1.2 \cdot I_{rM}$
$\cos \phi$:	0.2 to 0.3 inductive	0.9 to 0.3 inductive
Remarks:	Switching of starting currents $I_{st} \leq 600 \text{ A}$ ⁶ can cause overvoltages as result of multiple re-ignition and virtual current chopping	Switching of normal operating currents causes no impermissible overvoltages.
	Motors with starting current $\leq 600 \text{ A}$ ⁶ must be equipped with surge arresters; except motors with individual power factor correction.	

Table B-9: Switching of motors

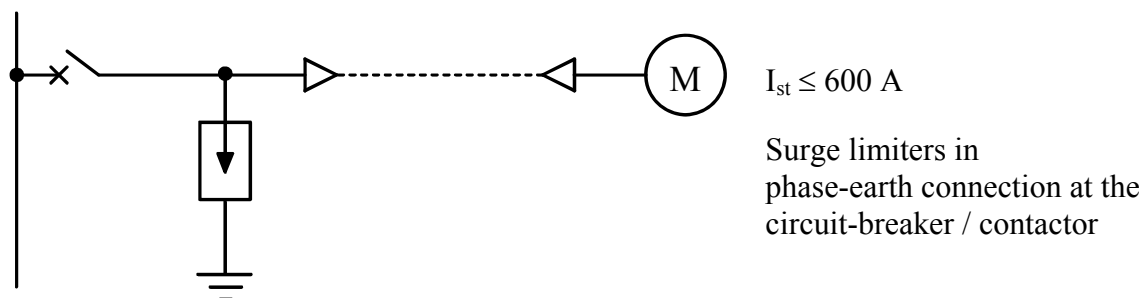
B 8.1 Overvoltage protection for motors

For economical reasons the insulation level of machine windings, particularly the impulse withstand capability, is considerably lower than the insulation level of switchgear; see table 1 in [2]. This does not play any role when switching under normal service conditions. However, when a motor is switched off with blocked rotor or during start-up, inadmissibly high overvoltages can occur which must be limited by surge arresters. Exceptions are motors with power-factor correction, which do not need overvoltage protection, if the compensation power amounts at least 1/5 of the motor apparent power, see chapter B 8.6.

A simple decision criterion, whether overvoltage protection is required or not, is the starting current. Is the latter in the area up to 600 A, the motor must be equipped with overvoltage protection. For motor-transformer combinations, the current flowing through the circuit-breaker (or contactor) is the decisive criterion. Further considerations of other installation parameters, such as e.g. the cable to the motor, thus are no longer required; [3], [4].

The following clauses show various arrangements with different connections points of surge limiters or surge arresters.

B 8.2 Direct connected motor (direct on line)

**Figure B-4: Surge arresters at the breaker terminals**

⁶ For motor-transformer combinations, the transformer primary current is the criterion.

At first sight, surge arresters at the breaker or contactor contradict the known rule to connect arresters at the object to be protected. However, there are good reasons for it: arresters are susceptible against vibration and high ambient temperatures prevailing in a motor terminal box. Moreover a large terminal box would be required for which most often there is no space. Surge arresters at the breaker / contactor must have a particularly low residual voltage so that they protect the motor despite the travelling wave effects at the cable end on the motor side. The Siemens surge limiters type 3 EF or other arresters with the same protection level are recommended (Chapter E). 3 EF type is an especially developed arrester for the protection of motors or other equipment with sensitive windings [5]. It satisfies the prerequisite of a particularly low residual voltage and therefore can be attached also at the breaker side of the motor cable.

Motor voltage up to:	3.6 kV	4.8 kV	7.2 kV	12 kV ⁷	15 kV
Surge limiter types	3EF1 036-0A	3EF1 048-0A	3EF1 072-0A	<u>3EF3 120-1</u>	3EF1 150-0A

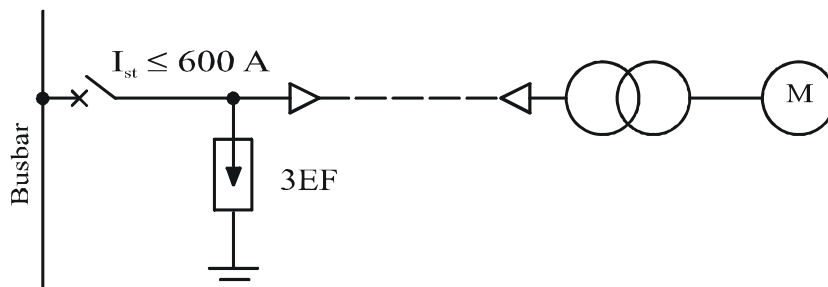
Table B-10: Recommended surge limiters for motors

B 8.3 Motor with transformer (unit)

Two variants of overvoltage protection are possible for motors with block transformer at the same protective effect.

Arrangement 1

Surge limiters in phase-earth connection at the circuit-breaker or contactor



Arrangement 2 (preferred)

Surge limiters or arrester in phase-earth connection at the transformer

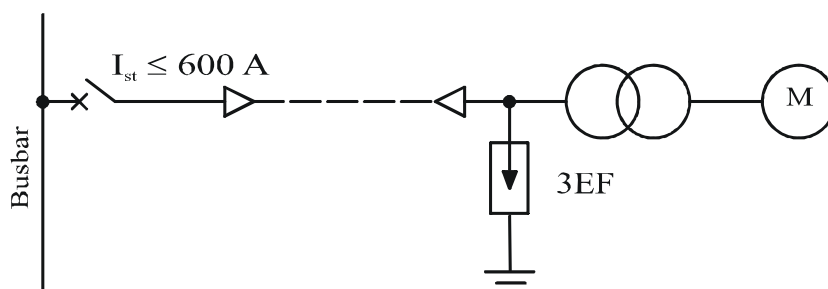


Figure B-5: Surge protection for a motor-transformer combination

Recommended surge arresters are the Siemens 3EF surge limiters or other arresters with equal protection level; see chapter E.

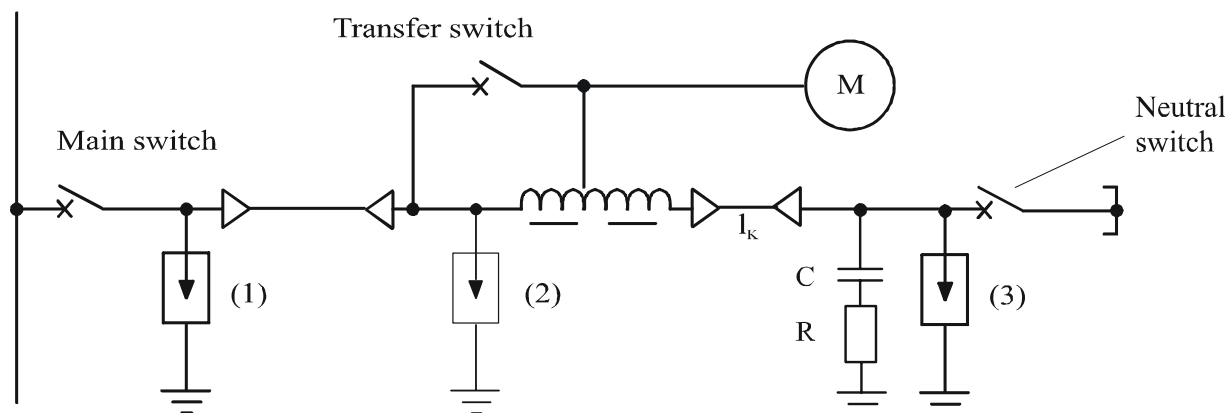
⁷ For direct connected motors with 12 kV surge limiters at the breaker the type underlined must be used to ensure the protection level required.

Rated voltage of the motor or transformer up to:	Surge arresters for installation at the	
	circuit-breaker	transformer
3.6 kV	3EF1 036-0A	3EF1 036-0
4.8 kV	3EF1 048-0A	3EF1 048-0
7.2 kV	3EF1 072-0A	3EF1 072-0
12 kV	3EF1 120-0A	3EF1 120-0A
15 kV	3EF1 150-0A	3EF1 150-0A

Table B-11: Recommended surge limiters for motor-transformer combinations

Note to arrangement 2: At the transformer normal arresters can also be used (see chapters E) instead of the recommended surge limiters if the transformer insulation corresponds to the upper value of the rated insulation levels to table 2, IEC 60076-3 [6]; the values are the same as in column (4), Table H-3.

B 8.4 Motor with starting transformer



Starting current	Connection of surge limiters	RC circuitry
$I_{st} \leq 600 \text{ A}$	at main main switch (1) or transformer (2); <u>and</u> at transformer neutral point (3)	always at transformer neutral point, irrespective of the starting current
$I_{st} > 600 \text{ A}$	at transformer neutral point (3)	

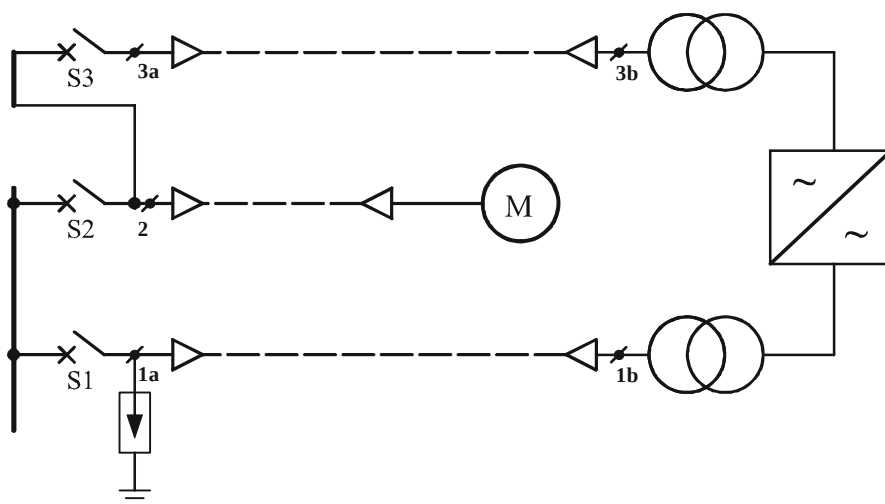
Figure B-6: Surge protection for motors with starting transformer

The insulation level of starting transformers⁸ frequently does not meet the values standardised for power transformers according to table 2, IEC 60076-3 [6]. Therefore, only surge limiters 3EF should be installed at the transformer (2), because of their very low residual voltage (standard surge arresters may not be suitable for this duty). Recommended devices are the Siemens 3EF surge limiters or other surge arresters at equal protection level. The arresters at the transformer neutral point must be selected in accordance with rated voltage of the transformer and the insulation level of its neutral point. Additionally, RC- circuitry must be installed at the transformer neutral point, as listed in Table B-12.

Rated voltage of transformer up to:	Surge arresters at ...		RC circuitry
	circuit-breaker	transformer	
3.6 kV	3EF1 036-0A	3EF1 036-0A	R = 30 Ohms C = 200 nF The values for R and C are valid with a cable length $l_C < 30$ m between transformer neutral and circuit-breaker.
4.8 kV	3EF1 048-0A	3EF1 048-0A	
7.2 kV	3EF1 072-0A	3EF1 072-0A	
12 kV	3EF3 120-1	3EF1 120-0A	
15 kV	3EF1 150-0A	3EF1 150-0A	

Table B-12: Recommended surge limiters for motors with starting transformer

B 8.5 Motors with starting converter



Surge limiters in line earth connection at the three connection points 1a or 1b, 2 and 3a or 3b, if:

- Circuit-breakers S1 to S3 are not interlocked with the converter, and
- The motor starting current is ≤ 600 A.

Figure B-7: Motor with starting converter (example with two transformers)

⁸ Autotransformers have a gapped iron core to increase the magnetizing current during the reactor starting phase (i.e. second phase of start-up with open transformer neutral). Transformers with a closed iron core are not suitable for this starting method.

Starting converters (“soft starters”) are bridged or switched off after the start-up of the motor. Under normal service conditions the converter controls the current and the breaking operation. However, instantaneous tripping of the circuit-breaker during the start-up phase cannot be precluded unless the control of the converter is interlocked with the circuit-breaker (the circuit-breaker must be fitted with a leading auxiliary switch for this purpose).

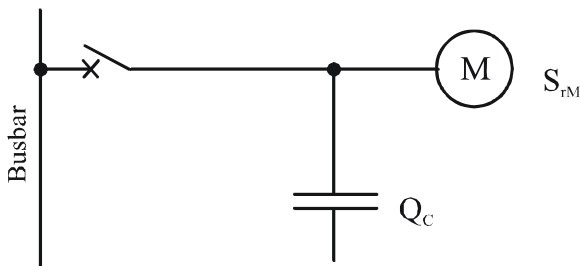
- Surge protection is not required if the converter control and the corresponding interlockings ensure that the circuit-breakers (1) to (3) never switch off starting currents ≤ 600 A.
- If the circuit-breakers are not included in the control of the converter and the motor starting current is ≤ 600 A, surge protection must be installed for the converter transformers and the motor. The surge limiters for the motor must be mounted at the circuit-breaker S2 (connection point 2). For the converter transformers they may be mounted at the circuit-breaker (connection points 1a and 3a) or alternatively at the transformer terminals (connection points 1b and 3b). Surge limiters according to chapter B 8.2 are applied to the motor; for the converter transformers refer to chapter B 11.2 and B 11.3.

B 8.6 Motors with their own p.f. improvement

No overvoltage protection is necessary.

Motors with individual power factor correction do not need overvoltage protection, if the p.f. correction capacitors are permanently connected to the motor and the compensation rating (Q_C) is at least 1/5 of the motor's rated power (S_{rM}), normally $Q_C = (1/3) \cdot S_{rM}$ is installed. The compensation capacitance reduces the frequency of the transient recovery voltage for the first pole-to-clear to less than the limit where multiple reignitions occur. Therefore no overvoltages occur either.

Thus individual compensation can also be used as an alternative method of providing protection.



$$\text{Prerequisite: } Q_C \geq \frac{1}{5} \cdot S_{rM}$$

$$\text{normally } Q_C = \frac{1}{3} \cdot S_{rM}$$

Figure B-8: Motor with power-factor improvement

B 9 Generators

Duty	Generator short-circuited	Load and no-load operation
Current:	short-circuit current ⁹	up to $1.2 \cdot I_{RG}$
$\cos \phi$:	0.15 lag.	lag. $\leftrightarrow$ lead.
Remarks:	When short-circuit currents $I_k'' \leq 600 \text{ A}$ ¹⁰ are switched off, overvoltages due to multiple re-ignitions may occur.	Switching off under load or no-load conditions causes no impermissible overvoltages
	In many cases surge protection is basically installed to ensure safety of operation since overvoltages may be transferred from elsewhere in the network.	

Table B-13: Switching of generators

B 9.1 Selection of the circuit-breaker

Special attention has to be paid to the *rated voltage* and *rated short-circuit breaking current* when selecting a breaker for generators.

Rated voltage: The event of load shedding has to be considered when selecting this rating. The voltage on the generator side of the breaker rises after load shedding. A standard value of 20 % rise is usually assumed. A higher value up to 40 % may be assumed if the simultaneous occurrence of several faults need be considered (e.g. load rejection and defective voltage regulator). The requirements for the circuit-breaker should be co-ordinated with the client.

Rated short-circuit breaking current: The peak value (making current) and the DC component of the current during short-circuit near-to-generator¹¹ are higher than during short-circuit elsewhere in the system ("far-from-generator"). Typically the DC component is very high so that in some cases the AC component may decrease more rapidly than the DC component. This leads to delayed current zeros (DC component > 100 %). However the circuit-breaker needs current zeros for clearing.

The real breaking current depends on the time interval between initiation of the short-circuit and the opening of the breaker because of the current decays during that time (tripping times of protection relay and opening time of c.b.). The values of the breaking current and the DC component must be stated by the customer or be calculated in case of doubt.

See also chapter H 2.3 for short-circuit current and DC component.

⁹ In case of fault at the busbar or breaker terminals

¹⁰ The current through the breaker is decisive in generator-transformer arrangements

¹¹ The short-circuit is "near-to-generator" if the ratio initial to continuous symmetrical short-circuit current is $I_k''/I_k > 2$

B 9.2 Overvoltage protection

Switching of generators is similar to motor switching with respect to the transients. The decisive criterion for surge protection on account of the breaker is the short-circuit current of the generator during fault at the busbar or breaker terminals. If it is ≤ 600 A, surge limiters or arresters are used. However, surge protection is often universally fitted as a basic measure against overvoltages which may be carried over from the network.

B 9.3 Generators with $I_k'' \leq 600$ A feeding into a cable system

a) Direct connected generator

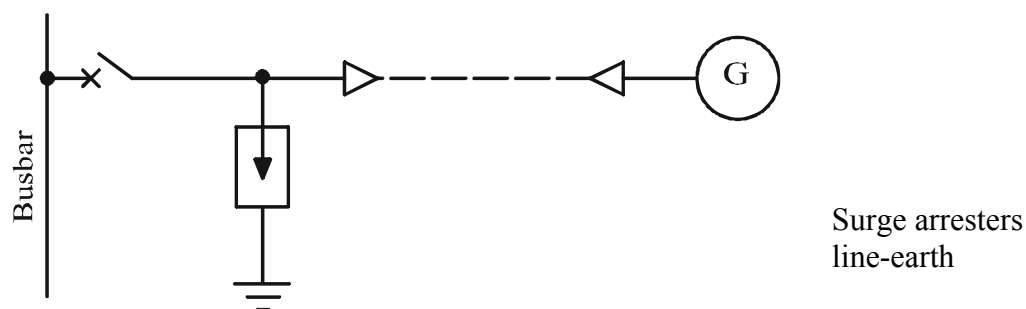


Figure B-9: Surge protection for generators

Recommended surge arresters are the Siemens types 3EF and 3EE as well as other arresters with equal protection level.

Generator voltage up to: ¹²	3.6 kV	4.8 kV	7.2 kV	12 kV	15 kV
Type 3EF	3EF1 036-0A 3EF3 036-0	3EF1 048-0A 3EF3 048-0	3EF1 072-0A 3EF3 072-0	3EF1 120-0A 3EF3 120-0	3EF1 150-0A
Type 3EE	For the selection of ratings refer to chapter E				

Table B-14: Recommended surge arresters or limiters for generators

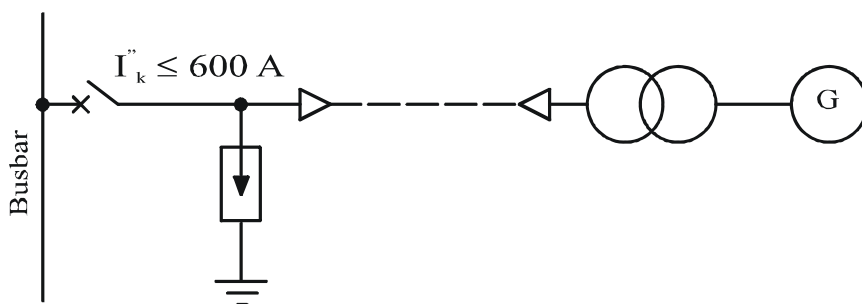
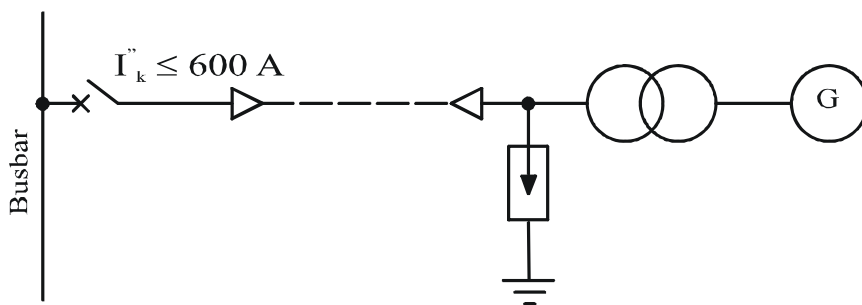
For operating voltages above 15 kV the type 3EE2 is used; refer to chapter E for the selection of the ratings.

B 9.4 Generator-transformer unit

For generator-transformer combinations there are two arrangements of the surge arresters with equal effect of protection.

¹² Maximum value, including temporary voltage rise – where applicable

Arrangement 1

Surge arrester line-earth
at the circuit-breakerArrangement 2
(preferred)Surge arrester line-earth
at the transformer**Figure B-10: Overvoltage protection of generator-transformer units**

With arrangement 2 normal surge arresters can also be used at the transformer instead of the recommended surge limiters if the transformer insulation complies with the upper value of the rated insulation levels to table 2, IEC 60076-3 [6]; the values are the same as in column (4), Table H-3.

Transformer voltage ¹³ up to:	Surge arresters at	
	circuit-breaker	transformer
3.6 kV	3EF1 036-0A	3EF1 036-0A
4.8 kV	3EF1 048-0A	3EF1 048-0A
7.2 kV	3EF1 072-0A	3EF1 072-0A
12 kV	3EF3 120-1	3EF1 120-0A
15 kV	3EF1 150-0A	3EF1 150-0A
> 15 kV	For the selection of ratings refer to chapter E	

Table B-15: Recommended surge arresters for generator-transformer units

¹³ Maximum value including temporary voltage rise – where applicable

B 9.5 Generators connected to the HV grid

This almost only concerns generators of large size, which feed into high voltage systems ≥ 110 kV. The protective measures must be planned individually; they are independent of the breaker.

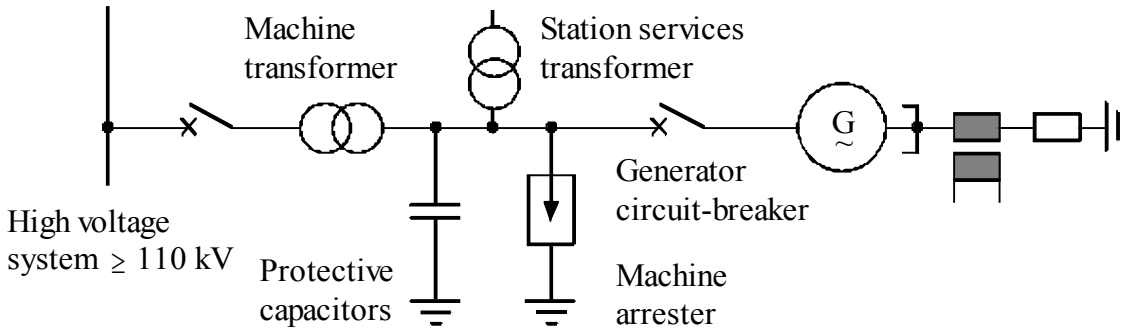


Figure B-11: Generator connected to a HV grid

B 10 Furnace transformer

The following duties are included in this field:

- Arc furnaces, reduction furnaces, induction furnaces
- Exception: medium frequency furnaces are not included → see converter transformers.

Switching duty:	Arc furnace	Reduction furnace, induction furnace
Current:	0.01 up to 2.0 x rated transformer current	0.01 up to 2.0 x rated transformer current
$\cos \phi$	0.2 $\longleftrightarrow$ 0.9 lag.	0.5 $\longleftrightarrow$ 0.8 lag.
Remarks:	During opening operations, multiple re-ignitions may cause resonant oscillations in the transformer; at currents ≤ 600 A high overvoltages due to virtual current chopping may occur as well. Consider the insulation co-ordination; see section B 10.1	

Table B-16: Switching of furnace transformers

Additional measures: RC-circuitry and surge arresters at the transformer and the busbar.

Circuit-breakers for furnace transformers have to meet very high electrical and mechanical requirements partly under unfavourable operating conditions such as high temperature environments or pollution from electrically conductive dust. The currents to be switched are between almost zero and two times the rated current of the furnace transformer; they may be unbalanced and distorted. The switching frequency may be up to 100 cycles per day and in exceptional cases it may be even higher.

B 10.1 Insulation co-ordination for operating voltages above 36 kV

Under certain conditions 36 kV vacuum circuit-breakers can also be used with higher operating voltages up to 40.5 kV (mainly in networks with effectively earthed neutral). Frequently a maximum voltage of 38.5 kV is used which corresponds to installations with 35 kV, plus 10% tolerance.

Insulation co-ordination: the insulation level of 36 kV circuit-breakers can be rated to maximum values 185 kV lightning impulse withstand voltage (BIL) and 85 kV short-duration power-frequency withstand voltage (the standard insulation relating to the upper values according to IEC is 170 kV / 70 kV). All other equipment, including protective components such as RC-circuits and surge arresters, shall be correspondingly dimensioned; the complete switchgear installation must fulfil these insulation values.

B 10.2 Protective measures against overvoltage

Furnace transformers are generally equipped with RC-circuitry and surge arresters. RC elements prevent resonant oscillations in the transformer in that they form a high pass filter to earth for transient high-frequency currents caused by multiple re-ignitions. Arresters limit the overvoltages caused by virtual current chopping, which can occur on switching off currents up to 600 A. Currents in this range are possible even if the rated operating current of the transformer is far above 600 A, as the actual values to be switched during operation lie between the magnetising current (no-load) of the furnace and twice the rated value (electrode short circuit). Depending on the method of neutral point earthing 3 surge arresters in phase-earth connection are used or additionally between the phases (6 arrester connection).

It depends on the network configuration whether the busbar needs surge protection as well. Installations with a low earth capacitance of the inferring system require power capacitors at the busbar with a damping resistor (as shown in the figure below) or RC-circuitry similar to that on the transformer. Under certain conditions surge arresters must be additionally fitted to busbar: they limit – together with the arresters at the transformer – the overvoltages across the contact gap.

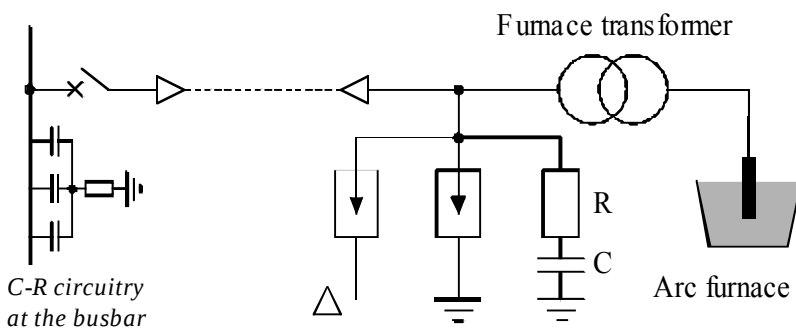


Figure B-12: Overvoltage protection of a furnace transformer

The protection devices have to be matched individually to each system configuration by means of a system study. This optimises the efficiency of protection and is inevitably necessary to protect the components themselves. The arc furnace causes harmonics which in turn drive harmonic current through the capacitors. The latter plus the damping resistors must be dimensioned for the resulting thermal load. Furthermore the capacitance must be matched to the inductance of the inferring network in order to avoid resonances, which stress the equipment by voltage rise and reactive current. See also chapter I 2 for information.

B 11 Converter transformer

This heading comprises transformers with:

- controlled rectifiers
- converter-fed drives
- voltage / frequency converters
- static compensators (static VAR or SVC)

Duty:	unloaded	loaded
Current:	magnetising current 0.5 - 3 % rating current	up to rated current
cos ϕ :	< 0.3 ind.	lag. $\longleftrightarrow$ lead.
Note:	See distribution transformers	When switching off under load at currents ≤ 600 A, overvoltages may occur; therefore overvoltage protection is required.

Table B-17: Switching of converter transformers

B 11.1 Protective measures

In normal service the load current is controlled by the converter so that the transformer is switched off only under no-load condition, which is uncritical – just like distribution transformers. However, a direct switching off operation, initiated by the circuit-breaker, cannot be precluded unless the controls of converter and circuit-breaker are interlocked (for this purpose the circuit-breaker must be fitted with a leading auxiliary switch). Switching off a loaded converter transformer may provoke the same conditions that prevail during the transformer inrush phase and can be associated with unduly high overvoltages. Therefore overvoltage protection should be generally installed. Experience has revealed that in converter installations above all the line-to-line insulation must be protected against overvoltages whereas the line-to-earth insulation is less critical.

In systems up to 15 kV operating voltage surge limiters or arresters in line-to-earth connection can also reduce the line-to-line switching surges to permissible values. This is, however, only applicable if the transformer is insulated in accordance with the upper rated insulation level of table 2, IEC 60076-3 [6] – these value are the same as of column (4), Table H-3.

All other cases require a 6-arrester arrangement which must be individually rated according to the operating voltage, method of system neutral point earthing and insulation level of the equipment; see chapter E. The same applies to installations at operating voltages above 15 kV.

B 11.2 Systems up to 15 kV operating voltage

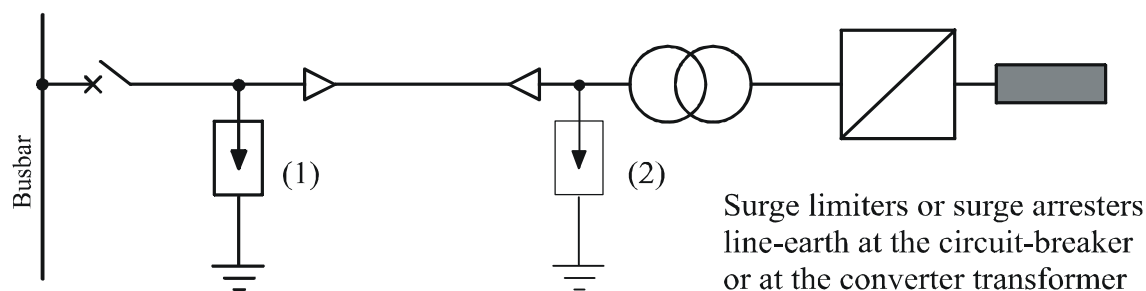


Figure B-13: Overvoltage protection of converter transformers up to 15 kV

Surge limiters or arresters at the circuit-breaker (1) are permissible only if the transformer insulation complies with the upper value of the rated insulation level according table 2, IEC 60076-3 [6]; the values correspond with column (4) Tabelle H2. If the insulation level is lower, the limiters or arresters must be installed at the transformer (2).

B 11.3 Systems above 15 kV operating voltage

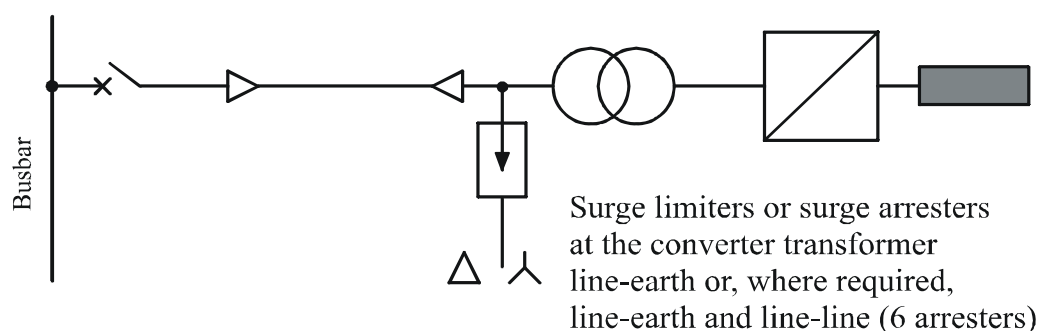


Figure B-14: Overvoltage protection of converter transformers above 15 kV

Rated voltage of transformer up to:	Suge limiters at	
	circuit-breaker	transformer
3.6 kV	3EF1 036-0A	3EF1 036-0A
4.8 kV	3EF1 048-0A	3EF1 048-0A
7.2 kV	3EF1 072-0A	3EF1 072-0A
12 kV	3EF1 120-0A	3EF1 120-0A
15 kV	3EF1 150-0A	3EF1 150-0A
> 15 kV	For the selection of ratings refer to chapter E	

Table B-18: Recommended surge limiters for converter transformers

B 12 Capacitor banks and filter circuits

Capacitor banks and filter circuits pose similar demands on the circuit-breaker. Potentially critical impacts are the inrush current and the stress of the recovery voltage. The following paragraphs deal with the requirements of

- capacitor banks without reactors
- capacitor banks with inrush limiting reactors (reactor-capacitor units)
- filter circuits

B 12.1 Capacitor banks (without reactor)

Duty:	- Single capacitor bank - Paralleling of capacitors (back-to-back switching)
Current:	- up to 1.43 times the capacitor rated current at the fundamental component (factor 1.43 includes harmonics and tolerances of the capacitance) - on back-to-back switching, 100 times the rated current of the capacitor may occur [9]
cos ϕ :	leading
Remarks:	When paralleling, a high inrush current (I_e) with high rate of rise (considerably above the value of a short-circuit) may occur. The permissible inrush current (peak value) of a circuit-breaker depends on the geometry and the mechanical travel characteristics of the breaker contact and should not exceed following values: - with flat contact pieces (vacuum circuit-breaker and contactor) $I_e = 10 \text{ kA}$ - with tulip contact pieces (SF_6-, minimum oil, compressed air) $I_e = 5 \text{ kA}$ When closing on a single capacitor bank, the inrush current does not exceed the peak value and the rate of rise of a power-frequency short-circuit, which the breaker must be capable to cope with in any case.
Measures:	Circuit-breaker must feature a very low restrike probability and comply with class C 2 according to IEC 62271-100 [7]. Single capacitor banks do not require additional measures. When back-to-back switching of capacitor banks, the inrush current must be determined and – where applicable – be limited; B 12.3.

Table B-19: Switching of capacitor banks (without reactor)

B 12.2 Reactor-capacitor combinations

Duty:	- Single capacitor bank - Paralleling of capacitors (back-to-back switching)
Current:	up to rated current of the capacitor bank or the filter

cos ϕ :	leading
Remarks:	After the opening operation the voltage on the capacitor side is higher than the system voltage (Figure B-18), so that the recovery voltage is higher in contrast to capacitors without reactor. The rated voltage of the breaker must not be exceeded by this effect. When paralleling, high inrush currents (I_e) with high rate of rise may occur, depending on the reactor ratings. However, the inrush current does not exceed the permissible limits of breaker and capacitor if reactors are used (usually tuned to between 4th and 5th harmonic).
Measures:	If the voltage at the breaker exceeds its rated value, either a breaker of a higher rated voltage level or 2 series-connected breakers have to be used. Circuit-breaker must feature a very low restrike probability and comply with class C 2 according to IEC 62271-100 [7]. When back-to-back switching of capacitor banks, the inrush current must be determined and – where applicable – be limited; see B 12.3.

Table B-20: Switching of reactor-capacitor units and filters

B 12.3 Permissible inrush current

The permissible inrush current depends on the ratings of both the circuit-breaker and the capacitor bank.

Capacitor bank: Independent of the circuit-breaker, the peak value of the inrush current may not exceed 100 times the rated normal current of the capacitor, in order to limit the effect of the electrodynamic forces. The factor 100 is a general rule only, at high switching rates the standard [9] recommends to limit the inrush current to lower values.

Capacitors are normally equipped with discharge voltage transformers or resistors. If re-closing cycles may occur in normal service, the discharge time constant must be chosen short enough that the capacitor is almost completely ($\leq 10\%$) discharged before re-energising. Otherwise the inrush current can increase to undue values if the polarity of the system voltage is in opposition to the residual charge.

Circuit-breaker: In order to avoid inadmissible stress and wear of the contact pieces, permissible limits of the inrush current must be observed. For Siemens circuit-breakers the following inrush currents are permissible without reservations:

- $I_e \leq 5 \text{ kA}$ for tulip contacts (SF₆ or minimum-oil circuit-breakers)
- $I_e \leq 10 \text{ kA}$ for flat contacts (vacuum circuit-breakers)

Regarding flat contacts the limit value is founded on the tendency to contact welding if the inrush current does not decay rapidly enough during the pre-arcing time (1 ... 2 ms) of the contact closing travel. Inrush currents above the limits mentioned above require an agreement with the manufacturer. On the other hand, if the inrush current decays rapidly below the limit, considerably higher initial values of the inrush current are permissible (Figure B-15).

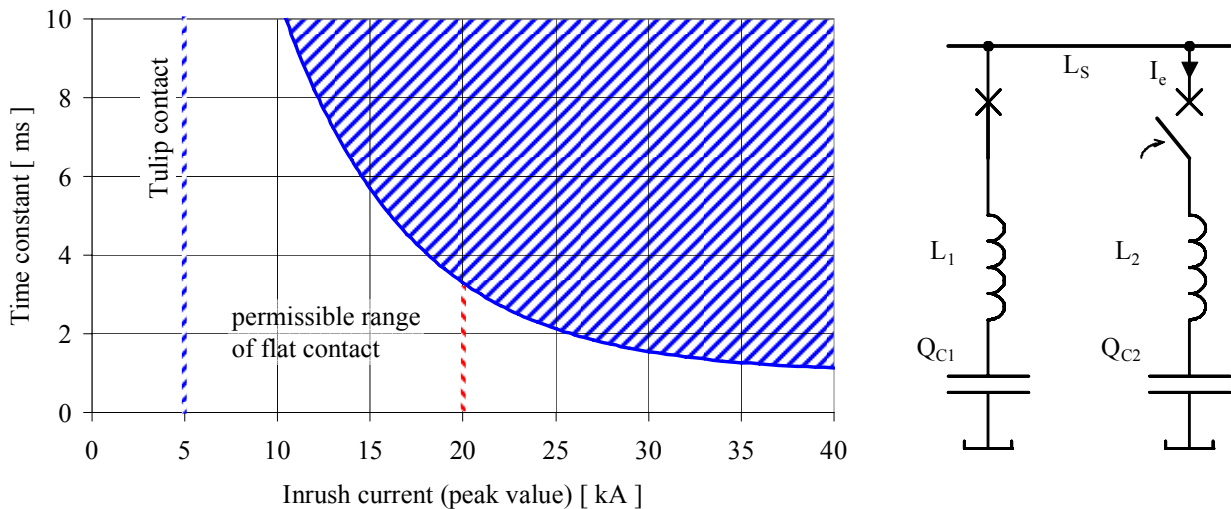


Figure B-15: Permissible back-to-back inrush making current dependent on the time constant

The limit value 20 kA of the inrush making current marks the rated back-to-back inrush making current for capacitor banks recommended by the circuit-breaker standard [7].

The decay time constant of the back-to-back inrush making current can hardly be determined without knowledge of the impedance (cable or bar, length, cross section and shape) between the capacitor banks. It is extremely difficult to determine the resistive component since the skin effect reduces the active conductor cross-section at some kHz frequency of the back-to-back inrush making current. An assessment by means of the inductance between the capacitor bank gives a hint whether the inrush current lies in the critical range and requires detailed calculation.

B 12.4 Measures to limit the inrush making current

There are two possible ways to reduce a high inrush making current and to move it into the permissible region:

- The limitation of the inrush current to ≤ 10 kA (or ≤ 5 kA) by means of a reactor
- The reduction of the time constant (attenuation constant) by means of a resistor-inductor unit in parallel with the reactor. However this measure is only convenient for existing reactor-capacitor units.

For a given reactive power and inductance between the capacitor banks, the inrush making current on back-to-back switching can be read from the graphs (Figure B-16). If the inrush current is too high, the diagram shows the inductance which is required to keep the inrush current below the limit. The difference between the existing and the required inductance should be installed as an additional reactor; see (a), Figure B-17. The red border lines (Figure B-16) mark the area (grey) for 6 kV to 30 kV operating voltages within which the attenuation constant of the inrush making current is too high. For these border lines a Q-factor (quality factor) 60 of the parallel oscillating circuit is presumed.

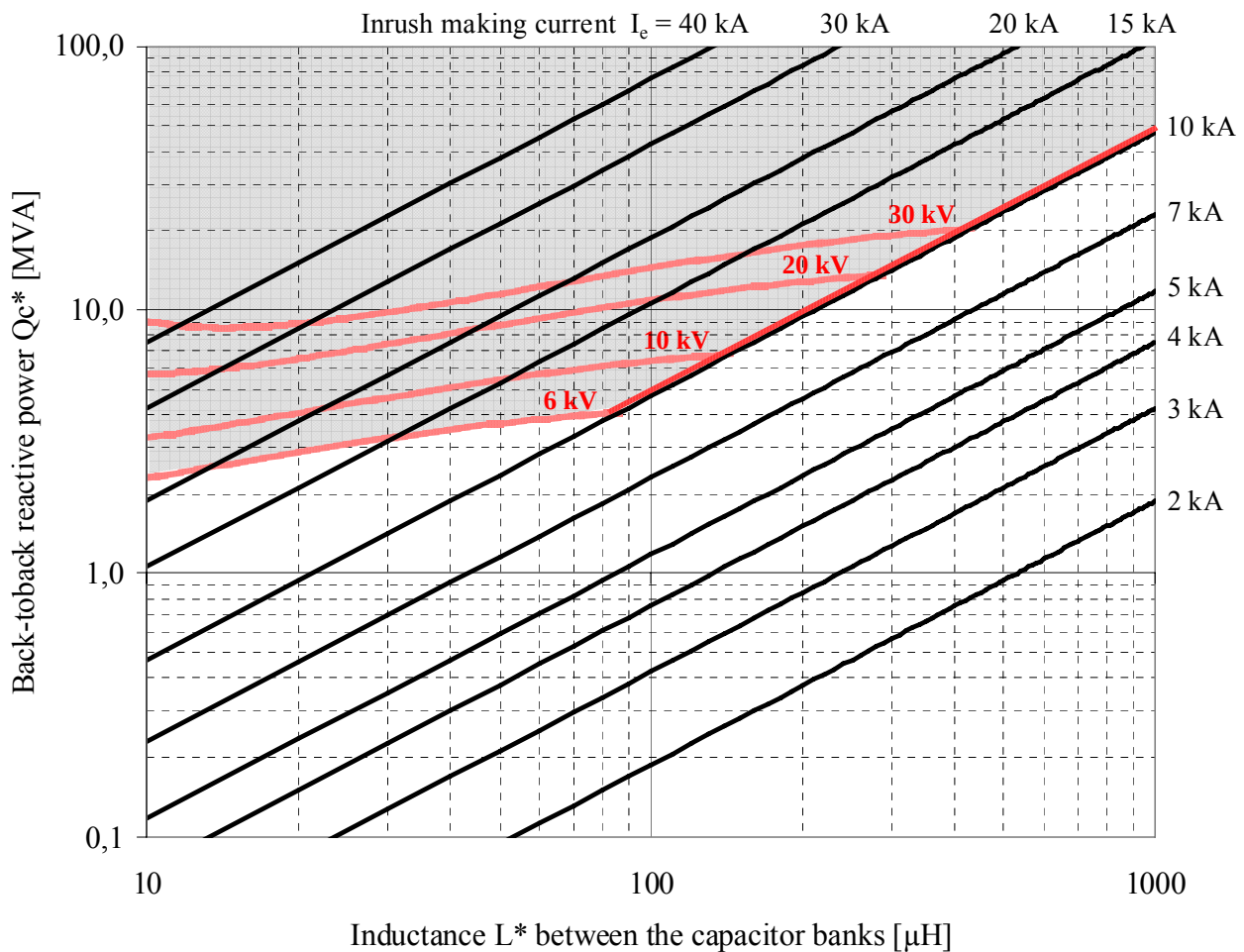


Figure B-16: Back-to-back inrush making current of two capacitor banks, depending on the inductance between the banks

The back-to-back reactive power results from the series connection of the two capacitor banks (Figure B-15).

$$Q_C^* = \frac{Q_{C1} \cdot Q_{C2}}{Q_{C1} + Q_{C2}}$$

The inductance between the capacitor banks consists of the inductances of the connecting conductors and the switchgear assembly. The following values can be presumed: for L_1 and L_2 insert the values of the relevant cables / bars (in the range of ca. 0.3 ... 0.7 $\mu\text{H}/\text{m}$). For each functional unit (panel) of the switchgear assembly insert 2 μH for the busbar, and 5 μH for the two feeders (including current transformers); n = number of functional units (panels) between the capacitor bank feeders.

$$L^* = L_1 + L_2 + L_S$$

$$L_S \approx 5\mu\text{H} + n \cdot 2\mu\text{H}$$

Figure B-17: A reactor which can be freely selected (a) is the easiest method to limit the inrush making current. In the case a reactor is already installed or planned but the inrush current is still too high, a resistor in parallel (b) can tune the attenuation constant. The resistance, however, may vary in a small range only. It must neither be too high (to be efficient) nor too low (to avoid thermal overload of the resistor). An L-R impedance in parallel to the reactor (c) facilitates more exact tuning. In any case the damping elements need to be individually planned for the given installation.

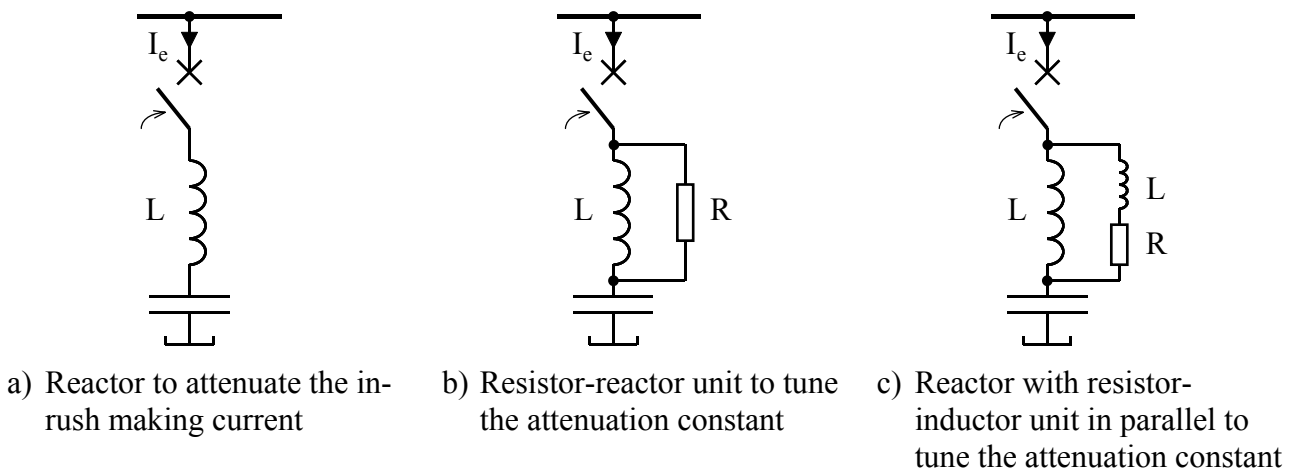


Figure B-17: Methods to limit the inrush making current

B 12.5 Permissible voltage at the circuit-breaker

When filter circuits or reactor-capacitor units are switched off the recovery voltage across the breaker is higher than when other loads are switched. The reasons for this are on the one hand the properties of the combination of reactor + capacitor and on the other hand the fact that these filters are used in systems where the voltage stress on the equipment is increased by distorted voltage due to harmonic oscillations.

The voltage on the load side of the breaker can exceed the rated value, even if the system voltage is below the rated breaker voltage, because the capacitor voltage appears at the breaker after switching off. The capacitor voltage in turn is higher than the system voltage; see B 12.6 (Figure B-18).

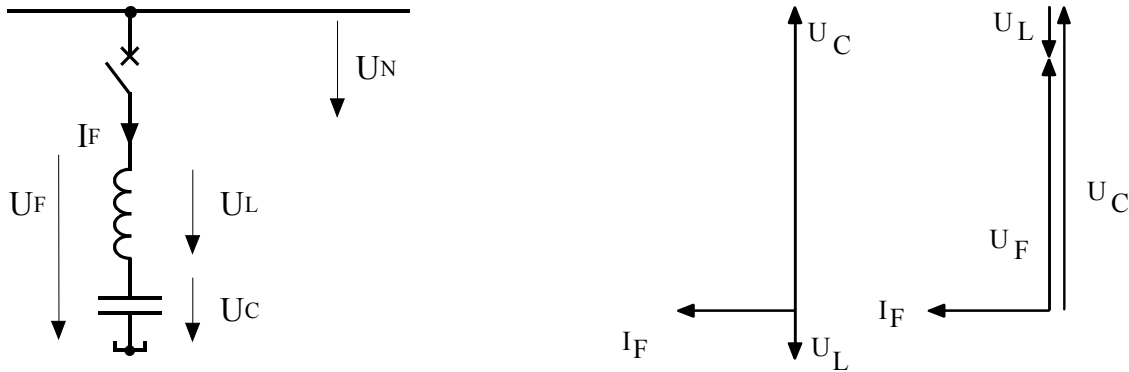
Additional stress across the breaker may occur after – for example – faulty or unintentionally tripping, if the system is still inductively loaded and the system voltage on the busbar side drops after switching off the filter (due to the loss of capacitance). If, moreover, the system voltage is heavily loaded with harmonics, the addition of all unfavourable effects can lead to an extremely high voltage across the breaker. Consequently it must be checked very accurately whether the stress on the circuit-breaker is within the permissible range.

If the capacitor voltage (U_c) exceeds the rated breaker voltage (U_r), a breaker of the next higher voltage rating must be used; e.g. a 36 kV breaker instead of a 24 kV breaker, or two breakers must be connected in series.

The following section summarises how the voltage stress caused by filters and reactor-capacitor units are determined, und which parameters need be checked regarding the circuit-breaker.

B 12.6 Determination of the voltage on the load side of the breaker

Immediately after switching off the voltage U_F is present on the load side of the breaker, which can be determined as described below.



- U_N Voltage of network
- U_F Voltage at filter
- U_L Voltage across reactor
- U_C Voltage at capacitor
- I_F Filter current
- L Reactance
- C Capacitance of capacitor bank

$$\text{Filters frequency: } f_F = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

$$\text{Filter- / system frequency ratio } v = f_F / f_N$$

v = Harmonic number (ordinal number)

Figure B-18: Voltage at a filter or a reactor-capacitor unit

When circuit is closed the voltage on both sides of the circuit-breaker, filter and busbar, is the same ($U_F = U_N$). Immediately after switching off (marked by subscript “o”) the capacitor voltage appears at the breaker since the voltage across the reactor drops to zero.

Thus the voltage on the breaker load side is $U_{Fo} = U_{Co}$

After the opening operation the filter voltage is equal to the capacitor voltage which is calculated with the harmonic number v :

$$U_{Fo} = U_{Co} = U_N \cdot \frac{v^2}{v^2 - 1}$$

Example: $v = 5$, i.e. filter frequency 250 Hz:

$$U_{Fo} = U_{Co} = U_N \cdot \frac{5^2}{5^2 - 1} = 1,042 \cdot U_N$$

This means that immediately after switching off the voltage on the load side of the circuit-breaker is 4.2 % higher than the the system voltage on the busbar side.

B 12.7 Check for permissible stress on the circuit-breaker

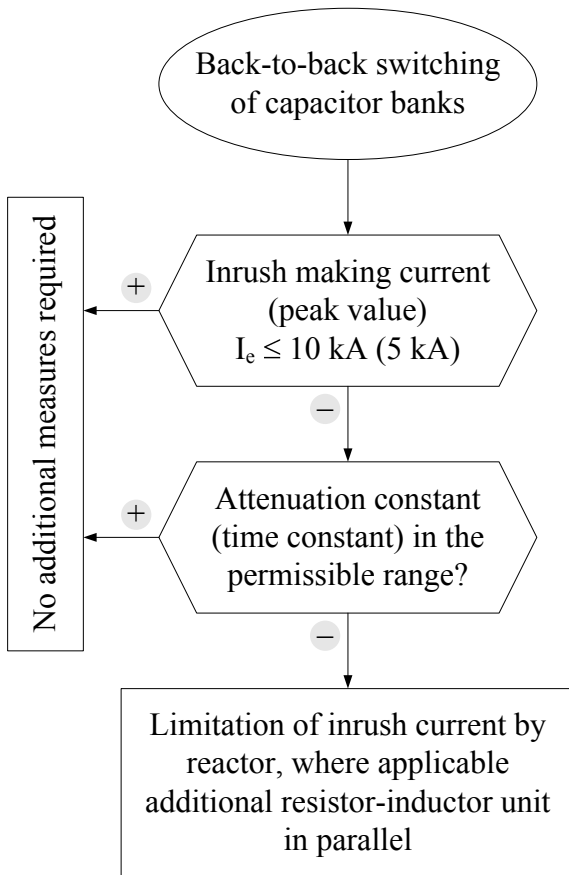


Figure B-19: Inrush current check

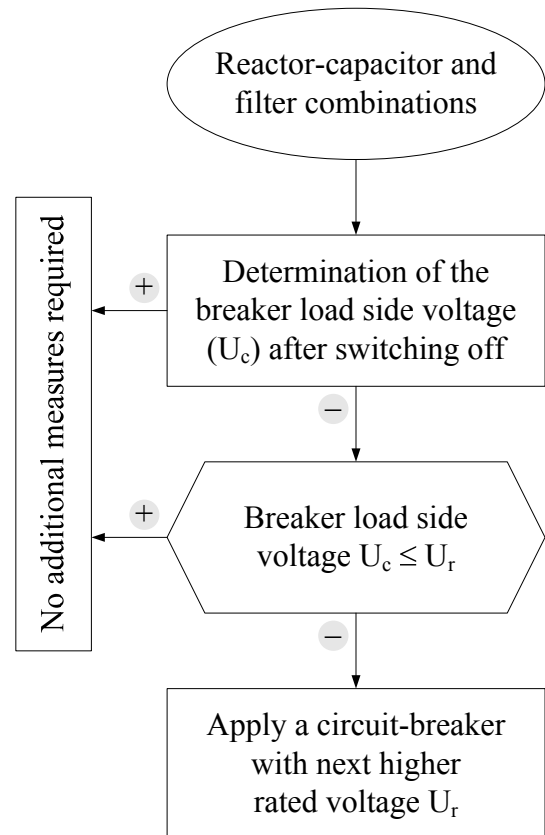


Figure B-20: Voltage check

If the back-to-back inrush making current is below the permissible peak values (see section B 12.3) or the attenuation of the current is strong enough, no additional measures are required. Otherwise a detailed assessment as described in section B 12.4 has to be carried out.

With filters or reactor-capacitor units the voltage on the load side of the circuit-breaker must not exceed the rated value at the instant of switching off. There is a particular danger if the operating voltage of the system is very close to the rated voltage and at a low ordinal number of the harmonics.

B 13 Audio frequency ripple control systems

AF ripple control systems feed audio-frequency impulses into distribution systems. The audio-frequency varies from 160 Hz up to 1.600 Hz. Series injection is usual for the lower frequencies, for the upper range only parallel injection is used. In both cases the circuit-breaker switches a capacitive current, consisting of a power-frequency proportion on which the audio-frequency proportion is super-imposed. Vacuum circuit breakers are restrike-free and thus they are well suited for this switching duty.

Current:	up to 20 A
cos ϕ :	leading
Remarks:	An audio-frequency current (160 Hz up to 1.6 kHz) is superimposed on the power-frequency control (50/60 Hz). Air and hard gas (gas evolving) switches are <u>not suitable</u> for this switching duty.

Table B-21: Switching of AF ripple control systems

Additional measures: None

C RATED VALUES OF SWITCHING DEVICES

C 1 Overview

The following table lists the most important values of the primary circuit, in accordance with which a device has to be selected. The symbols are those used in the standards IEC 62271 series.

Value „Rated - ...“	Symbol	Circuit- breaker	Switch (dis- connector)	Contactor ¹⁾	HRC fuse	Surge arrester
Voltage	U_r	x	x	U_e	x	$U_L/U_c/U_r$
Insulation level						U_{res}/u_{ai}
- lightning impulse withst. volt.	U_p	x	x	x		
- power-frequency withst. volt.	U_d	x	x	x		
Frequency	f_r	x	x	x		
Current	I_r	x	x ²⁾	I_e ²⁾	x	
Short-time withstand current	I_k	x	x	x		
Duration of short-circuit	t_k	x	x	x		
Peak withstand current	I_p			x ³⁾		discharge current I_s
Short-circuit making current	I_{ma}	x	x	I_m		
Short-circuit breaking current	I_{sc}	x		I_c		
Mainly active load-breaking current	I_l		x			
Closed-loop breaking current	I_{2a}, I_{2b}		x			
No-load transformer breaking current	I_3		x			
Cable-charging breaking cur.	I_{4a}		x			
Line-charging breaking current	I_{4b}		x			
Earth fault breaking current	I_{6a}		x			
Cable- and line-charging break- ing current under earth fault conditions	I_{6b}		x			
Cable- and line-charging break- ing current under earth fault conditions <i>with superimposed load current</i>			*			
Transfer current	$I_{r-transfer}$		x ⁴⁾			

Table C-1: Primary ratings of equipment

x Selection values foreseen by the standards.

* Recommended selection value, not required by the standards.

1) The symbols used for high voltage contactors are sometimes different, since they were – historically – designed in accordance with the low voltage standards.

- 2) In switch-fuse combinations the rated current is limited to the rated current of the fuse.
- 3) Not defined in the standard; see note (1).
- 4) Applies only to switch-fuse combinations.

C 2 Rated voltage U_r

is the upper limit of the highest voltage of systems for which the device is intended and designed. It must be at least equal to the highest expected operational voltage at the installed location, considering effects such as:

- short duration voltage rises
- harmonics
- load shedding
- increased levels at capacitors and filters

C 3 Rated insulation level U_d and U_p

is the dielectric strength (lightning impulse and power-frequency withstand) phase to earth, between phases and across open switch gaps or isolating distances. The insulation level comprises the

- Rated lightning impulse withstand voltage U_p (1.2/50 μ s)
- Rated power-frequency withstand voltage U_d (50 Hz / 1 min)

Instead of rated lightning impulse withstand voltage U_p the term BIL (basic impulse level) is also often used.

For medium voltage the standards do not specify a switching impulse voltage withstand but this value is of importance for the selection of overvoltage protection devices for transient switching surges. This switching impulse level (SIL) is set at $0.8 \cdot \text{BIL}$, because the much longer transient tail time of the switching impulse requires a lower dielectric strength than the lightning impulse.

The insulation level is related to the rated voltage. If it is not adequate for a particular duty, because external or internal overvoltage sources have to be considered, the fitting of surge arresters is recommended.

C 4 Rated normal (operating) current I_r

is the (r.m.s.) current which the main current path of the device can carry continuously under defined conditions.

The value normally applies to equipment in free air. The actual permissible value depends, therefore, on the temperature at the installed location. The permissible value may be reduced by

- installation within a housing or cubicle (restricted heat dispersion)

- the current carrying capacity of connected equipment (cables, fuses)
- harmonics (total current $I_{ges} \leq \sqrt{I_{50Hz}^2 + \sum I_{OS}^2}$)

With HRC fuses, the rated current is just an "ordering size". Because of the particular character of this device, the actual value to be chosen depends on various other factors; see section D.

C 5 Rated short time withstand current I_k

is the effective (r.m.s.) value of the short circuit current which the device, when closed, can carry for a specified time under defined conditions.

C 6 Rated duration of short circuit t_k

is the time for which the device, when closed, can carry a current equal to its rated short time withstand current. The standard value is 1 second. If a longer time is necessary, the recommended alternative is 3 seconds. By agreement between manufacturer and user, a value < 1 s may be chosen.

C 7 Rated peak withstand current I_p

is the peak current of the first major loop of the rated short time withstand current which the device can carry, when closed, under defined conditions. For devices which have full fault closing capability (↗ rated short-circuit making current) this value is inherent.

In switch and fuse combinations, the magnitude of the let through current of the largest fuse for which the combination is designed, is adequate.

C 8 Rated short-circuit making current I_{ma}

is the current which the device can safely handle when making onto a short circuit at its terminals. The stress is greater than that given by the rated peak withstand current since dynamic forces and the movement of the switch blades aggravate the condition.

⇒ Normally the short circuit making current is taken as 2.5 times the r.m.s. short time short circuit current. That multiple corresponds to the relationship in distribution networks when a generator-remote short circuit occurs (peak value of the initial short circuit a.c. current $I_p = 1.8 \cdot \sqrt{2} \cdot I_{sc}$; peak factor $\kappa = 1.8$). Close up to motors and generators, the peak value of the making current may be more than the power frequency short circuit current. In such cases, the switching device must have a rated value at least equal to this duty!

In switch and fuse combinations, the magnitude of the let through current of the largest fuse for which the combination is designed, is adequate.

C 9 Rated short-circuit breaking current I_{sc}

is the current which the device can safely interrupt when the short circuit is at its terminals.

⇒ In the selection of this value, the rated making current shall also be considered. Normally $I_{ma} = 2.5 \cdot I_{sc}$, but if the relationship $I_m/I_{sc} > 2.5$ in the network, then a device with a larger rated breaking current must be chosen.

C 10 Rated mainly active load-breaking current I_1

Is used with switchgear only and designates the same as the rated (normal) current.

C 11 Rated closed-loop breaking current I_{2a} , I_{2b}

is the same as the rated (normal) current.

C 12 Rated no-load transformer breaking current I_3

applies to general purpose switches and is defined as the current of an unloaded transformer; the value amounts 1 % of the rated operating current.

C 13 Rated cable-charging breaking current I_{4a}

is between 6A (at 7.2 kV) and 20 A (at 36 kV) according to the standard. Manufacturers may give higher values. Here, the charging current of unloaded cables is meant.

C 14 Rated line-charging breaking current I_{4b}

is between 0.5A (at 7.2 kV) and 2 A (at 36 kV) according to the standard. Manufacturers may give higher values. Here, the charging current of unloaded overhead lines is meant.

C 15 Rated earth fault breaking current I_{6a}

is the largest earth fault current which the switching device, in a network with unearthed neutral point, must be able to interrupt.

This refers to a fault on the line side of the switch, with unloaded line (see Table A-3, case No. 11). The switch must be able to interrupt the charging current of all galvanically connected lines (sometimes a larger value), at normal recovery voltage

C 16 Rated cable- and line-charging breaking current under earth fault conditions I_{6b}

is the largest current in the fault-free conductors, which the switch must be able to interrupt.

This refers to a fault on the line side of the switch, with unloaded cable (see Table A-3, case No. 9). The switch must be able to interrupt the charging current of the connected cables (or lines). And that at $\sqrt{3}$ x recovery voltage, because the earth fault remains, on the line side. Hard gas and air-break switches have very small capability in this case.

C 17 Cable switching current under earth fault conditions with superimposed load current

This current is not defined in the standards but is a realistic operational case. The standard requires only a value for unloaded cable switching under fault conditions. In practice, however, load currents are almost always present.

For hard gas and airbreak switches, this is a very critical case (see Table A-3, case No. 10). Before using such a switch, the network conditions must be ascertained and the capability requested from the manufacturer.

C 18 Rated transfer current $I_{transfer}$

is the largest current which a switch, in a fuse switch combination, must be able to interrupt. This value is critical for the selection of the associated fuse; see section D.

C 19 Rated voltage U_L (surge arrester with spark gaps)

is the highest power frequency (network) operating voltage at which the arrester can still extinguish the follow current after sparkover.

C 20 Rated voltage U_r (metal oxide surge arrester)

is the maximum power frequency voltage which the arrester can withstand, when operating, under the conditions of a short term voltage rise of at least 10 seconds.

C 21 Continuous operating voltage U_c (metal oxide surge arrester)

is the maximum network operating voltage which may be applied continuously to the arrester.

C 22 Sparkover voltage

is the voltage which causes the arrester to operate; that is, to break down its spark gap(s). The form of the voltage determines the speed of the breakdown and the threshold; one therefore qualifies this value by distinguishing between switching impulse sparkover voltage u_{ai} , front of wave sparkover voltage u_{ast} and 100% lightning impulse sparkover voltage u_{as100} .

C 23 Residual voltage u_{res}

is the maximum voltage across the arrester terminals when the discharge current is flowing. Sparkover and residual voltage determine the protection quality of the arrester and are thus very important values for insulation coordination calculations.

C 24 Rated discharge current i_{sn}

is the maximum value of the discharge current which the arrester can carry without exceeding the highest permissible residual voltage.

D SHORT-CIRCUIT PROTECTION WITH HRC FUSES

D 1 Selection criteria

In switch and fuse combinations, protection against short circuit is performed by the fuses. Switches will interrupt operating currents and only small overcurrents, since their interrupting capability is limited. Between operating current and full short circuit the switching duty transfers from one component to the other. Switch and HRC fuses must, therefore, be matched correctly to each other. Mostly, one uses current limiting fuses; selection procedures are described later in this chapter.

The electrical characteristics of a fuse are: rated voltage and rated current (U_{rHH} , I_{rHH}). The diagram clarifies the factors which determine selection. The factors are coupled by a logic "AND", that is, they must all be considered in determining rated voltage and current.

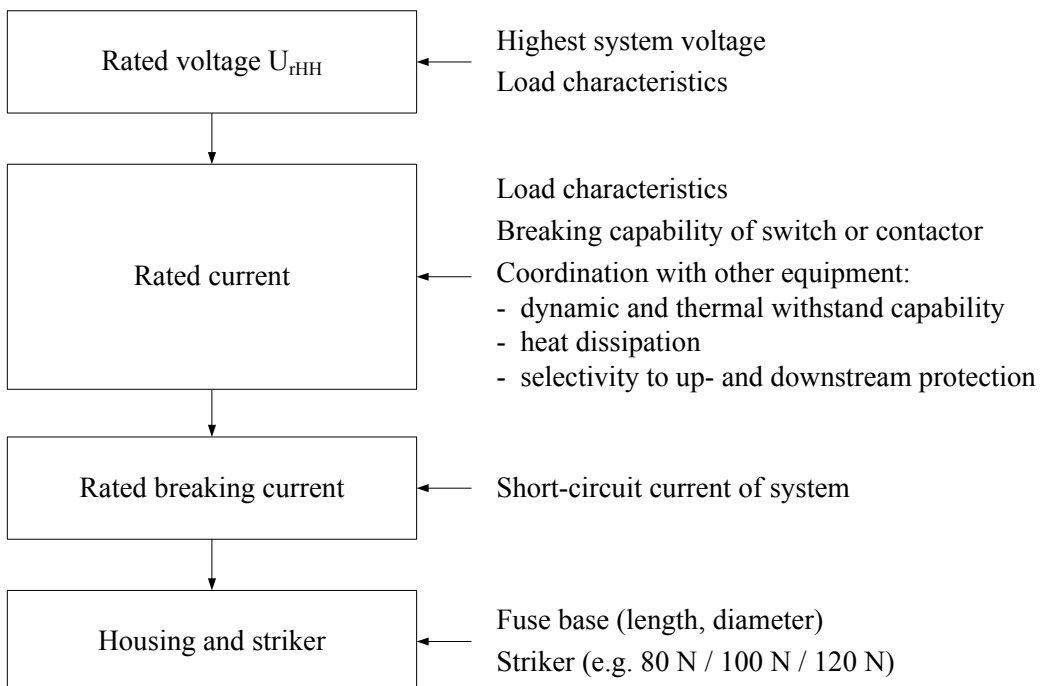


Figure D-1: Criteria influencing the selection of fuses

Mechanical criteria, e.g. diameter, length, striker pin power, all depend upon the type and design of the switchgear assembly or switch; they are not discussed here.

D 2 HRC fuses for distribution transformers

D 2.1 Fuse rated current I_{rHH}

There is a reference list of fuses defined by the manufacturer, which HRC fuses are suitable for transformers of given voltage and power ratings. This list is based on the requirements of IEC 60787 [27]. The selection is determined by:

- the inrush current on energising the transformer
- the primary current when the secondary is short circuited
- selectivity requirements and coordination with up- and downstream equipment

D 2.1 a Inrush current

It affects the fuse in the same way as a large, time limited overcurrent. The fuse element of the fuse shall not be pre-conditioned by the heating effect of this current. A fuse with rated current larger than the transformer rated current is therefore selected. Depending on power, short circuit voltage and connection group, the smallest usable fuse size results.

- For a simplified selection method the inrush current is set to 12 ... 15 times the rated normal current of the transformer, with a duration of 0.1 s; point 'A' in the figure below.

D 2.1 b Primary current while terminal short-circuit on the LV side of the transformer

On interruption of such a terminal short circuit, very steep transients result. Because of the limited interrupting capability of the switch, these currents should be interrupted by the fuses. The primary side short circuit current can be very much damped but, even so, the HRC fuses must operate and interrupt positively and safely. This factor determines the largest possible rated fuse current.

- For a simplified selection method the short-circuit duration on the HV side shall correspond to the maximum permissible short-circuit duration of the transformer; as a rule the value is 2 s; point 'B' in the figure below.
- Minimum values of the short-circuit impedance u_k are listed in IEC 60076-5 [29].

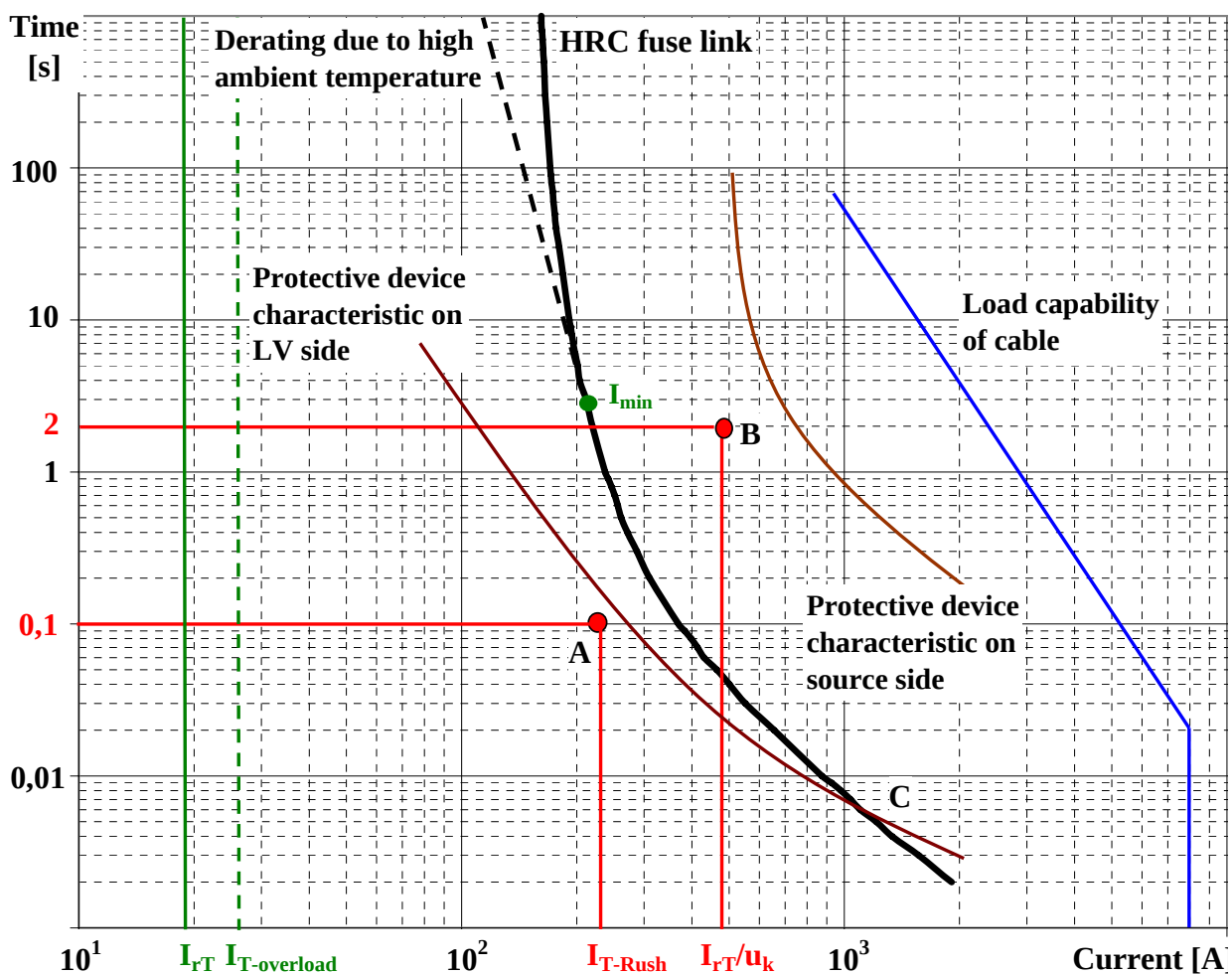


Figure D-2: HRC fuse characteristic for the protection of distribution transformers

The fuse time-current characteristic must lie between the points A and B.

Point A: $I = 10 \dots 12 \cdot I_{rT}$
 $t = 0.1 \text{ s}$

Point B: $I = I_{rT} / u_k$
 $t = 2 \text{ s}$

D 2.1 c Coordination with other equipment

- The fuse rated current must be selected such that the temperature rise of the fuse link does not exceed the limit given at the installation location. In particular this applies to the installation in enclosed switchgear.
- The same condition is applicable for locations at very high ambient temperatures; see section D 7.
- When using switch-fuse or contactor-fuse combinations, the breaking capability of the switching device must not be exceeded; see section D 5.
- The time-current characteristic of the HRC fuse should lie to the left of the thermal load capability of the cable.
- The cut-off (let through) current assigned to the rated normal current of the fuse must be smaller than the dynamic load capability of the cable.

D 2.1 d Selectivity to other protection devices

- Between HRC fuses: when two fuses are operated in series – which can occur in long radial feeders (dead-end feeder), the rated current of the upstream fuse must be 1.6 times the rated current of the downstream one ($I_{rHH\text{-up}} \geq 1.6 \cdot I_{rHH\text{-down}}$). Factor 1.6 roughly corresponds to two steps of the rated current.
- Between HV and LV fuses: firstly, the currents must be adjusted for the voltage levels. The rated current of the high voltage fuse must be compatible with the current of the (largest - if a number are in parallel) low voltage fuse.
- Between HV fuse and LV circuit breakers: the LV breaker shall clear all faults which are downstream of its terminals. For selectivity one needs the pre-arcing time characteristic of the fuse (calculated for the low voltage side) and the opening time of the LV breaker. The procedure is similar to that determining selectivity between fuse and motor protection relay.

⇒ Additionally, the requirements of chapters D 5 to D 7 must be observed.

D 2.2 Rated voltage U_{rHH}

The rated voltage of the fuse in most cases is determined by the network voltage only.

D 3 HRC fuses for capacitors

D 3.1 Fuse rated current I_{rHH}

When energising capacitors – particularly when paralleling them – extremely high inrush currents can occur, with amplitudes of the order of short circuit magnitude. Inrush duration, however, is short - in the range of milliseconds. These short circuit-like currents impose a very high degree of stress on the fuses.

In addition to the 50/60 Hz basic frequency, higher harmonics always flow through a capacitor, dependent upon the harmonic content of the network. The effective value of the total current can, under normal network conditions, reach 1.43 times the capacitor rated current.

For these reasons, the rated fuse current shall be explicitly higher than the capacitor rated current (I_{rC}), preferably 4 times higher – at least twice as high,; $I_{rHH} = 2 \dots 4 \cdot I_{rC}$

⇒ Additionally, the requirements of chapters D 5 to D 7 must be observed.

D 3.2 Rated voltage U_{rHH}

The rated voltage of the fuses shall be one step higher than the network voltage, so that there is adequate margin to cover the harmonic content.

D 4 HRC fuses for motors

Fuses provide short circuit protection, not overload protection for the motor! For the thermal motor protection, a definite minimum time, current proportional protection relay is used. (In English terminology an i.d.m.t. relay, in German, an AMZ relay).

D 4.1 Fuse rated current I_{rHH}

Catalogues from fuse manufacturers give selection recommendations, which consider the following points:

- the starting current of the motor
- the run-up time and starting frequency
- compatibility with a motor protection relay, if fitted.

D 4.1 a Motor starting current, run up time and frequency of starting

Starting currents, which can be 5 to 7 times the motor full load current, have the same effect on the fuses as a large, time limited overcurrent. The fuse element of the fuse shall not be pre-conditioned by the heating effect of this current. The motor starting current and run up time gives the smallest usable fuse.

If no reference list of the fuse manufacturer is available, the fuse can be selected in the following way:

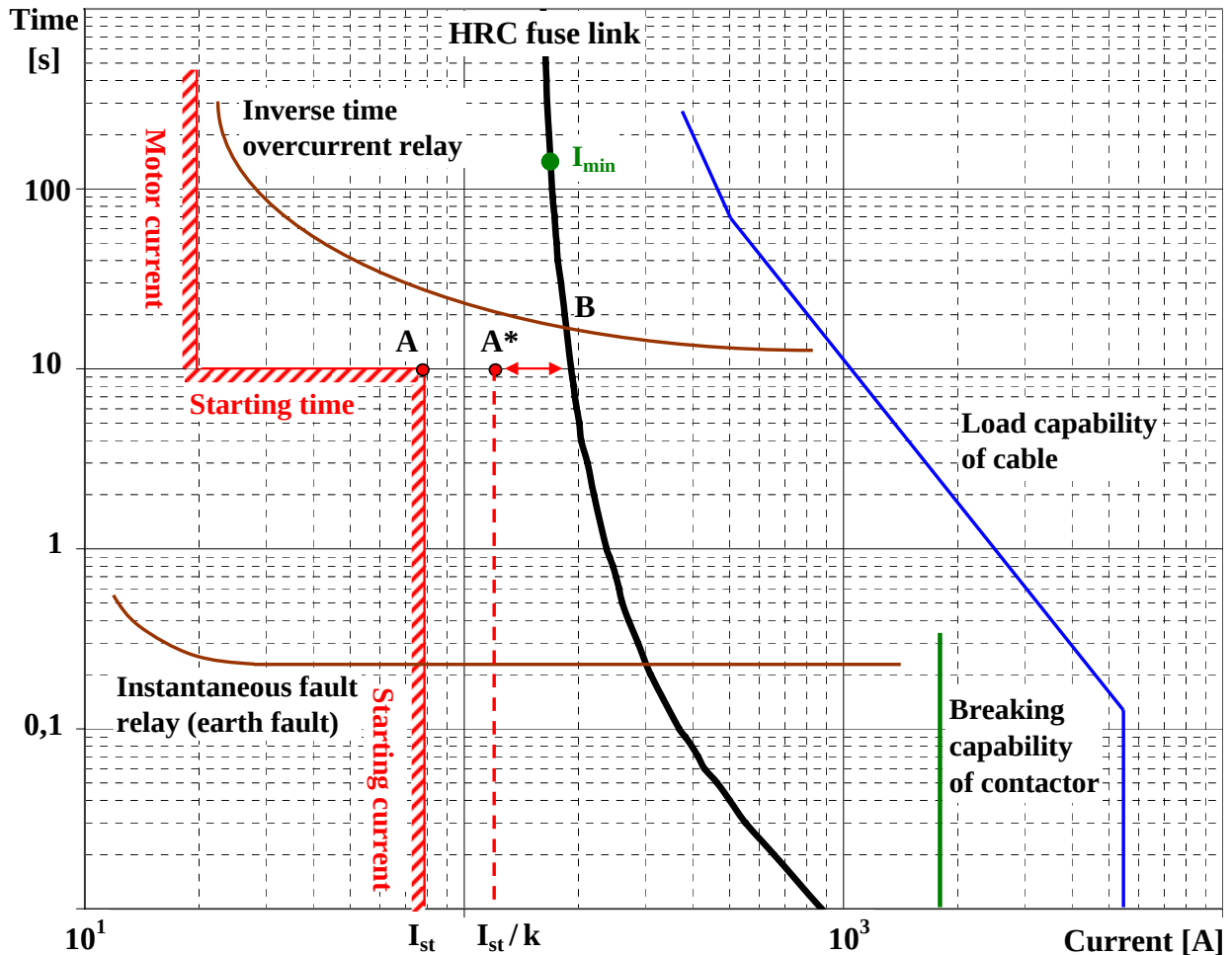


Figure D-3: HRC fuse characteristic for motor protection

⇒ The motor starting current (I_{st}) is given, otherwise the starting current is presumed to be 6 times the motor rated current ($I_{st} = 6 \cdot I_{RM}$) – this refers to direct starting asynchronous machines.

On indirect starting, i.e. slipping motor or run-up via autotransformer or converter (soft starter), the starting current (I_{st}) is much smaller; regularly in the range of $1.2 \dots 2 \cdot I_{RM}$

⇒ The motor starting current (I_{st}) is divided by a derating factor (k) of the HRC fuse, which takes into account the the number of starts per hour; see Table D-2: Derating factor , k ' depending on the number of starts per hour.

⇒ The value I_{st} / k together with the starting time t_{st} result in point A*, which must lie to the left of the fuse characteristic (a fuse may be selected whose characteristic is directly next point A*).

For slipping motors or for motors running up at reduced starting current, via autotransformer or converter, smaller HRC fuses can be selected. However, the fuse rated current must be at least 1.3 times the motor rated current ($I_{RHH} \geq I_{RM}$).

Starting time / s	Motor application
6	Pump
15	Mill
30 ... 60	Fan

Table D-1: Typical starting times (Source: SIBA, catalogue HHM)

Starts per hour $N_{\max} / \text{h}$	Derating factor k_{SIBA}	Derating factor k_{general}^{14}
2	0.59	0.55
4	0.53	0.50
8	0.48	0.45
16	0.43	0.40
32	0.39	0.33

Table D-2: Derating factor ,k' depending on the number of starts per hour**D 4.1 b Coordination with other equipment**

- ⇒ If the motor is equipped with a inverse overcurrent protection, the current at intersection point B must be larger than the minimum operating current $I_{\min}$ of the fuse. If that cannot be achieved, it must be ensured that overcurrents up to $I_{\min}$ will be broken by the switching device, for example, by a contactor-fuse combination with tripping by the fuse striker pin.
- ⇒ The fuse rated current must be selected such that the temperature rise of the fuse link does not exceed the limit given at the installation location. In particular this applies to the installation in enclosed switchgear. The same condition is applicable for locations at very high ambient temperatures; see section D 7.
- ⇒ When using contactor-fuse combinations, the breaking capability of the switching device must not be exceeded; see section D 5.
- ⇒ The time-current characteristic of the HRC fuse should lie to the left of the thermal load capability of the cable.
- ⇒ The cut-off (let through) current assigned to the rated normal current of the fuse must be smaller than the dynamic load capability of the cable.
- ⇒ Additionally, the requirements of chapters D 5 to D 7 must be observed.

D 4.2 Rated voltage U_{rHH}

The rated voltage of the fuse is determined by the network voltage only in almost all cases.

¹⁴ The factor “ k_{general} ” should be used if no information from the fuse manufacturer is available.

D 5 Co-ordination with a switch or contactor

A switch-fuse or contactor-fuse combination must be able to safely interrupt every possible current, up to full short circuit. The procedure is laid down in IEC 62271-105 [30]¹⁵. Switch and fuse must be so co-ordinated that

- the switch safely handles all currents up to the minimum interruption current of the fuse;
- the fuse interrupts all currents which lie beyond the interruption capability of the switch.

The largest (inductive) current which the switch can interrupt is called the rated transfer current of the switch.

Dependent upon the fuse rated current and the opening time of the switch there is a current above which the fuses alone must interrupt the circuit. This current is the transfer current for the fuse and switch combination, with the fitted HRC fuse. The transfer current shall not be larger than the rated transfer current of the switch.

Determination of the transfer current uses the following data:

- the time current characteristic of the fuse
- the characteristic opening time of the switch T_0 (for direct release by striker pin or tripping coil)
- the rated transfer current of the switch I_{transfer} (manufacturer's data)

- ① For **direct mechanical striker pin release** of the switch: Draw a line parallel to the current axis through the point $0.9 \cdot T_0$, to the pre-arcing time axis. Then to ③.
- ② For **electrical release** of the switch, by a tripping coil: Draw a line parallel to the current axis through the point T_0 to the melt axis; if a relay is in circuit with the tripping coil, draw the line through the point $T_0 + 0.02\text{s}$.
- ③ The intersection of this line with the lower time/current characteristic of the fuse gives the associated transfer current I_{transfer} (three pole, symmetrical value).
- ④ The transfer current I_{transfer} thus determined must be smaller than the rated transfer current $I_{\text{r-transfer}}$ stated by the manufacturer, that means $I_{\text{transfer}} > I_{\text{r-transfer}}$, and must be larger than the minimum breaking current (I_{min}) of the fuse, i.e. $I_{\text{transfer}} > I_{\text{min}}$.

Additional requirement for the protection of distribution transformers

In case of a short-circuit at the transformer secondary terminals (LV side), the HRC fuses shall interrupt the short-circuit current, so that the switch – although the current still may be within the range of the breaking capacity – is not stressed with the high transient recovery voltage. This results in the following condition which must be fulfilled additionally:

- ⑤ The transfer current I_{transfer} must be smaller than the short-circuit current $I''_{\text{kT-3pol}}$ of the transformer at secondary terminal short-circuit; ($I''_{\text{kT-3pol}} > I_{\text{transfer}}$).

¹⁵ Contactor-fuse combinations are not within the scope of this standard. The described method can, however, be used for the practical use also for contactors.

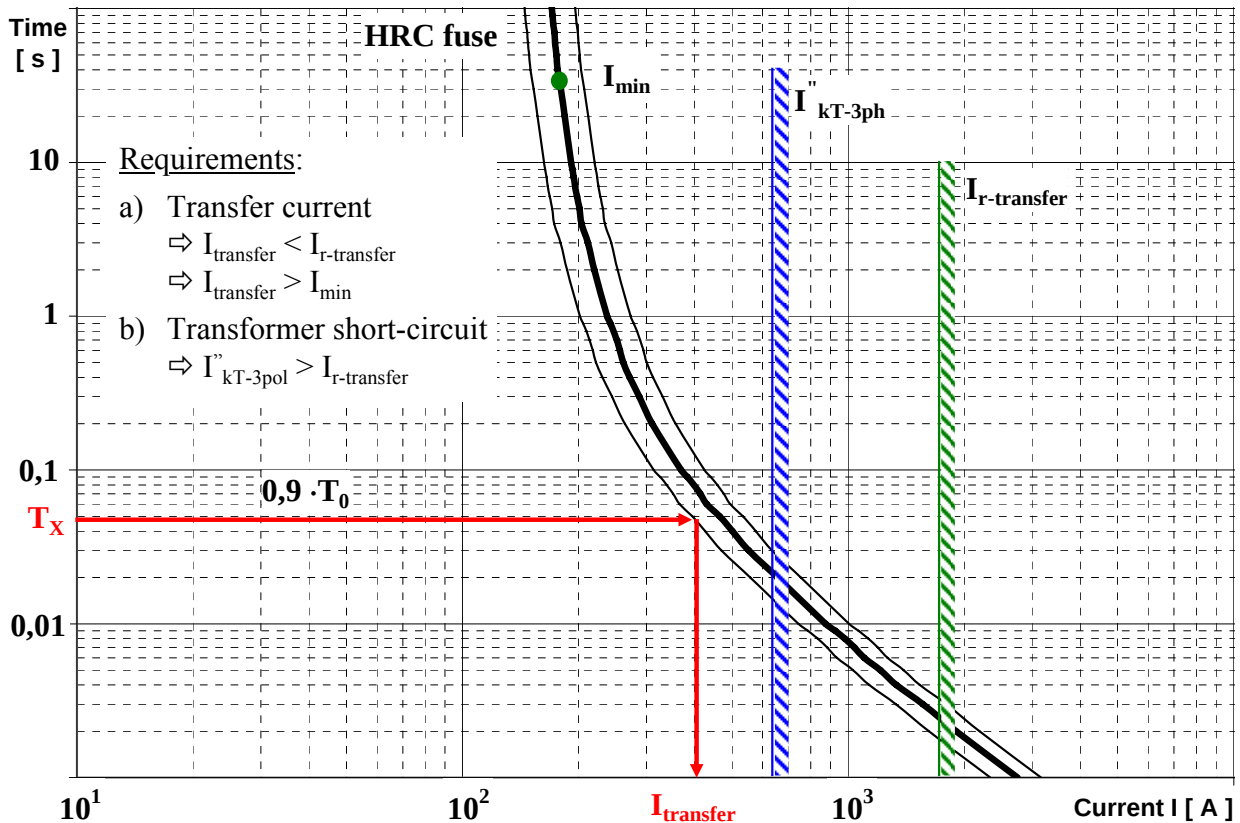


Figure D-4: Coordination of HRC fuse and switch

Example to determine the transfer current from the HRC fuse characteristic (50 A) and the opening time of a switch:

- HRC fuse, type 3GA: $I_{\text{rHH}} = 50 \text{ A}$
 - characteristic opening time of switch: $T_0 = 50 \text{ ms}$
- $\Rightarrow$ transfer current of this combination: $I_{\text{transfer}} = 405 \text{ A}$

Largest permissible HRC fuse

Conversely one can determine the largest permissible fuse for a combination, using the opening time of the switch (T_0) and the rated transfer current (I_{transfer}).

- ① For **direct mechanical striker pin release** of the switch: Draw a line parallel to the current axis through the point $0.9 \cdot T_0$, to the pre-arcing time axis. Then to ③.
- ② For electrical release of the switch, by a tripping coil:
 Draw a line parallel to the current axis through the point T_0 to the pre-arcing time axis; if a relay is in circuit with the tripping coil, draw the line through the point $T_0 + 0.02\text{s}$.
- ③ Draw a line parallel to the time axis, through the point I_{transfer} on the current axis.

- ④ This gives an area bordered by current axis, time axis, line through $0.9 \cdot T_0$ and line through I_{transfer} .
- ⑤ All fuses whose characteristics run through this area are suitable for use in this switch and fuse combination.

The illustration shows this procedure in diagram form.

$I_{\text{kT-3pol}}$ is the current on the primary side in case of a short-circuit at the secondary terminals of the transformer (short-circuit at the LV terminals).

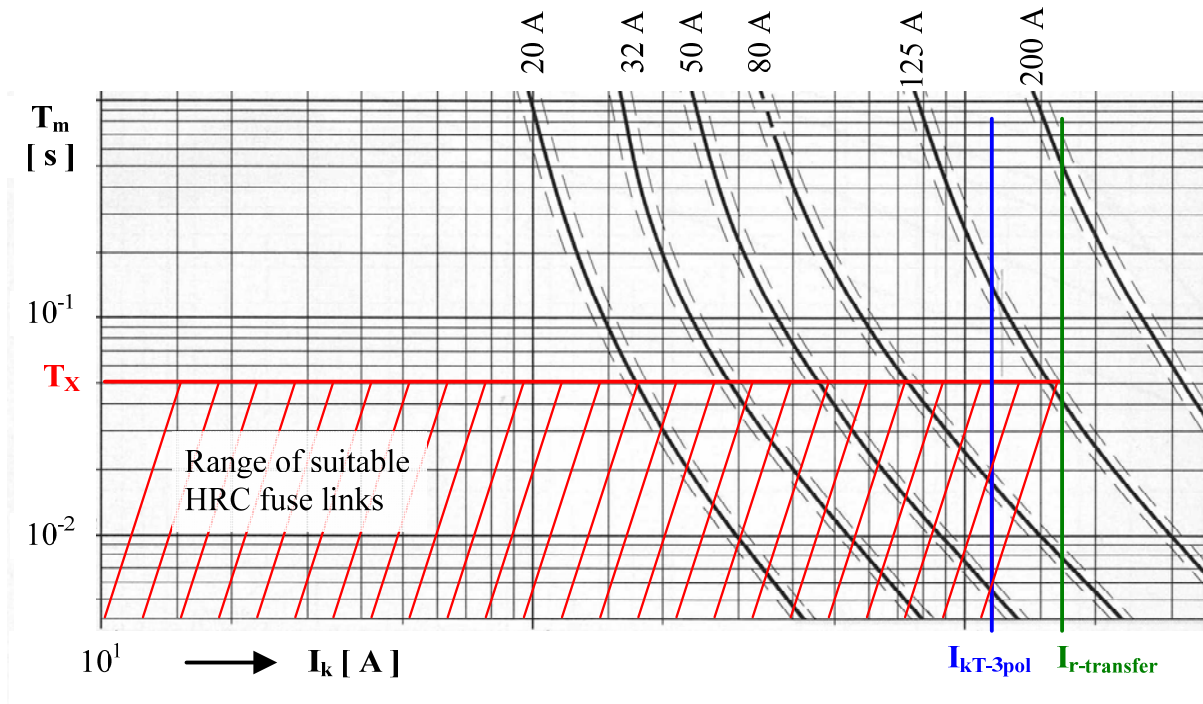


Figure D-5: Suitable HRC fuses for a given rated transfer current of the switch

Depending on the tripping method T_X is:

$0.9 \cdot T_0$	for direct striker-pin release
$1.0 \cdot T_0$	for electrical release
$T_0 + 0.02 \text{ s}$	for electrical release using a relay

D 6 Let-through (cut off) current

An HRC, current limiting fuse restricts the rising prospective fault current to its let-through value and protects connected equipment from the extreme dynamic and thermal effects of the unrestricted current. The connected equipment does not need to be designed for the full prospective short circuit current of which the network in front of the fuse is capable.

- The let-through current must not exceed the rated withstand current of connected equipment; and
- must not exceed the rated short circuit making current of the associated switch.

Current limiting characteristics give the maximum let-through (cut off) current I_{CO} related to initial power frequency short circuit current and fuse rating. Conversely, one can determine the maximum permissible fuse rating from the given dynamic withstand capability of the equipment.

The diagram shows how the let-through current can be found from the characteristic. For example, at 40 kA (r.m.s. value) short-circuit current, a 50 A HRC fuse limits the peak current to only 9 kA, whereas the prospective value is 100 kA.

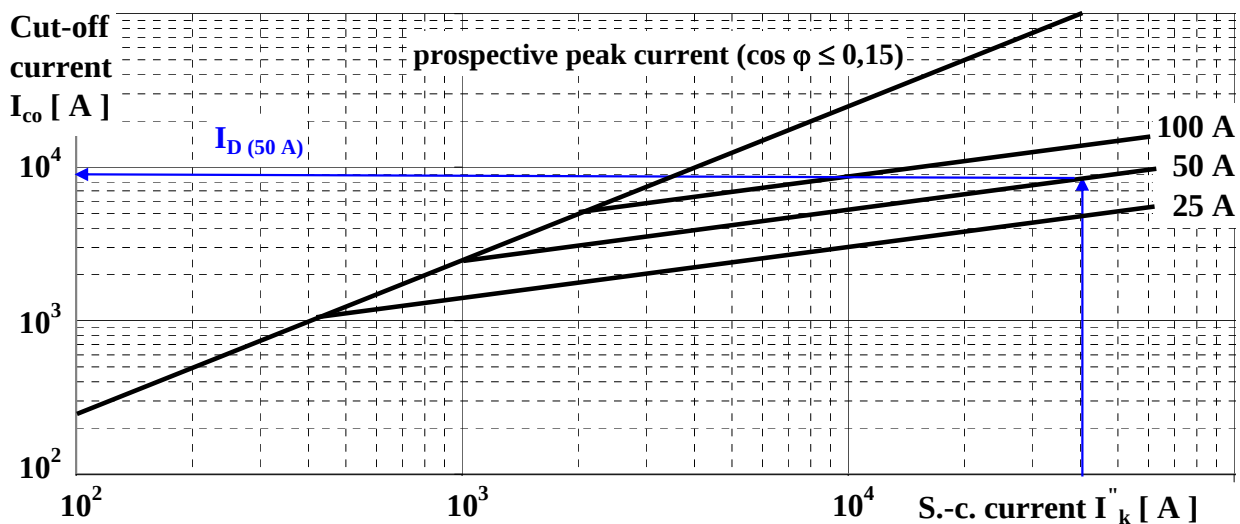


Figure D-6: Cut-off (let-through) current characteristic of an HRC fuse

D 7 Heat losses

The actual maximum permissible operating current of a fuse is, in general, less than its nominal rated current due to the thermal conditions at the point of installation (in a cubicle or enclosure), where heat dissipation may be restricted in comparison with installation in free air. In that case, the fuse cannot be operated at its full rating.

Heat loss check

The actual heat loss in operation at any current I_B is: $P_V = P_{Vr} \cdot \left(\frac{I_B}{I_{rHH}} \right)^{2.5}$

P_V heat loss generated by HRC fuse at operating current

P_{Vr} rated heat loss from HRC fuse at I_{rHH}

I_B actual operating current

⇒ For I_B insert the maximum value which can occur continuously in operation; e.g. transformer rated current or 1.2 times the transformer rated current for extensive overcurrent operation.

⇒ Check if this heat loss is properly dissipated at the installed location.

⇒ If not, choose the next higher fuse rating, as long as the other selection criteria permit it.

The above mentioned equation includes the influence of the temperature on the internal resistance of the fuse-element. When the fuse-element is loaded with less than its rated current, it heats less so that in turn the heat loss decays disproportionately high. This temperature influence is represented by the exponent 2.5 in the formula.

Example: HRC fuse with $U_r = 12 \text{ kV}$; $I_{rHH} = 100 \text{ A}$; $P_{Vr} = 110 \text{ W}$

10-kV- transformer 800 kVA, operating current $I_B = 46.2 \text{ A}$

$$\text{Actual heat loss } P_V = 110 \text{ W} \cdot \left(\frac{46,2 \text{ A}}{100 \text{ A}} \right)^{2,5}$$

$$\text{Actual heat loss } P_V = 16,0 \text{ W}$$

E SELECTION OF OVERVOLTAGE PROTECTION DEVICES

E 1 Selection criteria

The selection of surge arresters and their rated values can be done by the following scheme. The figure is an adapted version taken from several standards and selection guidelines for surge arresters [14] to [16].

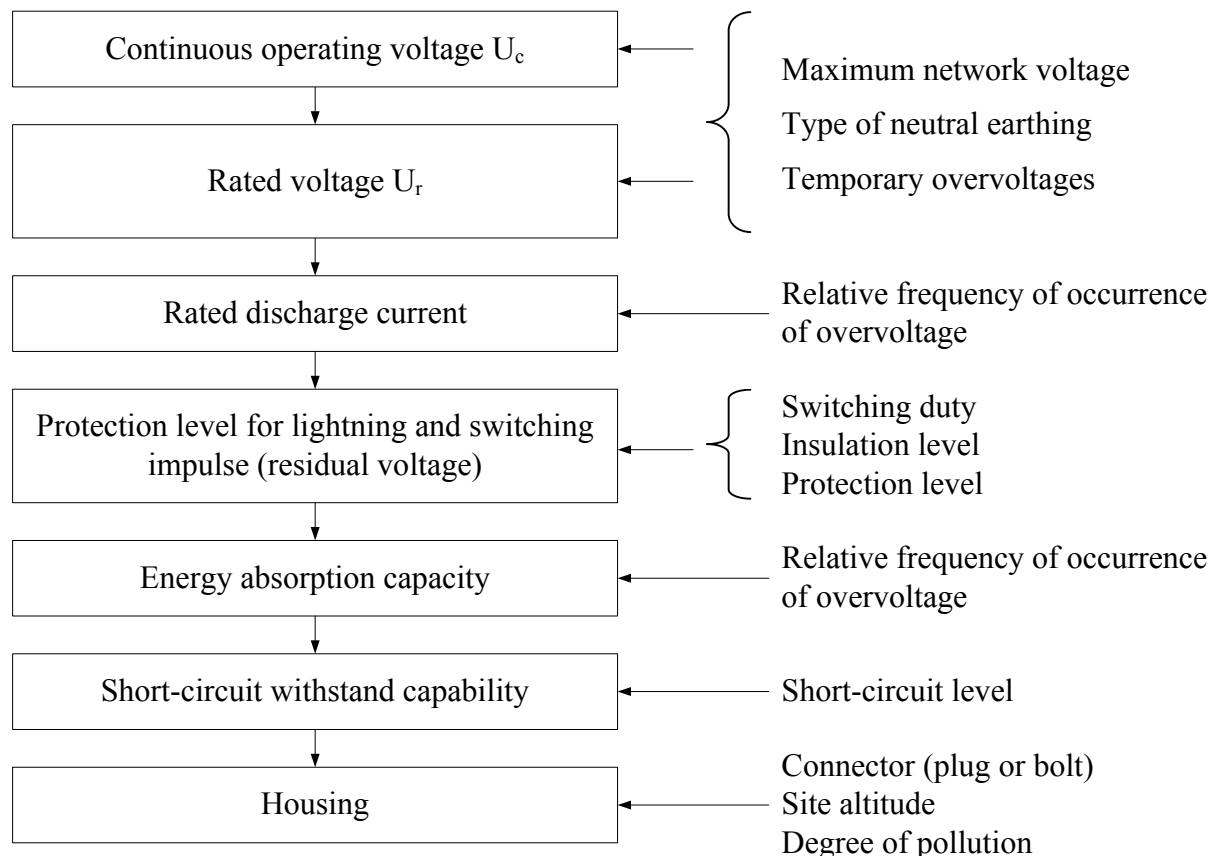


Figure E-1: Selection of medium voltage surge arresters

E 2 Continuous operating voltage and rated voltage

Continuous operating voltage U_c is the maximum permissible power-frequency voltage that may be applied continuously across the arrester terminals; continuously means more than 30 minutes.

Rated voltage U_r is the maximum permissible power-frequency voltage which the arrester can withstand for 10 seconds without suffering damage. This duration takes into account temporary overvoltages. The rated voltage also is a reference value for other characteristics of the arrester and used as ordering information.

Rated voltage of a spark-gap arrester U_r is the maximum permissible power-frequency voltage across the arrester terminals at which the arrester can safely interrupt the discharge follow-current. The rated voltage corresponds to the continuous operating voltage of non-gapped arresters.

For metal oxide arresters, one first selects the continuous voltage, then the rated voltage. In networks with free or resonant earthed neutral point, the continuous voltage must be equal to the max. line-line voltage, so that the arrester is also suitable for continuous earth fault conditions (voltage rise in the healthy phases).

For arresters with spark gap and surge limiters, almost only the rated voltage needs to be selected. If the values of rated and continuous operating voltage are not equal for the devices selected, the selection must be done as described for metal oxide arrester.

System neutral point	Metal-oxide arrester		Spark-gap arrester
	Continuous operating voltage U_c	Rated voltage U_r	Rated voltage U_r
solidly earthed	$U_c \geq 1.05 \cdot U_m / \sqrt{3}$	$U_r \geq 1.25 \cdot 1.05 \cdot U_m / \sqrt{3}$	$U_r \geq 1.4 \cdot U_m / \sqrt{3}$
impedance earthed	$U_c \geq 1.05 \cdot U_m / \sqrt{3}$	$U_r \geq 1.25 \cdot 1.05 \cdot U_m / \sqrt{3}$	$U_r \geq 1.4 \cdot U_m / \sqrt{3}$
isolated or resonant earthed	$U_c \geq U_m$	$U_r \geq 1.25 \cdot U_m$	$U_r \geq U_m$

Table E-1: Rated and continuous operating voltage for line-earth arresters, depending on the method of neutral point earthing

For **line-line arresters** (arresters between the phases) applies: $U_c \geq 1.05 \cdot U_m$

U_m is the maximum voltage for equipment, i.e. the highest operating voltage of the system at the point of installation. If the value U_m is not exactly known, the rated voltage U_r of the equipment to be protected can be used instead. U_m must include temporary overvoltages, e.g. caused by load shedding or by earth fault.

E 3 Rated discharge current

The rated discharge current is a characteristic value for use in insulation coordination, which defines the discharge current at which a given residual voltage (also called discharge voltage) will not be exceeded (nominal operating point). However, the arrester can withstand much higher discharge currents. It will not be destroyed when the rated discharge current is exceeded during a discharge, only the residual voltage is higher. Three typical rated discharge current values can be selected.

5 kA is adequate in medium voltage distribution systems under normal service conditions if the galvanically connected line system is less than 5 km.

10 kA is recommended for larger cable systems, connections to capacitor banks or in distribution systems where high rates of lightning strikes occur.

20 kA is applied in exceptional cases only, where high discharge energies prevail, high rates of operation can be expected, or where very low residual voltages are required (e.g. in arc furnace installations, large generators).

E 4 Residual and sparkover voltage (protection level)

The required residual or sparkover voltage of an arrester is derived from the insulation capability of the object(s) to be protected. The reference variable is the rated lightning impulse withstand voltage¹⁶ U_p . It is also used as reference for the protection against switching overvoltages, since the rated switching impulse withstand voltage¹⁷ U_s is not a standardised rating in the medium voltage range below 52 kV. Instead the switching impulse withstand capability is derived from the lightning impulse withstand voltage.

Sparkover (for gapped arresters) or residual voltage (MO arresters) must be less than the insulation strength of the connected equipment whereby the sparkover voltage of gapped arresters may lie a few kV above their residual voltage. The withstand capability of an insulation material depends on the duration of the overvoltage; it is greater for a short, steep front than for the slowly decaying transient. Devices can, therefore, withstand a short lived sparkover voltage which is slightly greater than the residual voltage.

When selecting an arrester to protect against switching overvoltages while breaking of small inductive currents, the permitted residual voltage should be related to a discharge current of 0.5 kA. If this value is not present in the selection tables, one must take the value for the smallest given current (e.g. at 1 kA, 2.5 kA or 5 kA).

E 4.1 Switching overvoltages

Switching operations can initiate transient oscillations with different instantaneous polarity of the voltages in the phases (differential mode overvoltage), so that the voltage between them can add up to greater values than to earth. If the switching operation might cause unduly high overvoltages, arresters must limit the overvoltages between the phases (L-L) just as phase-to-earth (L-E) to acceptable values. The objective is to achieve this with 3 arresters in phase-earth connection. If this is not possible, one needs a 6 arrester format.

Protection against switching overvoltages is always necessary for switching duties where multiple re-ignition or virtual current chopping can occur, when circuit breakers may interrupt pure inductive currents of less than 600 A. The necessary residual current of an arrester relates then to a discharge current in this range. The rated values are somewhat differently arranged. One looks in the data sheets for the residual voltage at a discharge current of 0.5 kA. If 0.5 kA is not listed as a rated value, one must take the smallest given value.

Both metal oxide and spark gap arresters are equally suitable for protection against switching overvoltages. If spark gap arresters are used, select only types for which a switching impulse sparkover voltage is given in the selection tables.

¹⁶ Often referred to in insulation coordination terms as the BIL (Basic Impulse Level)

¹⁷ SIL (Switching Impulse Level)

E 4.2 3 arresters in line-earth connection

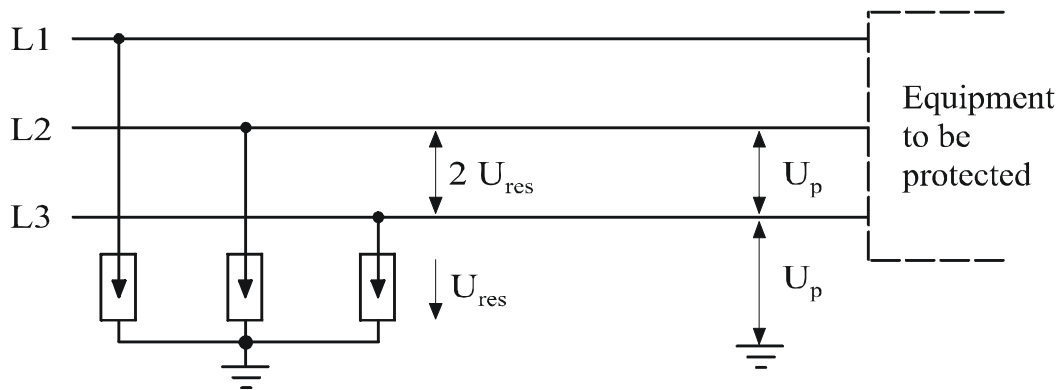


Figure E-2: Overvoltage protection by line-earth surge arresters

Required residual voltage, respectively switching surge sparkover voltage for protection line-line and line-earth:

$$U_{ai} \text{ or } U_{res} \leq \frac{1}{2} \cdot \frac{U_p \cdot 0.83}{1.15}$$

Required residual voltage, respectively switching surge sparkover voltage for protection line-earth:

$$U_{ai} \text{ or } U_{res} \leq \frac{U_p \cdot 0.83}{1.15}$$

u_{res} Residual voltage at 0.5 kA follow current (→ rated discharge current)

u_{ai} Switching impulse sparkover or residual voltage

U_p Rated lightning impulse withstand voltage of protected object (BIL)

0.83 Reduction factor, compared to the BIL, for switching impulse withstand voltage

1.15 Recommended safety factor to IEC [16]

$\frac{1}{2}$ Since the line-line overvoltage can rise to twice the line-earth voltage, the arresters must limit the overvoltage to half the permissible line-line value.

At system voltages above 15 kV in networks with isolated or resonant earthed neutral point, line-earth arresters with sufficiently small residual or sparkover voltage to ensure also the protection line-line are hardly available. In these cases one needs to install three additional arresters between the lines, i.e. a 6 arrester format.

E 4.3 6 arrester format

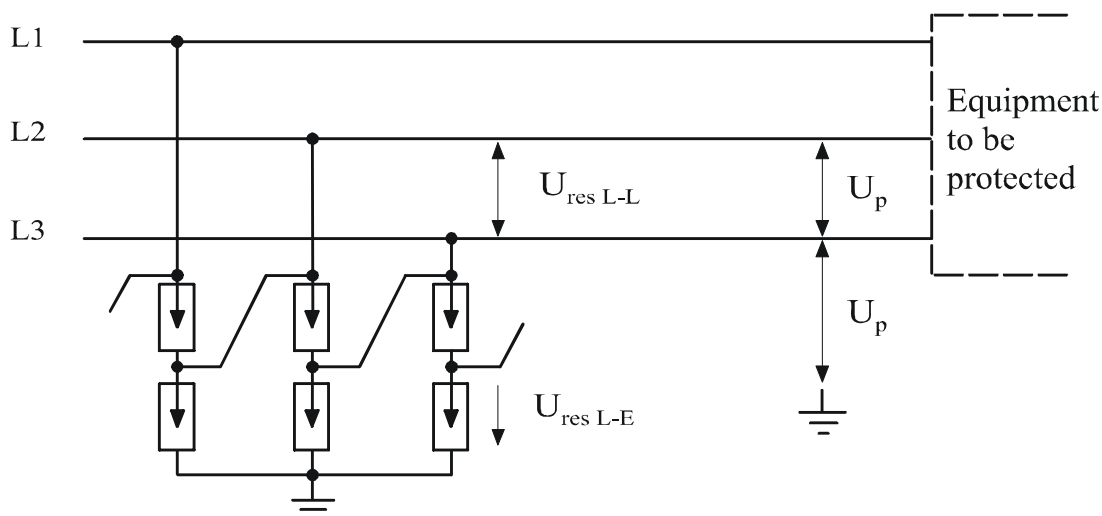


Figure E-3: Overvoltage protection by line-earth and line-line surge arresters

Required residual, respectively switching surge sparkover voltage: U_{ai} or $U_{res} \leq \frac{U_P \cdot 0.83}{1.15}$

- u_{res} Residual voltage at 0.5 kA follow current ($\rightarrow$ rated discharge current)
 u_{ai} Switching impulse sparkover (or residual) voltage
 U_p Rated lightning impulse withstand voltage of protected object (BIL)
 0.83 Reduction factor, compared to the BIL, for switching impulse withstand voltage
 1.15 Recommended safety factor to IEC [16]

E 4.4 Lightning overvoltages

These occur only between conductor and earth, single phase, in all conductors (common mode overvoltages). Therefore, to select the correct protection level one needs only to consider the stress to earth; **3 arresters in line-earth-connection** always provide sufficient protection against lightning surge.

Required residual, respectively switching surge sparkover voltage: $U_{res}; U_{ax} \leq \frac{U_P}{\gamma}$

- u_{ax} 100% sparkover lightning impulse voltage u_{as100} respectively front-of-wave impulse sparkover voltage u_{ast}
 U_p Lightning impulse withstand voltage (BIL)
 γ 1.25 ... 1.4 recommended safety factor for lightning protection

The recommended safety factor γ is higher than for switching overvoltages. It shall be at least 1.25 but it is recommended that one should aim for $\gamma = 1.4$.

E 5 Energy absorbtion capability

The energy absorbtion capability is no criterion for medium voltage surge arresters in pure distribution networks. The same applies to most of the industrial applications with the aforesaid inductive switching duties. The interruption of inductive currents can be associated with switching overvoltages which are, however, low-energy overvoltages. Unduly high overvoltages may occur only up to 600 A inductive breaking current. Table E-2 lists some benchmark values.

Operating values	6 kV	10 kV	15 kV	20 kV	30 kV
Residual voltage	18 kV	30 kV	42 kV	55 kV	79 kV
Absorbed energy	5.2 kJ	8.9 kJ	13.2 kJ	17.9 kJ	26.8 kJ

Table E-2: Average values of absorbed energy by surge arresters¹⁸

¹⁸ Siemens type 3EK7 operating in one phase when interrupting an inductive current of 600 A. Parameters: load cable 200 m, total feeding side cable length 3000 m (cable: XLPE, cross-sections 95 mm² to 500 mm²)

The energy absorbed by the arrester is much smaller than the rated absorption capability of most arrester types. If an arrester type features more than one rating for the energy absorption capability, always the lowest one may be selected. Exempted from this rule are arresters in connection with very large capacitors, large generators or motors as well as applications with extremely frequent discharges (for example arc furnaces). In these cases the energy absorption capability must be dimensioned individually.

E 6 Short-circuit withstand and housing

The short-circuit withstand capability¹⁹ designates the rated short-circuit current the arrester can withstand a defined time duration in case of an internal fault (internal flashover) without violent shattering of the housing. If more than one value is available for a certain type of arrester, the selected value should correspond with the rated short-time current at the place of installation respectively with the rating of the switchgear.

When selecting the housing the outer insulation capability must be considered. For indoor use as well as for site pollution severity classes a to c according to IEC/TR 60815-1 [17] the smallest housing available can be selected. Only higher degrees of pollution require larger housings with extended creepage distance.

E 7 Switchgear with overhead line connections

Such switchboards mostly have a (short) cable connection between station and overhead line. At the end of the OHL ①, an arrester is installed as lightning protection. Dependent upon the length of the cable, a second arrester, in the station, may be worthy of recommendation.

A lightning surge, limited to the residual voltage of the first arrester travels down the cable and, because of the alteration in wave resistance at the junction between cable and switchboard, will be reflected at point ②. The voltage at this cable end can approach double the value point ①. To protect the switchboard and, particularly the cable terminal, an arrester should always be installed at that point if travelling waves can build up in the cable. Above specific lengths that is always the case.

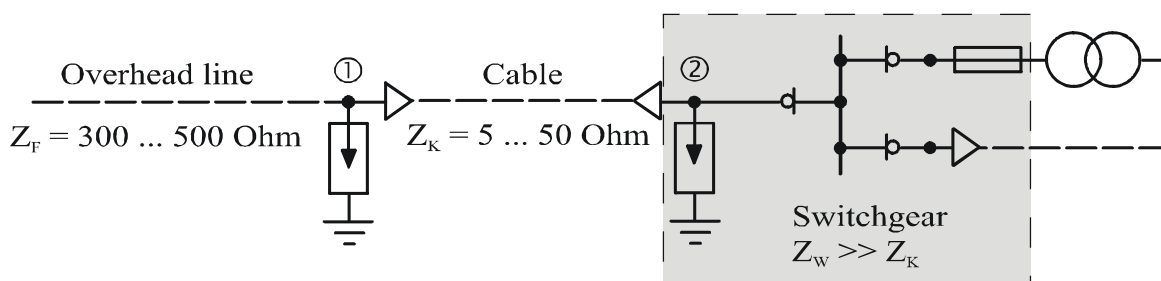


Figure E-4: Switchgear with connection to an overhead line, example of substation

¹⁹ The standards also use the terms „pressure relief class“ or “rated short-current“.

Lower limit of cable length

IEC 60071 [16] recommends to install additional arresters in the substation at ② for cable lengths exceeding the following length:

Highest voltage for protected object	Cable travelling wave resistance Z_K	Dielectric strength of protected object	Maximum permissible cable length <u>without</u> arrester
12 kV	10 Ω 15 Ω 20 Ω	75 kV	50 m 30 m 20 m
24 kV	15 Ω 20 Ω 30 Ω	125 kV	20 m 15 m 10 m

Reference value of overhead line: $Z_F \approx 400 \Omega$

Table E-3: Recommendation for surge protection depending on the cable length

For lower values of insulation rating, the recommended cable lengths are shorter.

Upper limit of cable length

If the length of plastic insulated cables exceeds approximately 500 m or with oil-paper insulated cables exceeds approximately 300 m the arrester at ② in the substation is not necessary since the travelling wave is effectively damped and furthermore the earth capacitance of the cable reduces the surge amplitude additionally.

The surge impedance of a cable is: $Z_K = \frac{\sqrt{\epsilon_r}}{C' \cdot 300} \frac{m}{\mu s}$

ϵ_r relative dielectric factor for the cable insulation

C' operational capacity of the cable per unit length (from data sheets)

Typical values ϵ_r :

3.4 ... 4	oil paper
2.4	PE, XLPE
5 ... 8	PVC
3	EPR

Arrester ① is an outdoor arrester, which must be suitable for lightning protection duty; for arrester ②, an indoor arrester with smaller energy absorption capacity. If the energy absorption capacity of arrester ② is smaller, it must be ensured that the sparkover or residual voltages are properly graded, so that the outdoor arrester always operates first.

F SWITCHGEAR CONFIGURATION

F 1 Principles of configuration

F 1.1 General

This section covers the basic technical aspects involved in selecting and rating the switchgear assembly and its main components, focussed on the primary (HV) part (the application guide does not replace the ordering data catalogue).

The process of designing secondary systems with devices for protection, control, measurement, and counting purposes is not covered here.

It is assumed that the network parameters and the switching duties the switchgear assembly has to comply with are already known for configuring the installation.

F 1.2 Requirements and complementary characteristics

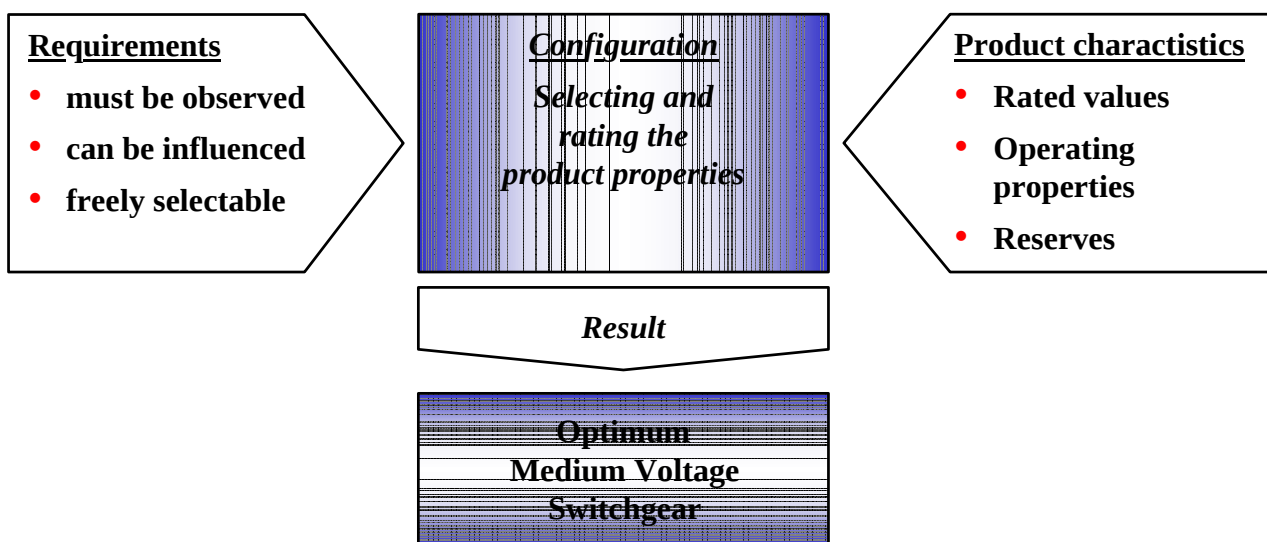


Figure F-1: Requirements and corresponding product features

On the basis of the requirements specified– which may be of different nature and vary in a wide range – the right products with the right rated values must be selected and configured. There is not always a clear choice or a definite configuration rule, so that for some requirements only recommendations can be given.

- Requirements that must be observed are those that relate to the electrical aspects of the switchgear, whereby the switchgear must offset the corresponding strength properties against the physical stresses. For these requirements clearly-defined configuration rules are almost always available. Legal regulations as well as personnel protection, fire protection, and environmental compatibility requirements must also be strictly observed.

Some requirements can be influenced, that is, measures taken on the electrical or spatial environment may affect the requirements regarding the switchgear which, in turn, optimises the selection and rating of the whole installation. For example, measures can be taken to reduce the duration of the short-circuit current; overvoltage protection can help avoid excessive insulation levels, while the building housing the switchgear may be modified to improve environmental conditions and reduce climatic stress.

There are recommendations provided for these "soft" requirements, rather than definite selection and rating rules.

Freely-definable – "negotiable" – requirements offer the greatest scope with regard to designing the switchgear. Operators can select specific product characteristics at their discretion to optimize the switchgear in line with their own requirements. Decisions may be based on, for example, tried-and-tested operating processes or internal company guidelines.

This document only covers those aspects of freely-selectable requirements that are relevant for configuration activities.

F 1.3 Procedure

Section G of this guide not only covers the influences and stress variables but also the associated characteristics and properties of the switchgear.

Section H breaks down the process of selecting and rating a switchgear system into individual steps and describes which influences and stress variables must be taken into account in each individual step. As far as available, rules and recommendations are provided for selection and configuring; otherwise the aspects that must be taken into account are defined.

A wide range of non-technical aspects must be taken into account when switchgear is configured:

- Requirements of state legislation always take priority over normative regulations (e.g. protecting the public, work safety, environmental protection).
- Tried-and-tested operations and procedures carried out by the operators can determine which equipment is required. After all, taking into account "standard practices" of operators also contributes to a safe working environment.
- Requirements and features that focus on operations and procedures can vary considerably from region to region.
- If applicable, company guidelines may also have to be taken into account.
- Recommendations of industrial associations.

These are just some of the requirements that manufacturers, planners, and operators must agree upon. A configuration guide cannot cover all aspects of these requirements. It can only highlight those points that are applicable to all switchgear systems at all times.

F 2 Switchgear requirements

The key influences and stress variables for switchgear depend on the task in hand and its position in the distribution network.

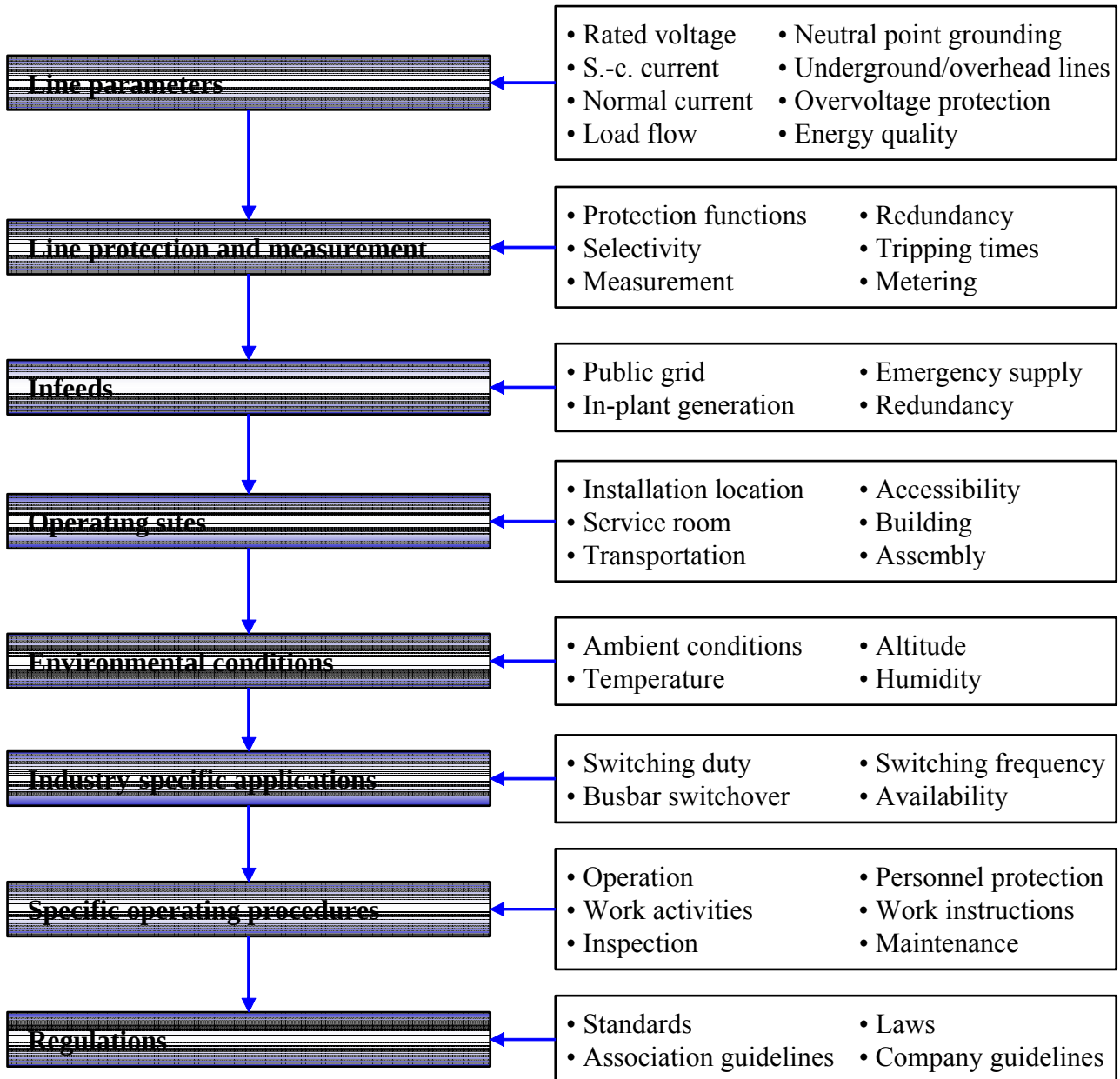


Figure F-2: Influences on the configuration of switchgear assemblies

These influencing factors and stresses, which are explained in detail in Section G, determine the selection and rating variables for the switchgear.

F 3 Properties to be selected

This diagram provides an overview of the main switchgear features to be configured in the sequence normally carried out when switchgear is selected and rated.

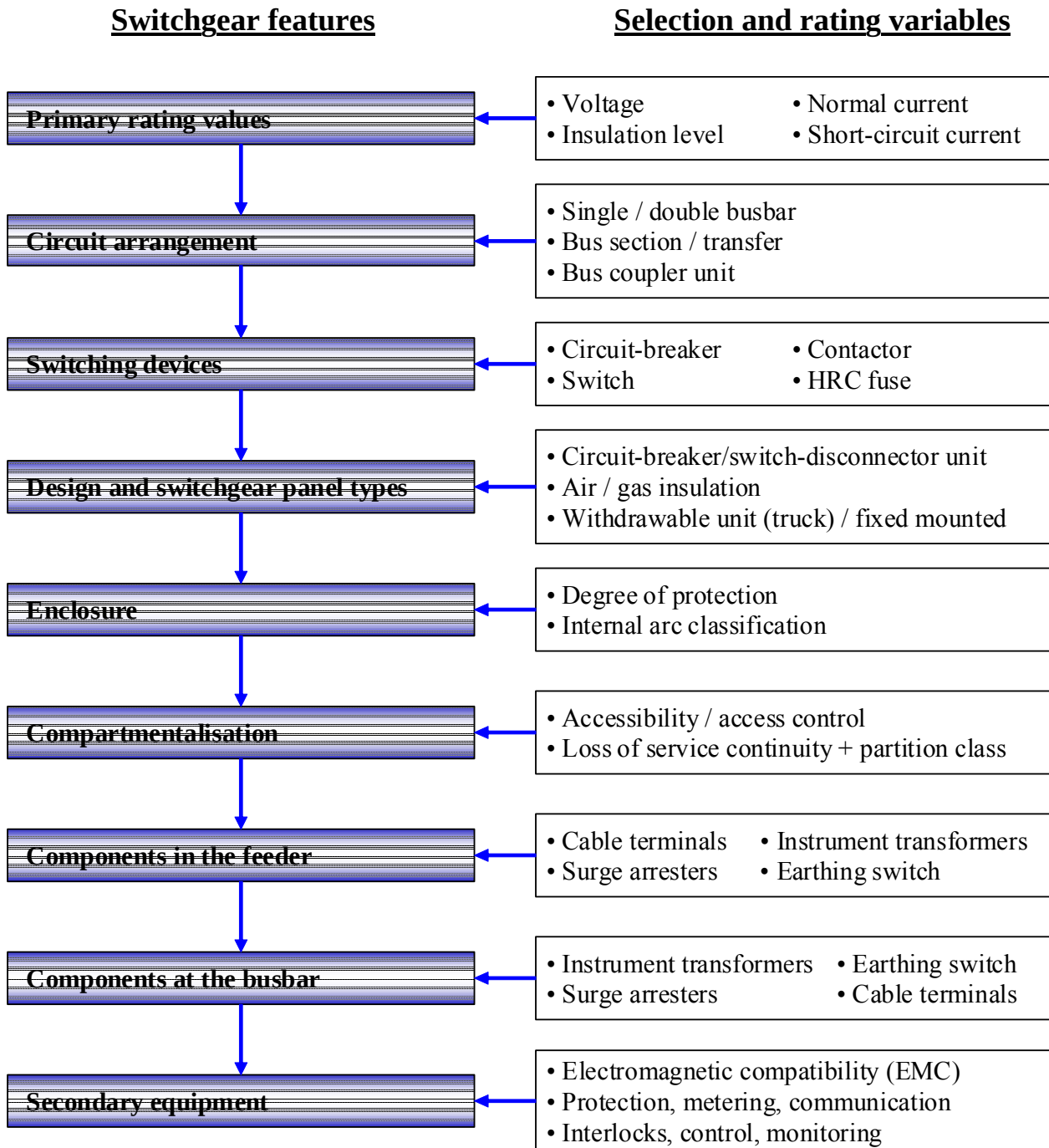


Figure F-3: Selection criteria and ratings of a switchgear assembly

Section H contains a detailed explanation of the configuration rules that need to be applied and other aspects that need to be taken into account.

G INFLUENCES AND STRESS VARIABLES

G 1 Network characteristic values

G 1.1 Line voltage

This determines the rated voltage of the switchgear, switching devices, and other installed components. The determining factor here is the maximum line voltage at the upper tolerance limit.

Assigned configuration criteria for switchgear:

- Rated voltage U_r
- Rated insulation level U_d ; U_p
- Rated primary voltage of voltage transformers U_{pr} and surge arrester – where applicable

G 1.2 Short-circuit current

This is characterized by the variables peak current I_p (peak value of the initial symmetrical short-circuit current) and sustained short-circuit current I_k . The required short-circuit current level in the network is specified by the dynamic behaviour of the loads and the quality of the energy, which must be maintained, and determines the making, breaking, and withstand capacity of the switchgear.

Note that the ratio of the peak current to the sustained short-circuit current in the network can be significantly greater than the standard factor $I_p/I_k = 2.5$ at 50 Hz (or 2.6 at 60 Hz) according to which the circuit-breakers and switchgear are designed. This could be due, for example, to motors that supply energy back to the network if a short-circuit occurs, which significantly increases the peak current.

⇒ For the short-circuit duration, see G 2.3 Tripping times

Assigned configuration criteria for switchgear:

- | | |
|------------------------------|--|
| • Main and earthing circuit: | <ul style="list-style-type: none"> - Rated peak current I_p - Rated short-time current I_k |
| • Switchgear: | <ul style="list-style-type: none"> - Rated short-circuit making current I_{ma} - Rated short-circuit breaking current I_{sc} |
| • Current transformer: | <ul style="list-style-type: none"> - Rated dynamic current I_{dyn} - Rated short-time thermal current I_{th} |

G 1.3 Normal current and load flow

The normal current refers to the current paths of the infeeds, busbar(s), and load feeders. The current is also subdivided due to the physical arrangement of the switchgear panels with the effect that different rated current values can be found in sequence along the conducting path (the currents in busbars and feeders are normally different).

Reserves must be planned for the value of the rated normal current:

- In accordance with the ambient temperature;
- For the planned overload;
- For temporary overloads in the event of faults.

With high normal currents, large cable cross-sections or several parallel cables must be connected in the switchgear panel; the field terminal must be designed to accommodate this.

Assigned configuration criteria for switchgear:
• Rated current of busbar(s) and feeders • Number of cables for each conductor in the switchgear panel (parallel cables) • Rating of the current transformers

G 1.4 Neutral point earthing

The type of neutral point earthing used, insulated / resonant earthed with an arc suppression coil²⁰ / (temporarily) resistively earthed / solidly (directly) earthed – governs the behaviour of the line voltage when switching operations are carried out or if a earth fault occurs in the network as well as the characteristics of the earth fault currents. This means that neutral point earthing has a major influence on the dielectric stress on the equipment and is important for insulation coordination.

Assigned configuration criteria for switchgear:
• Insulation level of the equipment assigned to the rated voltage U_r • Choice of switchgear • Rating and damping of voltage transformers • Design of current transformers and protection relays for earth fault detection • Rating of surge arresters

²⁰ Petersen coil

G 1.5 Underground / overhead lines

The network type governs insulation coordination and which overvoltage protection measures need to be taken. In overhead systems, powerful overvoltages can be caused by a lightning strike, while only weak switching overvoltages generally occur in underground networks. Overvoltages from overhead systems can reach switchgear indirectly or via a transformer. These connecting points must be taken into account and checked to determine whether surge arresters are needed.

The network type also affects the choice of switchgear: in overhead systems, for example, transient faults are more likely to occur. Circuit-breakers must be able to manage reclosing cycles and a high number of make-break operations. The short-circuit currents in medium-voltage overhead systems, however, are low (generally between 8 kA and 12 kA).

Assigned configuration criteria for switchgear:
• Selection and rating of circuit-breakers • Insulation level • Use and rating of surge arresters

G 1.6 Overvoltage protection

If the expected voltage stresses exceed the insulation level of the equipment, insulation coordination requires overvoltage protection. This can apply, for example:

- When external overvoltages can be expected as a result of lightning strikes;
- When (multiple) earth faults occur frequently;
- High transient overvoltages may occur as a result of switching operations;
- When, in the interests of economy, certain equipment (e.g. motors, resin-encapsulated / dry-type transformers) is rated for lower insulation levels than the other network components.

Overvoltage protection is also used as a general precaution to minimize the risk of failure and to protect equipment against any form of overvoltage. It is generally used for very large motors or transformers that are not only expensive and difficult to procure but also incur high costs if they fail.

Frequent overvoltages can also cause some insulation systems to age, even if the stresses are still within permissible limits. Overvoltage protection measures are also recommended in “unstable” networks (=> see G 1.7 Power quality).

Overvoltage protection systems normally comprise surge arresters. In certain cases, surge capacitors or resistance-damped surge capacitors (RC elements) are also required.

Switchgear must be checked to determine whether overvoltage protection is required, whether protection measures have already been taken, or whether existing protection devices need to be upgraded.

Assigned configuration criteria for switchgear:

- Insulation level
- Check for "critical" switching duties
- Application and rating of the surge arresters, space for installation and possibility for the connection of external arresters

G 1.7 Power quality (unstable loads)

The power quality refers to unwanted interference, such as voltage dips, flickers, asymmetry, harmonics etc.. These can be caused for example by rectifiers, converters, welding machines, direct-starting motors. Other loads (e.g. IT systems), however, are sensitive. To protect them, the interference is compensated as much as possible or the "stable" and "unstable" loads are distributed across sub-networks with separate infeeds. Depending on the circuit arrangement, switchgear with single or double busbars is required.

Assigned configuration criteria for switchgear:

- Single/double busbar
 - Bus section panel
 - Bus coupler unit
- Rated normal current (busbar)
- Rated short-circuit currents

G 2 Line Protection, measurement and metering**G 2.1 Short-circuit protection**

The line protection concept has a major influence on the switchgear that is selected and its design. The following devices can be used for short-circuit protection:

- HRC fuse (in a switch- or contactor-fuse combination)
- Instrument transformer + protection relay + circuit-breaker

If the majority of network branches are equipped with switch-fuse combinations, switch-disconnector units can be used; otherwise, circuit-breakers are used.

Assigned configuration criteria for switchgear:

- Design: circuit-breaker or switch-disconnector unit

G 2.2 Protection functions

Protection relays obtain their measurement signals from current and voltage transformers, which are installed in the switchgear. The range of available protection functions (e.g. inverse/definite-time overcurrent, distance/differential protection) requires current transformers whose cores can be combined in a variety of ways with different rated currents, overcurrent number, output, and class accuracy. Voltage transformers are also provided for protection with directional control or for determining the fault location (distance protection). Sensitive earth fault protection devices require a core-balance transformer around the three conductors to measure small earth fault currents in compensated networks or networks with an insulated neutral point.

The switchgear must provide a space in which these instrument transformers can be installed as well as space for the protection relays and their wiring. This may seem obvious, but it is important to remember that other components (surge arresters, multiple cable terminals etc.) also need space in the switchgear.

Assigned configuration criteria for switchgear:

- Installation of instrument transformers in the switchgear panel and on the busbar
- Installation of a core-balance transformer
(normally cable-type current transformer, or "earth fault winding")
- Installation of protection relays and wiring in the low-voltage compartment

G 2.3 Tripping times

The set tripping times (specified by means of selectivity requirements in accordance with the number of subordinate network levels and their equipment) are governed by the rated short-circuit duration of the switchgear, the current transformer, and the earthing circuit. The standards permit various rated values for the components. For short-circuit durations of > 1 s in particular, it is important to ensure that all components are dimensioned to manage the actual short-circuit duration at the minimum.

For the actual short-circuit duration, the mechanical delay (opening time) of the switching device must also be added to the tripping time of the protection system.

Assigned configuration criteria for switchgear:

- Rated duration of short-circuit
 - Main circuit (switchgear, disconnecter, and earthing switch)
 - Earthing circuit
 - Current transformer
 - Number and type of releases in the circuit-breaker

G 2.4 Measurement and metering

Measurement and metering systems generally require separate, additional transformer cores with a different rating to that of the protection cores.

Assigned configuration criteria for switchgear:

- Room for installing transformers as well as measurement devices and meters (see G 2.2).

G 2.5 Redundancy

Different protection functions can be combined in a single network branch (e.g. differential and overcurrent-time protection as backup). Depending on the degree of redundancy required, additional instrument transformers and protection devices may also have to be installed in the switchgear. Enough space must be available for these too (see above).

For contractual reasons, the same measurement device or meter may also be installed twice if contractual partners use their own devices at the point of supply ("check measurement"). This increases the number of built-in components.

Assigned configuration criteria for switchgear:

- Room for installing transformers as well as measurement devices and meters (see G 2.2).

G 3 Infeed types

The operating principle and number of infeeds are crucial for connecting the switchgear and for its rated current values. The supply from different networks, such as ...

- the public network
- in-plant generation
- the emergency power supply

... sometimes has to be disconnected during normal operation for safety, business, or contractual reasons. A decision must, therefore, be made regarding how the supply can be divided into busbar sections and which ones can be linked. The switchgear design as well as the rated normal and short-circuit current values depend on the infeed operating principle and the couplings.

Assigned configuration criteria for switchgear:

- System connection
 - Single/double busbar
 - Bus section panel
- Rated values of the switchgear
 - Normal current of the busbar(s)
 - Peak current and short-time current
- Control, interlocks, and switchgear interlocking
- Installation of instrument transformers in the switchgear panel and on the busbar
- Room for installing the protection relays and wiring in the low-voltage compartment

G 4 Operating sites

The type of operating site can also govern the choice and rating of switchgear. Given the broad range of different influencing factors, only the key points that need to be taken into account can be described here.

G 4.1 Installation location

Many locations are subject to legal regulations concerning safety and health, fire protection, and environmental compatibility. This mainly applies to systems in public areas (e.g. pedestrian zones), industrial premises (offices, workshops), public buildings (high-rises, hospitals, office buildings, bars, conference centers etc.). Special regulations also apply for nature reserves, mines, railways, and boats.

Even if the switchgear malfunctions, it must behave in such a way as to minimize negative impact. Malfunctions include situations in which the switchgear is subject to external damage (e.g. fire) or is itself the cause of the problem (e.g. internal faults).

Assigned configuration criteria for switchgear:
• Design • Internal arc fault classification • Pressure absorber, pressure release duct

G 4.2 Accessibility

The standards also take into account the different levels of accessibility of operating sites:

- Only authorized and trained personnel have access to closed electrical operating area; all other people must be accompanied.
- Operating sites in public areas can be accessed by everyone (e.g. standard for stations and switchgear in workshops).

Switchgear in public areas are subject to more stringent requirements.

Assigned configuration criteria for switchgear:
• Air or gas insulation • IP degree of protection • IK degree of protection (mechanical shock) • Internal arc fault classification

G 4.3 Switchgear room

Certain standards, e.g. IEC 61936 [22], and laws define specifications regarding how the system is set up in service rooms (e.g. the minimum width of operating and assembly aisles) and define the binding requirements for escape routes (e.g. width and maximum length of escape routes, preferred direction in which doors close etc.).

The service room might also contain other equipment for which operators can define their own specifications regarding free areas and setup.

The switchgear must enable all requirements to be fulfilled.

Assigned configuration criteria for switchgear:
• Dimensions of the switchgear panels, in particular the panel width • Position of door stops; opening angle of the switchgear panel doors • Position of controls and displays/indicators (front/rear) • Cable connection from the front or rear • Required accessories (switching levers, tools, etc.) • Labelling, information plates, warning signs

G 4.4 Buildings

The building itself can also influence the choice of switchgear. The following aspects must be taken into account:

- The available space
- The quality of the building fabric (in existing, older buildings)
- Vent outlets in the event of an internal arc fault

Assigned configuration criteria for switchgear:
• Switchgear panel width, depth, and height • Air or gas insulation • Internal arc fault classification • Pressure absorber, pressure release duct

Irrespective of the chosen switchgear, a dynamic pressure calculation must be carried out for the building to determine the stresses on the structure and the required cross-sections for vent outlets.

The building is also a crucial factor regarding the conditions under which the switchgear operates;
⇒ see G 5 Environmental conditions.

G 4.5 Transportation and assembly

In certain – albeit rare – cases, transportation and assembly conditions are a key selection criterion for the switchgear. Whether or not switchgear can be installed in a building depends on certain constructional factors, such as:

- The size and position of doorways
- Permissible floor loading
- Floor level
- Goods elevator

Assigned configuration criteria for switchgear:
--

- | |
|--|
| <ul style="list-style-type: none"> • Size of the transportation units • Weight of the transportation units • Packaging (stability, weather protection if the device is in temporary storage over a long period) |
|--|

G 5 Environmental conditions

G 5.1 Ambient room conditions

Switchgear installed in service rooms can be subject to the following ambient conditions:

- Heat and humidity
- Pollution
- Dust and smoke
- Salt (near the coast or in mining)
- Corrosive gases and vapours (natural and artificial)
- Insects / small animals

Due to the infinite variety of ambient conditions at installation locations, the applicable standards only define basic requirements for "normal service conditions". Each system must be examined individually to determine whether or not these are observed.

Numerous measures can be taken to provide protection against exceptional climatic conditions. For example, gas-insulated, hermetically sealed compartments that are completely immune to external conditions can be used. The degree of protection of the housing can also be increased. In parts of the world where high insect/small animal populations can cause problems, protection against bridging may be appropriate by fitting additional insulation to live and exposed components.

Assigned configuration criteria for switchgear:

- Design: air or gas-insulated switchgear
- IP degree of protection for housing (can be increased with drip-water protection if necessary)
- Type of ventilation
- Additional insulation for live and exposed components

Measures to provide protection against extreme ambient conditions can also be taken in the service room (air conditioning). In some cases, this can be more efficient than designing each individual component accordingly. It is also important to remember that protection, measurement, and control systems are more sensitive than switchgear, which is reason enough to ensure that the minimum requirements for air quality are observed.

G 5.2 Altitudes above 1000 m

The standardized insulation levels apply to normal ambient conditions at sea level. As the altitude increases, however, the air density decreases as do the insulating properties. The applicable standards take this into account and allow for a reduction of approx. 9% at altitudes of up to 1000 m. At higher altitudes, the required insulation level must be ensured by increasing the rated voltage (with respect to sea level values). Insulation coordination can also be ensured by means of additional surge arresters. Alternatively, gas-insulated switchgear in which the primary section is hermetically sealed can be used. In this case, the external air pressure is not an issue.

Assigned configuration criteria for switchgear:

- Design: air or gas-insulated switchgear
- Selection of a higher rated voltage with a higher insulation level
- Use of surge arresters

G 5.3 Ambient temperature and humidity

The ambient temperature directly affects the temperature of the switchgear which, in turn, affects its current-carrying capacity. As the ambient temperature increases, the current-carrying capacity decreases (and vice versa). To compensate for this, either the rated current value must be increased or sufficient ventilation must be ensured (ventilation openings affect the IP degree of protection).

Humidity has a negative effect on the insulating properties. High levels of humidity together with sudden temperature changes can cause condensation which, in turn, drastically reduces insulation levels. To prevent this, controlled or permanent heaters can be used in conjunction with humidistats.

Assigned configuration criteria for switchgear:

- Rated normal current
- Type of ventilation
- Differentiation of IP degree of protection according to protection against ingress of solid foreign bodies and shock-hazard protection
- Installation of a heater in the switchgear panel or in the low-voltage compartment

G 6 Industry-specific application

The following aspects cover the role and significance of the switchgear in the operator's network (industrial or public utility companies).

G 6.1 Switching duty and capacity

The choice and rating of the switchgear depends on the switching duty and the loads to be switched. Is the switchgear only required to switch normal currents? Or does it need to interrupt short-circuits too? Due to the transient switching operations, certain loads require overvoltage protection. In other cases, additional rating criteria apply to the switch and switchgear.

Assigned configuration criteria for switchgear:

- Switchgear: circuit-breaker, switch or contactor with HRC fuses
- Rated electrical values
- Additional measures (e.g. overvoltage protection)
- Classes for mechanical and electrical endurance
- Design: circuit-breaker or switch-disconnector unit

G 6.2 Switching frequency of the loads

Alongside the electrical requirements regarding the switching capacity, the switching frequency is an important selection criterion. The switching frequency depends on the process in which the switching device is used. Switches are rated for a short electrical lifetime (number of make-break operations), while contactors are rated for extremely long lifetimes; circuit-breakers fall in between. Once a basic decision has been reached regarding the type of switchgear, standardized lifetime increments can be selected for the switches (endurance classes).

For higher switching frequencies under normal operating conditions, switchgear must be serviced or replaced more often. In this case, the components must be easily accessible.

Assigned configuration criteria for switchgear:

- Switching devices: circuit-breaker, switch or contactor
- Classes for mechanical and electrical endurance
- Design of the switchgear assembly
 - Air or gas-insulated system
 - Withdrawable or fixed disconnector
- Loss of service continuity category

G 6.3 Frequency of switchover between busbars

In switchgear with double busbars, the lifetime of the disconnector plays a crucial role. For operational reasons, some networks require frequent switchovers between busbars. Due to the short mechanical lifetime of a disconnector / withdrawable unit as compared with a circuit-breaker, "standard" double busbar switchgear systems with just one circuit-breaker are unsuitable for this type of operation. Standard double busbar systems have a common connection (cross connection between the two busbars) between the two disconnectors and the circuit-breaker.

To prevent wear and tear to the disconnector / withdrawable unit and, in turn, minimize maintenance cycles, the busbars are switched by means of circuit-breakers. This requires two single busbar systems each with two circuit-breakers in one feeder circuit.

Assigned configuration criteria for switchgear:

- Design of the switchgear
- Double busbar with common connection or two single busbars
- Interlocks and switchgear interlocking

G 6.4 Availability (faults, redundancy, switchover time)

The term "availability" in this context means providing ways of compensating for line failures, for example, by means of redundant supply channels or defined switchover times. It also refers to the reliability of switchgear and features for planned maintenance activities or troubleshooting.

The switchgear provides the current paths for multiple supply channels and the switchover options. This can be used to determine the system circuit: single or double busbars and separated into different sections. The various options for linking busbars (busbar sections) with separate infeeds and the operating principle (NO / NC) of the couplings govern the rated current values.

The switchgear itself must also be sufficiently reliable, maintenance friendly (and not require excessive maintenance), and accessible. A decision regarding the Design of the switchgear assembly and the partitions can be made on the basis of these criteria.

Assigned configuration criteria for switchgear:

- Circuit arrangement
 - Single/double busbar
 - Bus section panel
- Interlocks and switchgear interlocking
- Rated values of the switchgear
 - Normal current of the busbar(s)
 - Peak current and short-time current
- Design: air or gas-insulated switchgear
- Loss of service continuity category
 - Design of partitions

G 6.5 Modifications or extensions

Switchgear is sometimes set up in sub-sections or needs to be extended or modified during the course of its operating life. If such measures are anticipated, these should be taken into account in the planning stage.

Assigned configuration criteria for switchgear:

- Design
- Extension to include additional switchgear panels
- Rated values for normal and short-circuit current
- Replacement of instrument transformers
- Option of upgrading the secondary system

G 7 Operating procedures

Operating procedure is a catch-all term that, with respect to configuration activities, will only be used to describe the following activities:

- Operation
- Work activities
- Maintenance

G 7.1 Operation

Operational activities include monitoring, switching, making settings, and reading displays / indicators. Operators can define how these activities are to be carried out, that is, whether they are to be carried out on site or remotely, (completely or partially) manually or automatically.

The automated integration of the switchgear in the network system management and production process makes important demands on the measurement, control, and remote control systems (secondary technology).

During operation, the switchgear must provide the required level of personnel protection (e.g. protection against accidental contact with hazardous live or mechanical components (IP degree of protection). Even in the (unlikely) event of an internal fault, the switchgear must offer means to protect the operator.

Assigned configuration criteria for switchgear:
--

- | |
|--|
| <ul style="list-style-type: none"> • Design of the switchgear <ul style="list-style-type: none"> - Air or gas-insulated system - Withdrawable or fixed disconnector • Type of compartments (access control) • Loss of service continuity category • Control and secondary equipment • Interlocks and switchgear interlocking • Manual or automatic drive mechanisms • IP degree of protection • Internal arc fault classification |
|--|

G 7.2 Work activities

Activities in this context refers, for example, to modification, servicing, and maintenance activities or replacing fuses. When such activities are carried out, the system must be either fully or partially taken out of service. How much of the system is taken out of service depends on the 'loss of service continuity category', which must be defined by the operator along with the type of access control to the disconnected compartments. Shock-hazard protection for live components can, to varying degrees, be installed permanently in the system or implemented manually. Again, the operator must decide which method to use. How the work procedures are organized and the level of training of the personnel play an important role here.

Assigned configuration criteria for switchgear:
--

- | |
|---|
| <ul style="list-style-type: none"> • Loss of service continuity category • Type of compartments (access control) • Partition class |
|---|

G 7.3 Inspection and maintenance

System inspection and maintenance requirements can vary enormously and are subject to numerous influencing factors completely unrelated to electrical engineering, such as:

- Environmental conditions
- Industry-specific operating procedure
- Legal regulations
- Internal organization and work instructions
- Level of personnel training

Inspection and maintenance must be treated as separate activities. It may be the case that certain procedures require more frequent inspections, for example, which means that the switchgear must be more readily accessible. In this case, therefore, a completely hermetically-sealed system may not be the best solution because it cannot be accessed. Components may need to be readily accessible if, for instance, they need to be replaced more often due to a high switching frequency. The degree of required accessibility also depends on various regulations and the level of personnel training. These aspects also govern the switchgear design.

Assigned configuration criteria for switchgear:
--

- | |
|---|
| <ul style="list-style-type: none"> • Design of the switchgear <ul style="list-style-type: none"> - Air or gas-insulated system - Withdrawable or fixed disconnector • Loss of service continuity category • Type of compartments (access control) • Selection of switching devices and its endurance classes |
|---|

G 8 Regulations

Switchgear is subject to numerous regulations relating to its design, manufacture, inspection, setup, and operation:

- Electrical engineering standards
- Recommendations of industry or utility associations
- Legal regulations
- Internal company regulations

While the electrical engineering standards are fulfilled by nearly all products, legal or internal regulations in different industries can pose special challenges.

Assigned configuration criteria for switchgear:
--

- | |
|---|
| <ul style="list-style-type: none"> • Determine any deviations from the requirements defined in the IEC / EN standards. |
|---|

H SELECTING AND RATING SWITCHGEAR

H 1 Overview (Checklist)

This table lists all the rating and selection variables along with the requirements and influencing variables, which are explained in detail in the following sections.

Selection variable		Key influencing factors
Primary rated values	• U_r Rated voltage • Rated insulation level • U_d short-duration power-frequency withstand voltage • U_p lightning impulse withstand voltage	• System voltage <i>Insulation coordination</i> • Neutral point earthing • Underground/overhead lines • "Critical" loads • Overvoltage protection • Altitude • Ambient conditions (pollution)
	• Rated withstand capability • I_p peak current • I_K short-time current • t_K duration of short-circuit • Rated switching capability • I_{ma} short-circuit making current • I_{sc} short-circuit breaking current	• Characteristic line values • Loads and power quality • Line protection, response times • Tripping time • Selectivity
	• I_r Rated current - busbars - feeder circuits	• Load (feeder circuit), power to be distributed • Ambient temperature • Reserves / availability
Busbar arrangement	• Single/double busbar • Bus sectionaliser panel (with switch or circuit-breaker) • Switchover with switch or circuit-breaker • Bus coupler unit (with double busbar)	• Line structure • Line protection, tripping times, selectivity • Reserves / availability, switchover time • Operating procedures • In-plant generation, emergency supply • Power quality (unstable loads)
	• Double busbar with common connection • Two single busbar systems	• Operating procedures • Frequency of busbar switchover • Interlocks and switchgear interlocking • Setup (physical)

Selection variable		Key influencing factors
Switching device	• Circuit-breaker • Switch • Contactor • HRC fuse	• Operating current and switching duty • Switching capacity (fault currents) • Switching frequency • Line protection, selectivity requirements
Design and switchgear panel types	• Circuit-breaker unit • Switch-disconnector unit • Design - extendable panels - block type	• Primary (HV) ratings • Switching devices • Operating current, switching capacity • Line protection • No. of switch / circuit-breaker panels • Operating procedures and operation • Expandability, electrical / mechanical reserves • Installation conditions • Transportation and assembly
Insulating medium	• Air (AIS) • Gas (GIS)	• Ambient room conditions: temperature change, humidity, pollution, salt, corrosive gases • Type of operating site • Installation location (space requirements) • Fire protection requirements (fire load) • Altitude • Switching frequency and switch lifetime
Disconnecter	• Withdrawable unit / truck • Disconnector (built in)	• Switching frequency • Component lifetime • Operational requirements (e.g. access to cable terminal, for maintenance and cable testing)
Enclosure	• Degree of protection (IP) • Internal arc classification (IAC) - A or B type of accessibility - F / L / R classified sides - I_A, t_A arc fault current and duration • Pressure release duct	• Ambient conditions • Personnel protection • Type of operating site • Building

Selection variable		Key influencing factors
Compartments	- Loss of service continuity category (internal structure of panel) - LSC 1 - LSC 2 - LSC 2A - LSC 2B	- Operating procedures - operation, work activities - maintenance requirements - Servicing / maintenance (component lifetime) - Operator's regulations - Personnel training - Shock-hazard protection during work activities - Switchgear space requirements
	- Access control by means of: - interlocking - work instruction + locking - tools - None-accessible compartment	
	- Partition class - PM (metal) - PI (insulating material)	
Feeder circuit components	- Cable connection - Sealing end: plug / standard - Number of cables - Cable cross-sections	- Operating and short-circuit current - Switching duty - Underground / overhead cables - Altitude
	Surge arrester	
	- Voltage transformer - earth fault winding (if required) - Current transformer - core number and data - Core-balance transformer (cable-type current transformer)	- Line protection - Measurement, metering - Control - Neutral point earthing
	- Earthing switch - Class E0, E1 or E2	
Busbar components	- Instrument transformer - Earthing switch - Class E0, E1 or E2 - Surge arrester	- Line protection and measurement - Operating procedures - Space requirements
Secondary equipment	- Protection relay - Equipment for control, interlocks and switchgear interlocking - Devices for measurement, metering, measuring transducer - Monitoring, communication devices - Motorized drive mechanisms - Voltage detecting system - Damping resistors for VT	- Line parameters - Type of line and load protection - Line system management - Integration in (industrial) processes - Operational procedures

Table H-1: Summary of selection criteria for switchgear assemblies

H 2 Primary rated values

Selection variable	Key influencing variables
- Rated voltage U_r - Rated insulation level - Lightning impulse withstand voltage U_p - Short-duration power-frequency withstand voltage U_d - Rated peak current I_p short-time current I_k short-circuit duration t_k - Rated short-circuit making current I_{ma} short-circuit breaking current I_{sc} - Rated normal current I_r - busbar - feeder circuits	- System voltage (operating voltage) - Insulation coordination - Neutral point earthing - Underground / overhead cables - Switching duties - Overvoltage protection - Altitude - Ambient conditions (pollution) - Characteristic line values - Loads and power quality - Protection, tripping times, selectivity - Load (feeder circuit), power to be distributed (busbar) - Ambient temperature - Reserves / availability

Table H-2: Key factors for the rated voltage

H 2.1 Rated voltage U_r

The maximum operating voltage of the network (U_{Nmax}) – at the upper tolerance limit – and the required insulation level of the equipment determine the rated voltage.

Rating rule: $U_r \geq U_{Nmax}$ and U_r corresponds with the required insulations level (see H 2.2)

For switchgear, the next highest standard value above the maximum operating voltage is set as the rated voltage. The value of the maximum operating voltage must cover effects of temporary over-voltages, for example caused by

- harmonics
- load shedding (generators for emergency supply, customer generation etc.)
- capacitive equipment, such as capacitor banks, filters

If a particular insulation level is pre-determined, the rated voltage must correspond with it.

Comments:

- a) The rated voltage of the switchgear may differ from that of
- Voltage transformers
 - Surge arresters

- HRC fuses

This is because these devices are subject to additional rating criteria (see sections D and E 2).

- Some switching duties require the switching devices to have an even higher rated voltage, although this is rare (see table in B 1). In certain cases, the entire switchgear system must be designed for higher voltages.
- Due to the reduced insulating properties at altitudes of above 1000 m above sea level, a higher rated value may be selected – where applicable (see H 2.2).
- A higher rated voltage can be set to fulfil the requirements of a higher insulation level in order to cope with special ambient conditions, for example pollution or humidity. (see H 2.2).

H 2.2 Rated insulation level

The insulation level comprises the lightning impulse withstand voltage (U_p) and the short-duration power-frequency withstand voltage (U_d).

Rating rule: $U_r \leftrightarrow U_d$ and U_p (see table in IEC 62271-1)

- The rated insulation level is assigned to the rated voltage in accordance with table 1a, IEC 62271-1 [1] the applicable standard and is, therefore, set at the same time as the rated voltage. Different allocations must be specified separately.
- In medium-voltage systems, the standard insulation levels do not differ with respect to the neutral point earthing.

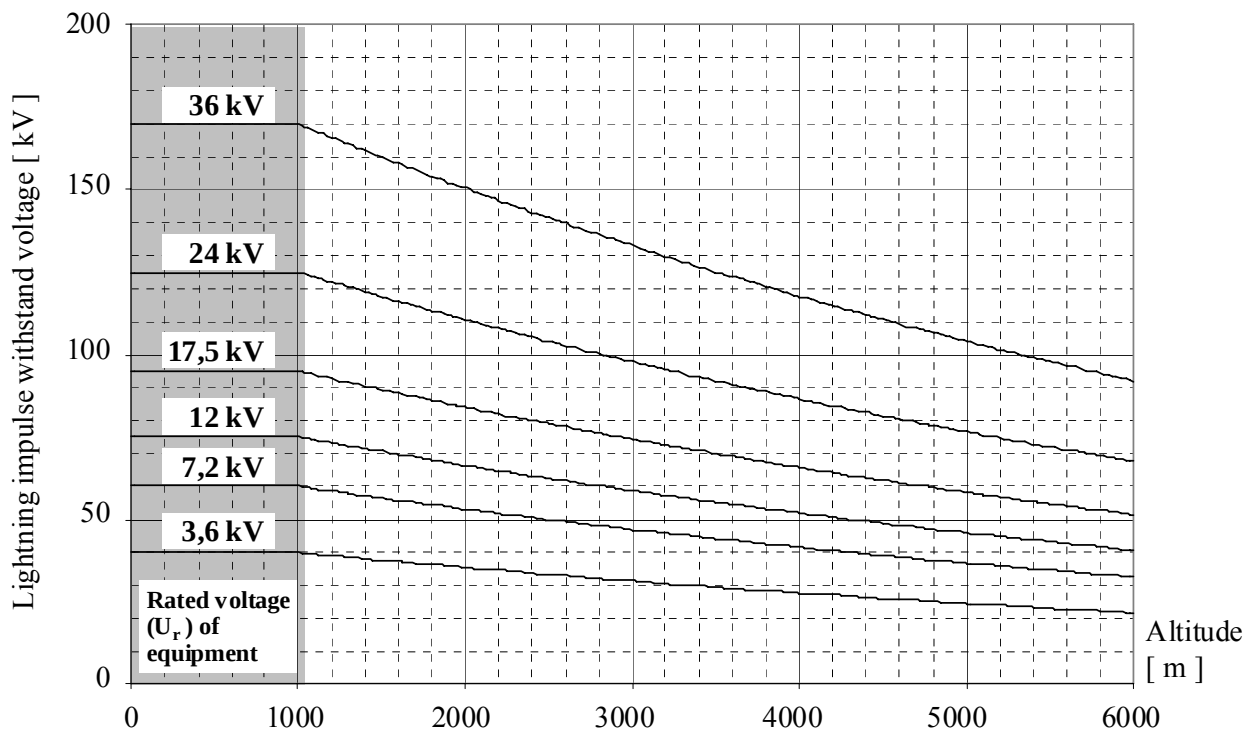
Rated voltage U_r / kV (r.m.s. value)	Rated short-duration power-frequency withstand voltage U_d / kV (r.m.s. value)		Rated lightning impulse withstand voltage U_p / kV (peak value)	
	Line-earth, line-line, across contact gap	Across isolating distance	Line-earth, line-line, across contact gap	Across isolating distance
(1)	(2)	(3)	(4)	(5)
3.6	10	12	20 40	23 46
7.2	20	23	40 60	46 70
12	28	32	60 75	70 85
17.5	38	45	75 95	85 110
24	50	60	95 125	110 145
36	70	80	145 170	160 195
52	95	110	250	290

Table H-3: Rated voltages and insulation levels in the medium voltage range

Comments:

- a) Operators may specify a higher insulation level in accordance with operational requirements. Reasons for this include foreseeable reduction in insulation due to moisture or pollution or high dielectric stresses during standard operation due to connected overhead systems, traction supply systems etc.
- b) At altitudes of at least 1000 m above sea level, the insulation level decreases caused by the lower air density. There are alternatives to compensate this decrease:
 - a higher rated voltage is set;
 - surge arresters are installed to limit possible overvoltages below the actual insulation capability. Based on the voltage withstand value at the relevant altitude (see Figure H-1) the required protection level of the arresters is determined, as described in section E 4;
 - gas-/solid-insulated switchgear is used with shielded, earthed connections (cable plug connectors, insulated bars), where the HV conductors are not surrounded by ambient air.

For low-voltage auxiliary and control equipment no precautionary measures need be taken up to 2000 m altitude. Regarding installation sites at higher altitude see IEC 60664-1 [18].



Example for diagram above: a lightning impulse withstand voltage of $U_p = 120$ kV is required at an altitude of 1800 m. A system with a rated voltage of 36 kV achieves this, while a 24 kV system is not suitable because it can only maintain a lightning impulse withstand voltage of 125 kV up to 1000 m.

Figure H-1: Lightning impulse withstand capability in air, depending on the site altitude

- c) In environments with high levels of pollution, longer creepage paths may be required [16]. This can be achieved not only with a higher insulation level, but also with alternative methods:
 - avoiding unprotected insulation

- additional insulation for exposed parts (e.g. heat shrink tube to act as bridging protection)
- gas-insulated switchgear with shielded, earthed connections (cable plug connectors, insulated bars)

Note:

In many cases, surge arresters fitted at central points can be used as an alternative to increasing insulation levels.

H 2.3 Rated short-circuit currents

Rated short-circuit currents include:

- The peak current I_p and short-circuit making current I_{ma}
- The short-time current I_k and short-circuit breaking current I_{sc}

The peak current and short-time current are withstand capability variables (steady state), while the short-circuit making and breaking current indicate the switching capacity. The applicable standard defines a fixed ratio between the impulse and short-time current as a basic design requirement for switching devices and switchgear: $I_p/I_k = 2.5$ (2.6 at 60 Hz). The same ratio applies to the dynamic variables I_{ma}/I_{sc} . The values that actually occur in the network, however, have priority.

<u>Rating rule:</u>	Standard value	System variable
a) I_{ma} <u>and</u> I_p	$\geq$	i_p
b) I_{sc} <u>and</u> I_k	$\geq$	I_k (resp. I_b or I_k)

Both conditions (a) and (b) must be fulfilled. For switchgear, the next highest standard value above the actual line variable is set.

Rated short-circuit breaking current

The rated short-circuit breaking current I_{sc} is characterised by the r.m.s. value of the AC component and the relative DC component, which results from the opening time of the circuit-breaker and the DC time constant of the short-circuit current.

The circuit-breaker may be equipped with more than one release having different tripping times, which in turn means different opening times. Thus – depending on the release – the DC component can also vary. The selection of the rated value I_{sc} must be based on the shortest opening time.

Unless otherwise specified the DC time constant of the short-circuit current is $\tau = 45$ ms (standard value). In some systems or with some applications the time constant may be higher, so is the resulting DC component then – related to the opening time of the circuit-breaker. Therefore the circuit-breaker standard IEC 62271-100 [7] allows another time constant of 120 ms (also 60 ms and 75 ms) for special applications.

Whether or not a circuit-breaker at given rated short-circuit breaking current is suitable for other (than the rated) DC components – based on different opening time or different short-circuit current time constant, can be verified by the total breaking current. Keeping I_{total} constant, higher DC components at lower AC component may be calculated. However, the total breaking current resulting from the rated values of the circuit-breaker – I_{sc} , T_{op} and τ – must not be exceeded.

DC component (β) at the instant of contact separation:

$$\beta = e^{\frac{-(T_{op} + T_r)}{\tau}}$$

Permissible total current, resulting from the rated short-circuit breaking current (AC component) at $\tau = 45$ ms and shortest opening time T_{op-min} :

$$I_{total} = I_{sc} \cdot \sqrt{1 + 2\beta^2}$$

For other short-circuit breaking currents ($\neq I_{sc}$) and other DC components ($\tau \neq 45$ ms; $T_{op} \neq T_{op-min}$) applies:

$$I_{total} \geq I_{AC(eff)} \cdot \sqrt{1 + 2\beta^2}$$

Warning: The conversion of breaking currents makes sense only up to 50 % DC component; higher values require the approval of the circuit-breaker manufacturer.

β	relative DC component at the instant of contact separation
τ	DC component of the system's short-circuit current
f_N	power-frequency, 50 Hz or 60 Hz
$I_{AC(eff)}$	$I_{AC} \neq I_{sc}$; short-circuit breaking current (AC component, r.m.s. value)
I_{sc}	rated short-circuit breaking current (AC component)
I_{total}	total (short-circuit) breaking current
T_{op}	opening time of the circuit-breaker
T_r	$\frac{1}{2}$ cycle of the rated frequency; 10 ms (50 Hz) or 8.3 ms (60 Hz)

Rated short-circuit making current and rated peak current

The design specification, given by the standard, establishes a fixed ratio between the rated peak and short-time withstand currents: $I_p / I_k = 2.5$ (2.6 at 60 Hz); the same ratio applies to the dynamic ratings I_{ma} / I_{sc} . In pure distribution networks the current almost always keep to this ratio. However, factor 2.5 (2.6 at 60 Hz) may be exceeded in the network, particularly when regenerative loads are connected to the system. The following can indicate a higher making or peak current that differs from the standard:

- higher number of motors
- motors of high rated power
- generators.

To minimize voltage drops (voltage quality) caused by large, direct-starting motors, networks may be designed for high short-circuit current levels. In those installations, the magnitude of the peak current must be thoroughly taken into account.

Rated short-time withstand current

Main and earthing circuits of switchgear assemblies can have different ratings. The rated short-time withstand current may be converted into other current or time values; see H 2.4 d).

H 2.4 Rated duration of short-circuit t_k

This refers to the duration for which switchgear can conduct the rated short-time current in a steady state.

Rating rule: $t_k \geq t_{k \text{ line}}$

A key factor here is the total short-circuit duration, which is governed by the settings of the protection relay, the selectivity requirements, the set tripping times, and the opening times of the switching devices.²¹ Values of between 3 s and 1 s are normal for switching devices and switchgear.

- a) In accordance with the applicable standard [1], the preferred value is $t_k = 1$ s, although 3 s has since established itself for most switching devices and switchgear; the protection settings do not, therefore, need to be taken into consideration. With very high short-circuit current values ≥ 40 kA, however, 1 s is still typical for cost reasons.

- b) Main and earthing circuits can have different rated values.

- c) For cost reasons, current transformers mostly are designed for times of < 3 s.

- d) "Thermal" conversion between the short-time current and the short-circuit duration:

The short-time current and the short-circuit duration can be converted by means of the I^2t value: $I_1^2 \cdot t_1 = I_2^2 \cdot t_2$. A conversion for lower short-circuit currents with longer duration is harmless. A conversion for larger short-time currents with shorter durations may only be carried out within the rated values, so that the peak withstand current and the making and breaking capacity of the circuit-breakers and the switchgear assembly are not exceeded.

H 2.5 Rated normal current I_r

A key factor for the rated value is the actual operating current I_B , which flows continuously or for a long period in the network, and the prevailing ambient temperature.

Rating rule: $I_r \geq I_{B\max}$ at a given ambient temperature

For switchgear, the next highest standard value above the maximum operating current is set as the rated current. Reserves have to be taken into account in the standard value to be selected if the ambient temperature or the characteristics of the load may change.

- a) Busbars and feeder circuits can have different rated values; the same applies to individual sections of busbars that have been sub-divided.
- b) Reserves for temporary (planned) overload or emergencies must be taken into account.
- c) When busbars are rated, the operating principle of couplings with parallel infeeds must also be taken into account at the planning stage.
- d) The operating current may contain harmonics which considerably contribute to the temperature rise; the total current determines the rating.
- e) The influence of the site altitude on the current carrying capacity is almost negligible in practice. The dissipation of heat losses – just as the insulation capacity – depends on the air density which decays with increasing altitude. Regarding the current carrying capacity, however, the reduced cooling effect at high altitudes is compensated by lower ambient temperatures [19].

²¹ A general value of 100 ms is normally assumed as the shortest possible breaking time (opening + arcing time), using a protection relay and a standard circuit-breaker.

H 3 Busbar arrangement

If the switching principle has not yet been defined during network planning or in accordance with operator specifications, the following general aspects should be taken into account to help reach a decision:

Selection variable	Key influencing factors
• Single / double busbars • Bus section panel • Bus section panel / transfer panel with switch or circuit-breaker • Bus coupler unit (with double busbar)	• Line structure • Line protection, tripping times, selectivity • Reserves / availability, switchover time • Operating procedures • In-plant generation, emergency supply • Power quality (unstable loads)

Table H-4: Key factors for the busbar design

H 3.1 Single busbars

A single busbar is suitable for most supply duties. In systems with a higher number of feeder circuits, the busbars can be sub-divided into sections each with their own infeed. In this way, each section can potentially draw a reserve supply from an adjacent section. Single busbar switchgear has the following benefits:

- it is completely transparent in all switching states;
- as a result, it is easy to use if network failures need to be rectified urgently, which greatly reduces the risk of switching faults;
- if switchovers caused by faults need to be carried out, only the circuit-breakers need to be operated. If the wrong circuit-breaker is operated inadvertently, this will not affect safety of the switchgear because circuit-breakers can make or break all load and short-circuit currents, even during earth fault and under any other fault conditions.

H 3.2 Double busbars

For technical or contractual reasons, some requirements can only be properly fulfilled by means of double busbars, for example if

- two (or more) infeeds must always be operated separately (e.g. infeeds from different public utility companies or the strict separation of in-plant generation and the public network);
- loads can interfere with the power quality when causing voltage fluctuations or flickers, and other equipment is sensitive to those interferences. Non-sensitive loads – depending on the load status – should be switched to either the stable or the unstable busbar;
- loads of different importance need to be distributed across "safe" and "less safe" busbars (i.e. busbars with different requirements on the availability);

- a network must be divided into two sub-networks due to the limited short-circuit strength of the installed equipment. Switchovers permit to balance fluctuating load current consumption.

H 3.3 Design of double busbars

The lifetime of a disconnector plays an important role for double busbar switchgear. If frequent switchovers are required, disconnectors should not be integrated in the switchover process due to their relatively short operating cycle lifetime. The average mechanical endurance of a disconnector (drawout unit or truck) is 1000 or 2000 operating cycles, corresponding with classes M0 and M1 [21]. Because of this low endurance – in comparison to circuit-breakers, not every design of double busbar switchgear is suitable for frequent busbar switchovers. A version with two circuit-breakers that switch between the busbars is more suitable.

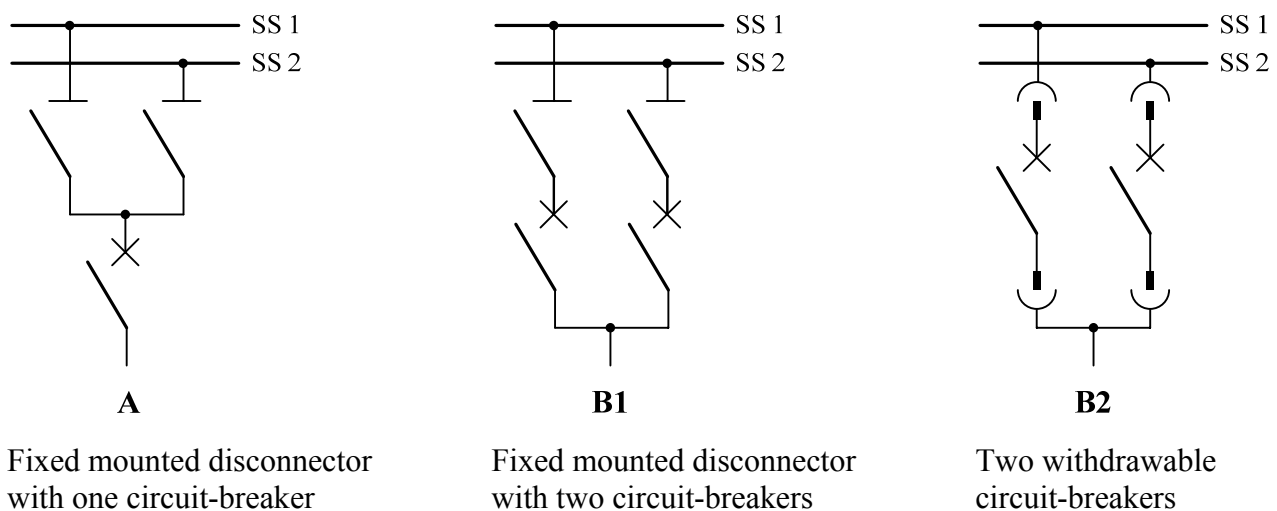


Figure H-2: Design alternatives of double busbar arrangements

Only the designs B1 and B2 suit the requirements for frequent busbar switchover. Only the circuit-breakers are operationally switched, the disconnectors are opened only for maintenance or work purposes. In contrast to this the classic double busbar design (A) is less suitable since every busbar switchover implies to operate the disconnectors.

H 3.4 Operating principle of bus couplings

If the system contains more than one busbar section, the planned operating principle of couplings governs the rated short-circuit current of the switchgear and the rated normal current of the busbars.

Normally open coupling (NO)

In "open" mode, the short-circuit current remains low, which allows systems, switches, cables etc. with low rated values to be used. With a bus section panel and an automatic changeover circuit, instantaneous reserves (dead time < 300 ms) can still be ensured even if the infeed fails. The short-circuit current is not increased as a result of this because one infeed line has already been disconnected.

Normally closed coupling (NC)

In "closed" mode, the switchgear must be rated for the total fault current of all the interconnected infeeds, even if selective mains decoupling has been achieved by means of a bus section panel and quick-disconnect technology. The advantage is that load differences can balance themselves, on the other hand disturbances can cause interference that affects the entire network.

Comments:

- a) Provided that certain safety measures are observed, system sections that are normally operated separately can be briefly interconnected during switchovers, even if the short-circuit current exceeds the rated system value; see subclause § 7.1.1 of IEC 61936-1 [22].
- b) Interlocking and switchgear interlocking: whenever any type of bus section panel or bus coupler unit is used for busbars, the extent to which interlocks and switchgear interlocking are required must be determined.
 - An interlock system must simulate the planned operating procedures and prevent impermissible switching states.
 - If disconnectors are directly involved in busbar switchovers or coupling maneuvers, switchgear interlocking must prevent impermissible switching operations with the disconnector.

H 4 Switching Devices

Selection variable	Key influencing variables	Section
• Circuit-breaker • Switch • Contactor • HRC fuse	• Operating current and switching duty • Switching frequency • Switching capacity • Protection concept, selectivity	B 1 A 4 A 2 to A 3, H 1 D 2 pp.

Table H-5: Key factors for the selection of the switching device

The listed influencing variables are equally important when it comes to choosing and rating the switching devices.

<u>Rating rules:</u>	see section	A 1 to A 4	Selection of the appropriate device
		B	Switching duties in medium voltage networks
		C	Rated values of switching devices

Comments:

In cases where switches or circuit-breakers can be used likewise for a particular switching duty, the selection can be determined by the protection concept and selectivity conditions. Examples of this include:

- Short-circuit protection shall be realised with defined characteristics, for which only circuit-breakers are suitable in combination with instrument transformers and protection relay.

- Overload protection can be achieved only with restrictions using standard back-up HRC fuses, since they do not melt after a defined period in the lower overload current range. If overload protection is to be achieved in this range, current transformers and protection relays are required. The switch then must be equipped with a stored-energy spring mechanism. Moreover it must be considered that the breaking capacity of the switch for inductive overcurrents is not exceeded.
- Protection functions (overload, load unbalance, etc.) for sensitive loads (motors, transformers) that are in accordance with defined characteristics can only be achieved by means of circuit-breakers in conjunction with instrument transformers and protection relays.
- A switch-fuse combination has the advantage – in contrast to a circuit-breaker – to limit the short-circuit current and cut the peak value, which is of interest for the personnel protection.
- A switch without fuse, on the other hand, may be required in order to avoid breaking operation at certain points in the network for selectivity reasons and to enforce the tripping of a certain breaker at a different point.

These requirements are normally already given by the network design.

H 5 Switchgear design and panel type

Selection variable	Key influencing factors
• Circuit-breaker unit • Switch-disconnector unit • Design - extendable panels - block type	• Primary rated values • Switching devices • Operating current, switching capacity • Line protection • No. of switch /circuit-breaker panels • Operating procedures and operation • Installation conditions • Transportation and assembly • Upgradeability, electrical / mechanical reserves

Table H-6: Key factors for the switchgear design

H 5.1 Basic selection criteria

The primary rated values must always cover the requirements that result from the line parameters. Switchgear with the required properties must be available with the required design. Unless the design is specified otherwise and the primary rated values permit switch-disconnector units and circuit-breaker units, the comparison of the standard characteristics of the two designs may give hints for the decision.

Switch-disconnector unit	Circuit-breaker unit
• Normal current: up to 630 A or 1250 A	• Normal current: up to 4000 A
• Short-circuit current strength: up to 25 kA_{rms} / 63 kA_{peak}	• Short-circuit current strength: up to 63 kA_{rms} / 160 kA_{peak}
• Switching devices - mainly switches - some circuit-breakers	• Switching devices - mainly circuit-breakers - some switches - contactors
• No or only low short-circuit breaking capacity required	• Short-circuit breaking capacity required
• HRC fuses as short-circuit protection in feeder circuits	• Short-circuit protection by instrument transformers plus protection relay
• Small switching frequency	• High switching frequency
• Simple secondary equipment	• Complex secondary equipment
• Sometimes suitable for harsh climates	• Generally requires a protected environment (for control, protection, and measurement electronics)

Table H-7: Characteristic features of switch and circuit-breaker switchgear

H 5.2 Panel and block design

The list below highlights some of the differences between panel and block design, which could be key decision-making criteria. Which of the following characteristics must the switchgear fulfil?

Panel design	Block design
• Flexible applications	• Given applications
• Panel type can be freely selected - Switch with/without HRC fuse - Circuit-breaker - Transfer and measurement panel	• Standardized versions
• Number of switchgear panels can be freely selected	• Number of switching functions depends on container size, containers can be arranged side by side
• All equipment variants	• Customized equipment
• Range of functions can be extended	• Standard range of functions
• Can be freely extended	• Can only be extended after prior planning

Table H-8: Distinguishing features of switchgear designs

H 5.3 Installation conditions, transportation and assembly

Switchgear dimensions and ambient condition at the installation site are a key decision-making criterion. Many new systems are replacements for "old" switchgear in existing buildings.

In addition to space for the switchgear in the room, adequate space must be available for operating and assembly activities as well as escape routes. Sufficient distance from other installations must also be ensured. Alongside the installation conditions specified by the manufacturer – they refer only to the switchgear itself, legal specifications must also be observed; see subclause 7.5 of IEC 61936-1 [22].

Points absolutely to be taken into account are:

- Wall clearances and minimum dimensions for free areas for operating and assembly activities (manufacturer)
- Minimum space for operation and installation to manufacturer's instructions
- Minimum width of operating and assembly aisles
- Minimum width and maximum permissible length of escape routes
- Direction of pressure release (internal fault)

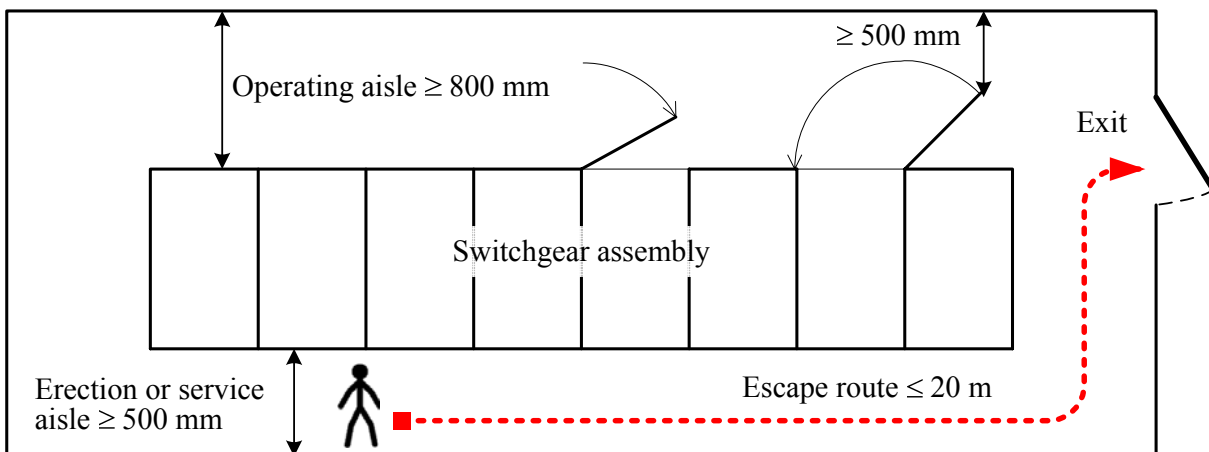


Figure H-3: Arrangement of switchgear to IEC 61936-1

The following must be taken into account when switchgear is transported and installed:

- Dimensions of the (door) openings in the switchgear room and access paths, load bearing capacity of access paths, including lifting equipment (elevators).
- Size, weight, and packaging of the transportation unit(s).
- The switchgear and its components must be protected against local climatic conditions before the final installation and commissioning if it is in temporary storage over a long period.

H 5.4 Additional aspects

There are no fixed rules for many of the selection criteria; decisions are rather made on the basis of the operator's or designer preferences.

- The ratio of switch panels to circuit-breaker panels may be a criterion for the type of switchgear design. The dominant switch type can sway the decision. On the other hand this is no clear rule; there are circuit-breaker units available that are made up almost exclusively of switches and vice versa.
- Operating procedures defined by the operator are closely related to the secondary equipment. Decision-making criterion here is whether or not the switchgear can feature the relevant functions which may include:
 - Actuating equipment (switching levers, instrument displays, locks)
 - Interlocks
 - Integration in other (production) processes in the company
- The devices required for protection, control (automation, communication), measurement, and metering functions govern the scope of the secondary equipment. The design must ensure that this equipment can be installed properly (e.g. instrument transformer in the primary section, devices in the low-voltage compartment). If remote control is used, the design concept must accommodate this by providing motorized drive mechanisms for the switchgear, for example. The higher the design category, the greater the design scope.

H 6 Electrical and mechanical reserves

Reserves are provided to handle expected or planned requirements of the plant operator. A design equipped with mechanical and electrical reserves is "overdimensioned" when it is first put into operation, although it can be extended at a later stage. Which options is the design to offer?

- Panel extension
- Loss of service continuity during work on the switchgear
- Space for installing replacement instrument transformers or additional cores
- Options for installing secondary devices in the low-voltage compartment
- Options for retrofitting control or automation devices
- Options for retrofitting motorized drive mechanisms
- Planned increase of the short-circuit current
- Increase of operating currents in the feeder circuits and busbars

H 7 Insulation medium

Selection variable	Key influencing factors
- Air insulation AIS* - Gas insulation GIS* * AIS: "air insulated switchgear" GIS: "gas insulated switchgear"	- Ambient room conditions: temperature change, humidity, pollution, salt, corrosive gases - Type of operating site - Installation location (space requirements) - Fire protection requirements (fire load) - Altitude - Switching frequency and switching device lifetime

Table H-9: Criteria for the selection of the insulating medium

In technical jargon the abbreviation AIS for air insulated switchgear is common as well as GIS for gas insulated switchgear. Instead of gas, the standard [23] uses the neutral term fluid for all gaseous (except for ambient air) and liquid media. GIS in the medium voltage range are seldom purely gas-insulated switchgear. With hybrid designs e.g. only the switching compartment is gas-insulated while the busbar is embedded in solid insulation. Nevertheless they are accepted as GIS. Encapsulated plug-in cable connections are a common feature of all GIS designs.

The table below compares the main features of systems with the two types of insulation. Which of these features is the switchgear to be configured to have?

Feature	AIS	GIS
Enclosure	Metal enclosure	Metal enclosure, the primary section is hermetically sealed
Climate	- Suitable for normal conditions - Upgraded degree of protection (IP) for harsh ambient conditions or measures taken in the service room - Humidity and condensation in conjunction with pollution layers can reduce insulation ⇒ Remedy: heater in switchgear panel	- Suitable for extreme conditions - In extreme conditions, only the secondary equipment needs protection. - Inert atmosphere minimizes external influences on the primary section; in humid conditions, heater in low-voltage compartment only
Maintenance	Maintenance required (e.g. cleaning)	Primary section does not need to be maintained
Accessibility	Easy access to all components	Access to components in primary section not required / not possible
Switching frequency	Highly suitable for switching duties with high number of make-break operations ⇒ Frequent access for maintenance	Not suitable for switching duties with high number of make-break operations (exception: switchgear panels with contactor)

Feature	AIS	GIS
Dimensions	Larger dimensions than GIS (above rated voltages > 12 kV)	Compact design, which allows greater flexibility during installation
Installation at altitude > 1000 m	May require a higher rated voltage (insulation level) or use of surge arresters	No measures required, even if the connections are fully encapsulated (cable plug connectors)

Table H-10: Characteristic features of air- and gas-insulated switchgear

Medium voltage Gis work at gas pressures between 50 kPa and 100 kPa in (hermetically) “sealed pressure systems” according to [1]. No gas must be refilled during the life time of at least 35 years. Because of this, as a rule, the operators of such switchgear are not concerned by the legal requirement of the EU Council Regulation on fluorinated gases [24]. GIS do not fall under the EU Council Directive on pressure equipment [25]; because of the low gas pressure of only 300 kPa.

Gas insulation has many benefits, although nearly all requirements can also be fulfilled with air insulation. In addition, certain areas of application are better suited to air-insulated systems, where operational aspects, like accessibility or maintainability with simple means, are in the foreground.

H 8 Design of the isolating distance

Selection variable	Key influencing factors
• Withdrawable unit / truck • Disconnecter (built in)	• Switching frequency • Component lifetime • Operational requirements (access to cable terminals)

Table H-11: Key factors for the isolating distance

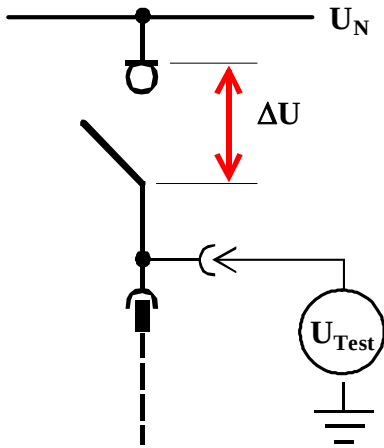
H 8.1 Accessibility

The type isolating distance can only be selected for air-insulated systems. If loads with a high switching frequency are connected to a switchgear system, a switch in a withdrawable unit (truck) is preferred because this enables it to be accessed quickly and easily for maintenance purposes or if it needs to be replaced at the end of its service life.

Even if the cable terminals for the switchgear panel needs to be readily accessible (e.g. voltage tests on cables), a withdrawable unit can still be a better solution than a fixed unit because more room is available for working on the switchgear panel once the unit has been removed. How easily the cable can be accessed depends on the type of partition; see section H 10.

H 8.2 Voltage tests on cables

If a cable cannot or must not be disconnected and dismantled from the switchgear, it must be considered that the isolating distance is dielectrically stressed with the sum of test voltage on the cable and the power-frequency voltage on the busbar²²; see ΔU , Figure H-4. In some cases practically no safety margin is left to the withstand capability of the isolating distance if the busbar side is still live when the cable test voltage is applied.



Two other aspects need be considered:

- during a DC test on paper-insulated cables the isolating distance is stressed with a pulsating voltage, which is not covered by a corresponding rating;
- if temporary or transient overvoltages (e.g. during earth fault) occur on the busbar side during the cable test, the rated insulation level of the isolating distance may be exceeded.

Figure H-4: Voltage test on cables, example with a switch panel

If withdrawable switching devices realise the isolating distance, this issue is not relevant since the withstand capability of the isolating distance is high enough – rather the clearance to other parts of the switchgear may be critical.

In case of fixed mounted switchgear designs the rated cable test voltages U_{ct} (a.c.) or U_{ct} (d.c.) of the switchgear assembly shall correspond to the test values of the cable connected. Otherwise the cable test voltage should be subject to agreement between manufacturer and user, if the cable cannot be dismantled.

H 8.3 Switching frequency

For switchgear with double busbars, see also section H 3.3 regarding operational aspects when frequent busbar switchover is required.

²²Other parts of the switchgear which remain connected to the cable are stressed with the cable test voltage as well.

H 9 Enclosure

Selection variable	Key influencing factors
- Degree of protection (IP) - Internal fault qualification - A or B - F / L / R - Test current and duration - Pressure absorber - Pressure relief duct	- Ambient conditions - Personnel protection - Type of operating site - Building

Table H-12: Key factors for the enclosure

H 9.1 Degree of protection

According to the IEC standard of switchgear assemblies [23] a minimum degree of protection of IP 2X is required. In the market higher degrees of protection IP 3XD or IP 4X are usual. These two degrees of protection are identical with respect to shock-hazard protection but differ with respect to protection against ingress of solid foreign bodies (1st numeral).

Water protection is not specified for systems operating under normal conditions inside buildings. For harsh environment the degree of protection can be upgraded on request; e.g. up to IP 51.

Requirements regarding ventilation/cooling and protection against ingress of solid foreign bodies are contrarily! Switchgear at large rated currents and high ambient temperature can hardly suit both requirements. The degree D for protection against electric shock, however, can always be achieved.

1st digit		2nd digit		Additional letter
Foreign bodies	Shock protection	Water protection		Shock protection*
0 non-protected	unprotected	0 non-protected		
1 $\geq 50 \text{ mm } \varnothing$	back of hand	1 vertically dripping		A back of hand
2 $\geq 12.5 \text{ mm } \varnothing$	finger	2 dripping 15° tilted		B finger
3 $\geq 2.5 \text{ mm } \varnothing$	tool	3 spraying		C tool
4 $\geq 1.0 \text{ mm } \varnothing$	wire	4 splashing		D wire
5 dust-protected	wire	5 jetting		
6 dust-tight	wire	6 powerful jetting		
		7 temporary immersion		
		8 continuous immersion		

* is specified if degree of protection is higher than specified with 1st digit

Figure H-5: IP codes [26]

H 9.2 Internal arc classification

This qualification specifies the type of accessibility of the operating site and the parts of the system that are qualified with respect to internal faults (e.g. IAC A FLR 25 kA 1s).

- A applies to switchgear in closed electrical operating areas, accessible only for authorized and qualified personnel
- B applies to switchgear at publicly accessible locations (higher severity of test)
- F / L / R designate the accessible, classified sides of the switchgear that have been tested for resistance to internal faults (front, lateral, rear).

Medium-voltage switchgear is generally tested for accessibility type A. Only complete, factory-assembled stations (transformer/load-center substations) are tested for type B. Standard systems do not need to be tested according to type B because they are always integrated in additional (station) housing in areas that can be accessed by the public.

The qualified accessible sides F / L / R must be in accordance with the type of installation in the service room. "FL" is sufficient for a wall-mounted installation, while "FLR" is required for a free-standing installation (all sides can be accessed during operation). Non-classified sides of a free-standing switchgear installation must be made inaccessible, for example by means of barriers.

H 9.3 Pressure absorbers and pressure relief ducts

With certain switchgear designs, pressure absorbers are available for low short-circuit currents (< 20 kA). If an internal fault occurs, they reduce the pressure in the service room.

- Using pressure absorbers can help protect the building fabric, particularly in older buildings.

A pressure relief duct can channel the internal fault gases out of the switchgear room, thereby protecting the service room from the pressure wave and smoke.

Notes:

The service room must always be taken into account when measures to provide protection against internal faults are elaborated:

- Calculation of the dynamic pressure in the service room, which the architect/structural engineer can use to determine the stress on the building fabric.
- Pressure relief outlets with a sufficiently large cross-section or pressure relief duct.

Further requirements are defined in IEC 61936-1 [22]. Other regional legal building regulations may also apply.

H 10 Compartments

Selection variable	Key influencing factors
- Loss of service continuity category (compartmentalization) - LSC 1 - LSC 2 - LSC 2A - LSC 2B	- Operating procedures - Operation, work activities - Maintenance requirements - Servicing / maintenance (component lifetime) - Operator regulations - Personnel training - Shock-hazard protection during work activities - Switchgear space requirements
- Access control by means of: - Interlock - Work instruction + lock - Tool	
Non-accessible compartment	
- Partition class - PM (metal) - PI (plastic)	

Table H-13: Key factors for the compartment design

H 10.1 General selection criteria

The decision regarding the type of partition depends on the requirements of the operator.

- Which recurring operating procedures require access to compartments? (e.g. changing the HRC fuse, reading short-circuit indicators, making adjustments)
- What servicing and maintenance work intervals are planned?
- Which system components must remain live even while servicing / maintenance work is being carried out within a compartment?
- Is shock-hazard protection during servicing / maintenance work to be achieved by means of metallic / non-metallic partitions?
- What level of training is required for personnel? Is shock-hazard protection to be permanently or realized automatically or manually?
- How much space is available for the installation of the switchgear?

H 10.2 Loss of service continuity category

The loss of service continuity category (LSC) defines the possibility to keep other compartments and/or functional units energised when opening a main circuit compartment. The LSC category does not describe ranks of reliability or of personnel protection.

- LSC 1 This category offers the least availability and does not include partitions between the busbars or adjacent panels. When work is carried out in the interior the busbar section or at least the adjacent panels must be de-energised.

- LSC 2** This category includes an isolating distance and partitions to the busbar and adjacent panels so that they can remain energised if the cable / connection compartment is open.
- LSC 2A** This category means that the panel has – besides the busbar – several accessible compartments. If either compartment is opened, busbar and adjacent panel can remain energised since an isolating distance and a partition to the busbar compartment is built-in.
- LSC 2B** In this category (known as "metal clad") the switchgear features an isolating distance and partition between busbar and switch or circuit-breaker as well as between switch or circuit-breaker and cable terminal. Busbar and adjacent panels as well as the cables in the connection compartment may remain live if the panel is opened.

Selection aspects

- LSC 1** is advisable if the operations permit to shut down parts of or even the whole switchgear installation for work or maintenance. The dead state provides safest work conditions.
- LSC 2** makes it possible to open a panel without shutting down the busbar section or the whole switchgear installation. With LSC 2 category switchgear only the cable / connection compartment is accessible, most gas-insulated switchgear belong to this category.
- LSC 2A** This option is recommended if quick and easy access to the cable terminal or transformers is required (on a regular basis too).
- The systems are more compact than those in category LSC 2B.
- When the switch is accessed, the cable must be disconnected from the power supply (supply cable or reverse voltage from the load).
 - A door interlock with the earthing switch is recommended.
- Due to the potential hazard mentioned, using systems with loss of service category LSC 2A makes more stringent demands regarding the training that staff working on the system require.
- LSC 2B** Systems in this category offer the highest level of "in-built" shock-hazard protection, although this means that the components can be more difficult to access.
- The systems are larger than those in category LSC 2A.
- In conjunction with interlock-controlled access, these systems are also suitable for personnel who do not work with high-voltage systems on a regular basis.

The 'loss of service continuity categories':

- Do not differentiate between permanently installed and temporary partitions (covers, removable shutters etc. that are present only temporarily);
- Are intended for systems with accessible compartments and are, therefore, applicable to gas-insulated systems only if they have accessible compartments – other than busbar and cable / connection compartment.
- Do not describe the partition for providing protection against an internal fault in an adjacent room, but only the shock-hazard protection against live, adjacent parts – 5. Safety Rules for Carrying Out Work [31].

Beyond technical characteristics, preferences of the operator can influence the decision for LSC 2, 2A or 2B.

H 10.3 Access control

While the compartment for the busbar in nearly all system designs can only be opened with a special tool (“**tool-based accessible compartment**”), the switch and cable compartment can be opened in one of two ways:

- **Interlock-controlled access**

With this method, shock-hazard protection is ensured automatically because the door / flap to the compartment can only be opened when all the primary circuit components inside have been short-circuited and earthed.

- **Process-based access**

With this method, the manufacturer must equip the compartments with locking devices. The operator is responsible for ensuring that access to the compartment is regulated by means of a work instruction. If the instruction is not observed, personnel risk coming into contact with live parts!

Provided a choice exists, operators must decide according to their own requirements. Interlock-controlled access is recommended due to the high level of inherent safety.

Again, as for the LSC category, preferences of the operator influence the choice of access control.

H 11 Feeder circuit components

Selection variable	Key influencing factors
• Cable connection - Sealing end: standard / plug - Number of cables - Cable cross-sections	• Operating and short-circuit current • Switching duty • Underground / overhead cables • Altitude
• Surge arrester	
• Voltage transformer - Earth fault winding (if required) • Current transformer - Core number and data • Core-balance transformer (cable-type current transformer)	• Line protection • Control • Measurement, metering • Neutral-point earthing
• Earthing switch - Class E0 - Class E1, E2	• Operating procedures

Table H-14: Key factors for the feeder circuit components

At the configuration stage, it is important to remember that many different components need to be installed in the limited space available on the switchgear panel.

H 11.1 Cable connections

The operating and short-circuit current determine the number and cross-section of the cables to be connected. In many cases, operators have standardized the cross-sections used in their companies. This has to be taken into account particularly with multiple cable connections for large operation currents.

H 11.2 Instrument transformers

In order to keep the spatial size and the electrical data as small as possible, instrument transformers should be selected accurately adapted to power consumption of the secondary devices to be connected. Digital protection relays feature a power consumption of less than 1 VA. Hence 2.5 VA or 5 VA rated output of the instrument transformers suffice in most cases, since the losses along the secondary cables are small as well due to the low burden. Overdimensioning – which is quite common practice, unfortunately – may even be counterproductive, because instrument transformers measure within their accuracy class not until a burden²³ of at least 25 % of the rated output [32], [33].

In many cases a separate measuring core is dispensable if an operational measurement at > 1 % accuracy is acceptable. In the range of normal currents CT protection cores transduce with satisfactory accuracy. CT of class 5P feature a current error of approximately 1 %, which may slightly increase at lower currents so that in average the overall accuracy is in the order of 3 %.

Voltage transformers (VT) in networks with an isolated neutral point should be equipped with a earth fault winding (da-dn winding, formerly "e-n winding"). Damping resistors are connected to the winding; see section I 1.

H 11.3 Earthing switches

Class E0 devices are standard earthing switches with no short-circuit making capacity. Class E1 or E2 switches can switch two times or five times onto a voltage that is present [21]. Earthing switches E1 / E2 are safe even if unintentional switching faults occur.

H 11.4 Surge arresters

Surge arresters also need space in the connection compartment. Therefore, depending on the switching duty, it must be determined whether the feeder should be fitted with overvoltage protection; see section B. Under certain conditions it may be more functional to mount the surge arrester within the panel instead of at the load to be protected; e.g. with motors.

²³ According to the standards other minimum values of the burden may be agreed on for CT < 15 VA [32] rated output and for VT < 10 VA [33] rated output.

H 12 Busbar / metering panel components

Selection variable	Key influencing factors
• Instrument transformer • Earthing switch - Class E0 - Class E1, E2 • Surge arrester	• Line protection and measurement • Operating procedures

Table H-15: Key factors for the busbar components

The aspects that were taken into account for the feeder circuit components also apply here (see section H 11).

- Components that have a direct electrical connection with the busbar can be installed in metering panels along with current and voltage transformers.

The following alternatives are available that do away with the need for a metering panel:

- With certain system designs, earthing switches for the busbar can also be housed in incoming feeder units, bus section panels, or bus coupler panels.
- With certain system designs, instrument transformers can be installed directly in the busbar compartment.
- Surge arresters can also be installed in switchgear panels that are always connected to the busbar, generally in the incoming feeder unit. If a busbar has more than one connected infeed, each incoming feeder unit has a set of arresters. This solution can be more cost effective than installation on the busbar.

H 13 Electronic secondary equipment

H 13.1 Electromagnetic compatibility (EMC)

If the secondary system of the medium voltage switchgear is equipped with electronic components, the electromagnetic compatibility (EMC) of these components must be specified. On the one hand there is susceptible electronics operating close to high-voltage circuits so that sufficient immunity has to be specified. On the other hand electronic devices themselves are a source of potential interference and disturbance whose compatibility with the environment must be ensured. In addition, the installation must comply with the legal requirements of the EU Council Directive on EMC [34].

Not all equipment of the secondary system of switchgear has to be included in the specification, though. Relevant to EMC are only susceptible devices or those which cause emitted interference. Devices without electronic components or circuits which neither respond to electromagnetic interference nor cause emissions are considered as “benign” equipment [35], i.e. non-critical regarding EMC. The table below lists examples of benign equipment.

EMC relevant equipment	EMC benign equipment (non critical)
• Protection relay • Equipment for control, interlocks and switchgear interlocking • Equipment for measurement, metering, including measuring transducers • Monitoring and communication equipment • Voltage detection system • Motorized drive mechanisms (with collector motors)	• Cables, terminal blocks, plugs • Auxiliary, position and signalling switches • Miniature circuit-breaker, fuses • Resistive loads without automatic switching device (heaters with no controls) • Batteries, accumulators • Passive components (capacitors, filament lamps etc.)

Table H-16: Benign equipment regarding EMC

H 13.2 EMC requirements on the switchgear

IEC/EN 62271-1 [1] provides the basic EMC requirements regarding emission and immunity for switchgear. The requirements refer only to the secondary system (low-voltage system) which contains electronic components.

The primary system (high-voltage part) is exempted from EMC requirements since its high-frequency emissions (caused by corona effects) are considered as negligible in the voltage range below 123 kV. Switching operations cause only occasional electromagnetic disturbances whose duration lies within the range of milliseconds. The frequency of occurrence, the levels and the implications of these interference emissions are considered part of the usual electromagnetic environment of high-voltage switchgear. Therefore no emission test and proof is required.

The same applies to switching devices (without electronic components) in the secondary system. CISPR 14 [36], dealing with interference emissions in sensitive domestic areas, exempts single switching operations from the proof of the compliance with radio interference limits.

H 13.3 EMC requirements on electronic equipment

Since a EMC routine test on the complete high-voltage switchgear is not possible, the individual components must fulfil minimum requirements so that they cooperate without unduly interference in the secondary system.

As a rule most of the devices and components comply with the specification of their relevant product standard. However, not all components were designed to operate in a high-voltage environment. Thus it must be thoroughly checked whether electronics complies with the immunity required for switchgear installations. Table H-17 summarises the tests and requirements, subdivided into devices and components with or without interface to high-voltage circuits.

Component “*with* interface to high-voltage circuits” means that it is connected via an instrument transformer or a coupling electrode to an HV conductor. Those components may face more severe disturbances and should thus be tested for higher immunity. In contrast to this a component “*without* interface to high-voltage” is only interconnected with other secondary equipment.

A guideline for EMC specifications is given by the standard of protection relays IEC/EN 60255-26 [37]. In one document it compiles all the requirements which might be applicable. However, not all of them are relevant for every component. Which specifications the devices or components must meet is determined by electromagnetic phenomena prevailing in the installation, which in turn depend on

- the type of the existing interfaces (e.g. ports for analogue or binary signals, power ports, auxiliary supply);
- the type and length of cables to be connected
- the installation situation, i.e. enclosures, shielding;
- the electrical and spatial environment.

For devices and components without interface to high-voltage circuits the immunity specifications of industrial environment suffice, supplemented with typical disturbance phenomena which appear at switching operations.

EMC	Electronic devices and components	
	with interface to HV circuits	without interface to HV circuits
Emission	IEC/EN 60255-26 Tables 1 and 2	IEC/EN 61000-6-4 Tables 1 to 3 IEC-CISPR 11 group 1, class A
Immunity	IEC/EN 60255-26 Tables 3 to 7	IEC/EN 61000-6-2 Tables 1 to 4 IEC/EN 61000-4-12 100 kHz, Table 1, Level 3 IEC/EN 61000-4-18 100 kHz and 1 MHz, Table 1, Level 3 with note „a“

Table H-17: EMC specifications for electronics in high-voltage switchgear

H 13.4 Legal EMC requirements

Switchgear installations intended for the European market must comply with the essential requirements and the specific requirements for “fixed installations” set by the EU Council Directive on EMC [34]; summarised in Table H-18.

Switchgear (fixed installations)	Specific apparatus for fixed installations
• Compliance with the essential requirements regarding emission and immunity • no conformity assessment required • no CE marking required • EMC documentation	• Compliance with the essential requirements <u>not</u> necessary • no conformity assessment required • no CE marking required • Instructions for EMC-correct installation

Table H-18: Requirements of the EU Council Directive on EMC

There is an exemption for electronic components of the secondary system that this kind of equipment stand alone does not need to comply with the essential requirements since in the end EMC is only relevant to the complete switchgear installation. However, this is not the optimum. On the one hand the switchgear manufacturer is dependent on using equipment with defined electromagnetic characteristic in order to ensure the EMC of the whole installation. And on the other hand only the component manufacturer has the knowledge to reliably evaluate the EMC characteristic of its equipment. Thus it is recommendable – as far as available – to use only EMC type tested low-voltage equipment, with the accompanying EC declaration of conformity and the CE mark.

Switchgear installations need accompanying EMC documentation, which confirms that the installation and their components is designed, manufactured and installed according to the state of the art regarding EMC. This EMC documentation may consist of the items listed in the table below.

Switchgear	Electronic secondary equipment
- Installation instructions (assembly, connections, commissioning) - Operating instructions (including maintenance instructions) - List of applicable standards	- Installation instructions - EC declaration of conformity (CE mark) - for “non CE-marked electronic products”: documentation, for example EMC type test reports

Table H-19: Example for EMC documentation

Medium voltage switchgear itself neither requires conformity assessment nor CE marking.

I APPENDIX

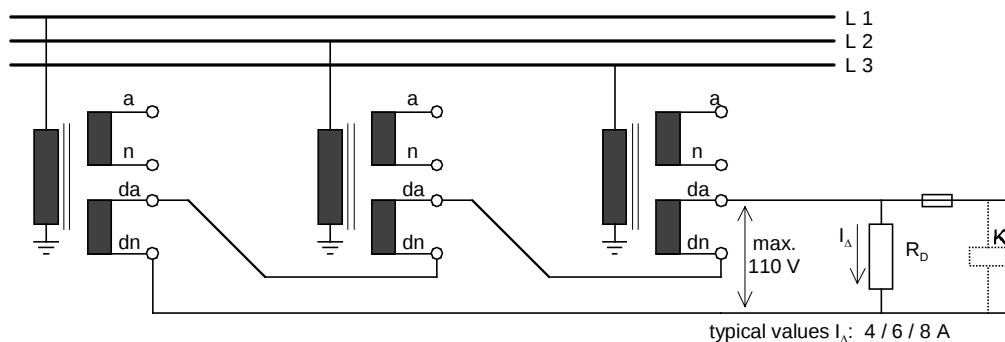
I 1 Damping relaxation oscillations

I 1.1 Relaxation oscillations (ferroresonance)

Relaxation oscillations can occur in applications with single-pole, inductive voltage transformers in certain network configurations, such as short underground or overhead line distances (low capacitance between conductor and earth):

Neutral-point earthing	Risk of relaxation oscillations
Effectively (solidly) earthed	None
Resistance earthed	None
Compensated (Petersen coil)	Slight
Insulated	High

Switching operations, earth faults, or other non-linear occurrences in the network can cause relaxation oscillations that are associated with high overvoltages and can subject the equipment to extreme dielectric and thermal stress; voltage transformers are especially at risk. The oscillations saturate the core causing considerable iron loss (sometimes indicated by a loud drone). As a result, thermal overload and flashovers can destroy the transformers and, in turn, damage the switchgear.



Relaxation oscillations can be damped by installing resistors on the earth fault windings connected to the open triangle ("e-n winding"). The choice of resistor depends on the thermal limit rating (or rated long-time current) of the da-dn winding in the voltage transformer. Since a earth fault always affects the entire galvanically-connected network, specific measures must be taken to protect the entire network against earth faults (this includes damping resistors). In many cases, however, general measures can be sufficient.

I 1.2 Standard values for damping resistors

Standard values for the resistors are provided in the table below. The choice of resistor depends on the thermal limiting output (or rated long duration current) of the da-dn winding in the voltage transformer.

da-dn winding of voltage transformer		Damping resistance
Thermal limiting output	Rated long duration current ²⁴	
75 W	4 A	25 ohms / 500 W
100 W	6 A	25 ohms / 500 W
150 W	8 A	12.5 ohms ²⁵ / 1 kW

If these standard values cannot be used, other values can be calculated.

I 1.3 Calculating the damping resistance

The damping resistance can be determined from the specifications on the rating plate of the voltage transformer.

Specifications: Rated thermal limiting output S_{sr} for 8 hours
 Secondary rated voltage U_{sr} of the da-dn winding (formerly "e-n winding")

Required: Lowest damping resistance value R_D
 Power loss (load-carrying capacity) of the damping resistor

The resistor must be rated in such a way that neither it nor the voltage transformer are overloaded, even if an earth fault occurs.

I 1.4 Formula, symbols and indices

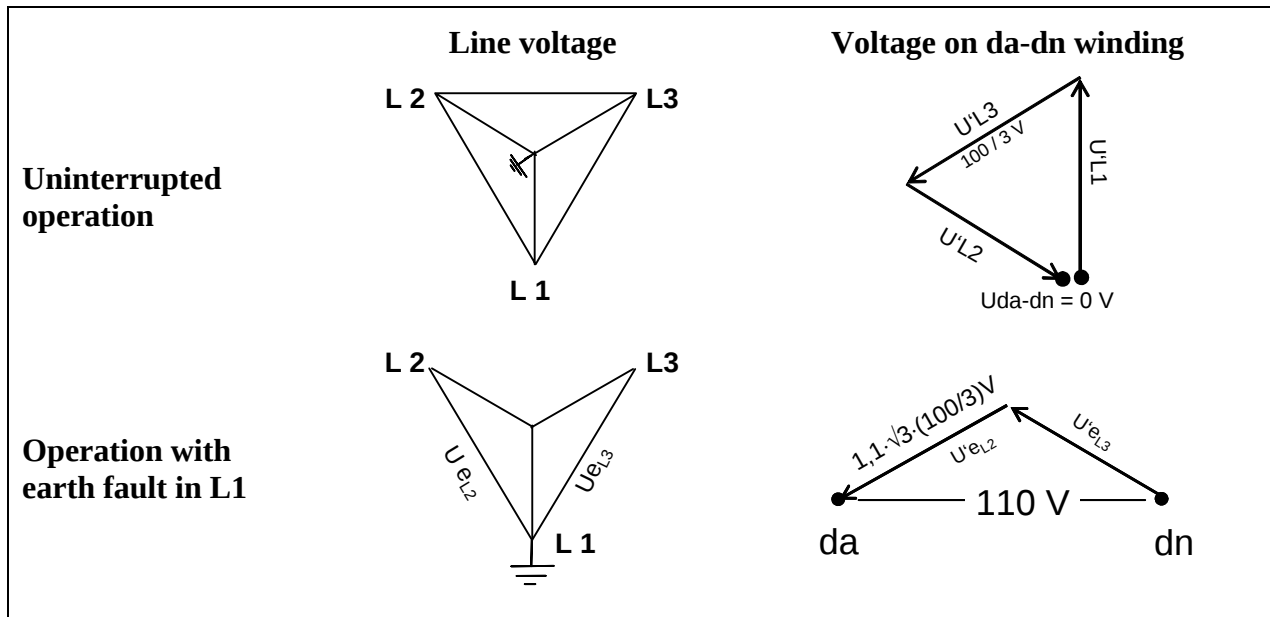
U	Voltage	D	Damping
S	Apparent power	r	Rated value
P	Active power	s	Secondary
R	Resistance	V	Power loss

I 1.5 Standard, uninterrupted line operation

- Voltage at the output of a single da-dn winding: $U_2 = U_{sr}$ (rated voltage)
 Example: secondary rated voltage $U_{2r} = \frac{100}{3} V$
- Voltage on the open triangle: $U_{\Delta} = 0 V$ (due to symmetrical, uninterrupted operation)

²⁴ The term „rated long duration current“ is still in frequent use, although current standards use the term „rated thermal limiting output“. Both terms are synonymous, however.

²⁵ Two 25 ohm resistors (parallel)



I 1.6 Operation with earth fault

- Values at the output of a single da-dn winding:

[F1] Voltage $U_{se} = 1.1 \cdot \sqrt{3} \cdot U_{sr} = 1.9 \cdot U_{sr}$

[F2] Current $I_{se} = 1.9 \cdot I_{sr} = 1.9 \cdot \frac{S_{sr}}{U_{sr}}$

[F3] Apparent power $S_{se} = U_{se} \cdot I_{se} = 1.9^2 \cdot S_{sr}$

Factors:

1.1 Voltage increase at fault location

$\sqrt{3}$ Earth fault factor

1.9 Rated voltage factor²⁶
 $1.9 = 1.1 \times \sqrt{3}$

F2: with a constant load resistance, the 1.9 x voltage on the winding results in 1.9 x current if a earth fault occurs.

The rated thermal limiting output S_{2r} refers to uninterrupted operation. It is a rated value, although it does not reflect the actual load-carrying capacity of the winding. In practice, the earth fault winding can handle 3.6 x the rated thermal limiting output over a period of 8 hours.

- Values at the terminals for the da-dn windings connected to the "open" triangle:

[F4] Voltage $U_{\Delta} = \sqrt{3} \cdot (1.1 \cdot \sqrt{3}) \cdot U_{sr} = 3.3 \cdot U_{sr}$ Typical value for U_{sr} : $\frac{100}{3} \text{ V}$

[F5] Apparent power $S_{\Delta} = 3.3 \cdot U_{sr} \cdot 1.9 \cdot \frac{S_{sr}}{U_{sr}} = 6.3 \cdot S_{sr}$

[F6] Current $I_{\Delta} = I_{se}$ Maximum permissible value

²⁶ Rated voltage factor: multiple of the primary rated voltage for which a voltage transformer must fulfill the thermal requirements for a defined stress time interval.

I 1.7 Damping resistance

The resistance value can be calculated using [F4] and [F5]:

$$[F7] \quad \text{Resistance} \quad R_D \geq \frac{U_{\Delta}^2}{S_{\Delta}} = \sqrt{3} \cdot \frac{U_{sr}^2}{S_{sr}}$$

$$[F8] \quad \text{Power loss} \quad P_V \geq \frac{(3.3 \cdot U_{sr})^2}{R_D}$$

R_D and P_V are the minimum permissible values

I 1.8 Sample calculations

Specifications on the rating plate of a voltage transformer:

- Rated secondary voltage of the earth fault winding U_{sr}	100 V / 3
- Rated thermal limiting output S_{sr} (same as the former "rated long-time current" specification)	100 VA 6 A)
=> Damping resistance R_D (acc. to F7)	$\geq 19.2 \, \Omega$
Load-carrying capacity P_V (acc. to F8)	$\geq 630 \, \text{W} \mid_{19.2 \, \Omega}$

A 25 ohm resistor is used as standard; load-carrying capacity 500 W or higher.

Sources for Appendix I 1

- Documents from Peter Dorsch and Dr. Kerstin Kunde
- IEC 60044-2 / VDE 0414-2

I 2 RC-circuitry for protection of MV equipment

Some switching duties require RC circuitry for surge protection in order to protect the windings of susceptible equipment against the effects of high-frequency switching transients. There is the possibility that switching operations may initiate internal resonance oscillations inside the equipment which can lead to dielectric overstress within the windings. Those internal overvoltages cannot be suppressed by surge arresters at the terminals. Hence resonant oscillations must be avoided from the first. RC elements are applied to:

- compensating coils (shunt reactors)
- furnace transformers
- equipment with insulation level below the standardised ratings
- old equipment with unknown insulation capability
- equipment which is frequently subjected to dielectric stress in normal service (in this case the RC elements prevent against early ageing)

It is always necessary to match the RC circuitry to the individual system configuration. The following exemplification may be used in order to estimate budget prices; by no means it can be used as a general design.

RC-circuits form a bypass for high frequency currents (and voltages) in that the transients are diverted to earth instead of reaching the equipment to be protected. The RC installation at the load is most economical since the capacitance of the surge capacitor then is smallest. Installation with small line-earth capacitance on the busbar side require an additional protection circuit at the busbar.

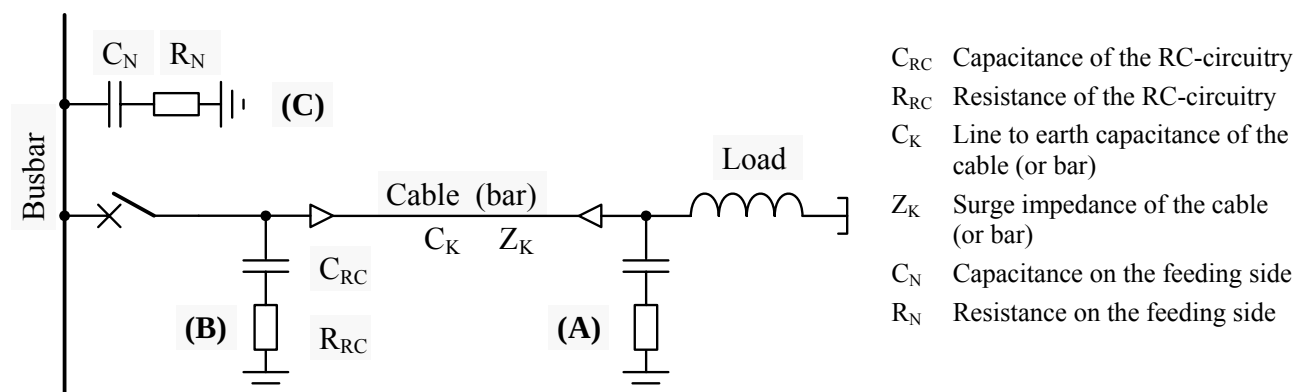


Figure I-1: RC circuitry for susceptible equipment

RC-circuits at the load (A)

With longer cables (> 50 m), the RC-circuits are installed directly at the load terminals. Typical ratings are $C_{RC} \geq 3 \cdot C_K$ and $R_{RC} = 1 \dots 2 \cdot Z_K$.

RC-circuits cannot prevent switching transients, but the RC-circuits damp the travelling wave and prevent the refraction ("reflection") at the load-side cable terminals, where the RC-circuits divert the HF transients to earth (bypass).

RC-circuits at the load side of the circuit-breaker (B)

If C_K is small (< 50 m cable), no distinct travelling wave effects occur – depending on the effective inductance (length of busbar, c.t. cores) between supply and load side. The RC-circuits are installed close to the circuit-breaker. Typical ratings are $C_{RC} \geq 6 \cdot C_K$ and $R_{RC} > Z_K$.

The RC-circuitry achieves an aperiodic damping of the HF equalising currents in case of a re-ignition during switching off. Thus only one re-ignition may occur; in this manner voltage escalation by repetitive re-ignitions is prevented.

RC-circuits at the busbar side (C)

Only with small phase-to-earth capacitance, i.e. if few cables or cables of short length are connected to the busbar, the RC-circuits increase the phase-earth capacitance (replication of additional cables). The capacitor forms a bypass for HF transients to earth, and travelling waves become spacially isolated at the system side. The resistor R replicates the surge impedance of a cable and damps the transient currents.

I 3 Installation of overvoltage protection devices

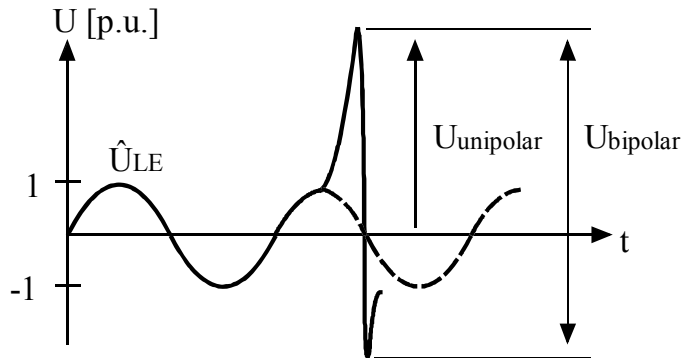
Surge arresters and RC-circuits shall protect equipment against transient, steep fronted overvoltages (high rate-of-rise). In order to ensure full effectiveness of the protection devices, the inductance of the connections shall be minimal. This means the feeding and earthing cables must be as short as possible.

With RC circuits is most important for the effectiveness to use low-inductance RC elements, cables and earthing conductors. This is best achieved by using bifilar windings for the capacitors and Schniewindt strips as resistors. Preferably capacitors and resistors should be installed in a common housing. RC elements must be insulated to the upper standardised value of the rated lightning impulse withstand voltage which corresponds to the relevant maximum operating and rated voltage.

Low-inductance connections should have a time constant not higher than $L / R \leq 50$ ns; where L is the total inductance of the RC element and the earth conductor, R is the resistance of the RC element. Low-inductance earthing is in most cases achieved by providing several earthing conductors leading to various points of the plant earth (e.g. to the earthing point of the cable shields). Copper conductors satisfying the earthing specifications for HV installations > 1 kV [22] must be used for earthing. The minimum cross-section is $A = 16$ mm². The individual conductors should be as short as possible.

I 4 Overvoltage factors (Definition)

Overvoltages usually are indicated as a factor which represents as a multiple of the operating voltage line-to-earth as reference value.



Unipolar overvoltage factor k

$$k = \frac{U_{unipolar}}{\frac{\sqrt{2}}{\sqrt{3}} \cdot U_m}$$

Bipolar overvoltage factor k'

$$k' = \frac{U_{bipolar}}{\frac{\sqrt{2}}{\sqrt{3}} \cdot U_m}$$

U_m Maximum operating (network) voltage (line-line)

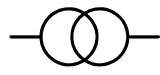
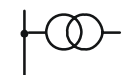
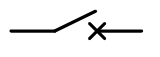
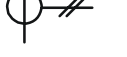
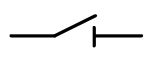
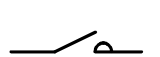
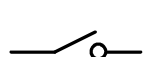
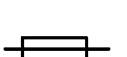
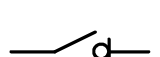
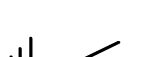
U_{LE} Operating (network) voltage line-earth $U_m/\sqrt{3}$

I 5 Abbreviations, Symbols and Formula Variables

Symbol	Variable	Device / Network*	Unit
U	Voltage, general		kV
U _r	Rated voltage	Device	kV
U _N	Network voltage	Network	kV
U _m	Maximum voltage permissible for a device	Device	kV
U _L	Rated (reseal) voltage (gapped arrester)		kV
U _c	Continuous operating voltage (MO arrester)		kV
U _r	Rated voltage (MO arrester)		kV
U _C	Capacitor voltage		kV
U _p	Basic Insulation Level	Device	kV
U _d	Power-frequency withstand voltage		kV
I	Current, general		kA
I _r	Rated current		A
I _{st}	Starting current	Device	A
I _{th}	Short time withstand current	Device	kA
I _k	Sustained symmetrical short circuit current	Network	kA
I'' _k	Initial peak symmetrical short circuit current	Network	kA
I _p	Peak current peak value (first half wave)	Network	kA
I _{ma}	Rated short circuit making current (peak value)	Device	kA
I _e / I _s	Closing current (peak value)	Device	kA
I ₁	Rated mainly active load-breaking current	Gerät	A
I _{2a} , I _{2b}	Rated closed-loop breaking current	Gerät	A
I ₃	Rated no-load transformer breaking current	Gerät	A
I _{4a}	Rated cable-charging breaking current	Gerät	A
I _{4b}	Rated line-charging breaking current	Gerät	A
I _{6a}	Rated earth fault breaking current	Gerät	A
I _{transfer}	Transfer current	Netz	A
I _{r-transfer}	Rated transfer current	Gerät	A
I _{min}	Minimum operating (clearance) current of HRC fuse	Gerät	A
I _D	Let through (cut off) current of HRC fuse		kA
S	Apparent power, general		kVA; MVA
Q _C	Capacitor reactive power		kVar; MVar
S _{Mot}	Motor apparent power		kVA; MVA
τ	Time constant, general		ms
t _L	Arcing time (HRC fuse)		s
t _m	Melting (pre-arcing) time (HRC fuse)		s
t _{th}	Short circuit duration	Device	s
T ₀	Opening time	Device	s

* *Device / Network* indicates whether the symbol or variable relates to network or device characteristics. Since the various standards sometimes use different symbols, repetition is also sometimes unavoidable.

I 6 Diagram Symbols

	Transformer		Current transducer (c.t.)
	Circuit-breaker		Voltage transducer (v.t.)
	Disconnecter (isolator)		Surge arrester / limiter
	Contactor		Spark gap
	Switch		Fuse-link
	Switch-disconnector		Capacitor
	Earthing switch		Resistor
	Make proof earthing switch		Reactance
			Compensation coil (shunt reactor), short-circuit limiting reactor

J RELEVANT STANDARDS AND REGULATIONS

The following list names the most important standards or specifications; it is structured according to

- Statutory regulations for medium-voltage equipment
- Generic standards for switching devices and switchgear
- Product standards for switching devices
- Product standards for switchgear and accessories

Generally, the IEC standards concur with the relevant national standards. A standard uses the symbols customary in the respective technical field. It is consequently possible for the same physical variable to be differently designated.

J 1 Statutory regulations for medium-voltage equipment

International	Germany	Title (English / German)
	BGV A3	Unfallverhütungsvorschrift – Elektrische Anlagen und Betriebsmittel
	BGV B11	Unfallverhütungsvorschrift – Elektromagnetische Felder
	BGV A8	Unfallverhütungsvorschrift – Sicherheits- und Gesundheitsschutzkennzeichnung am Arbeitsplatz
1999/519/EC ²⁷	26. BImSchV	Council recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) EMVU-Verordnung – 26. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über elektromagnetische Felder - 26. BImSchV) Vom 16. Dezember 1996
2004/108/EC ²⁸	EMVG	Directive 2004/108/EC of the European Parliament and of the Council of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility ... Gesetz über die elektromagnetische Verträglichkeit von Betriebsmitteln
	BGI 766	Instandsetzungsarbeiten an elektrischen Anlagen auf Brandstellen
	BGI 559	Handlungsanleitung zur Anpassung von Hochspannungsanlagen - DIN VDE 0101 (05/89) -

Note on BGV²⁹: Accident prevention regulations issued by the statutory industrial accident insurance institutions (Berufsgenossenschaften: BGs) are legally binding, according to the 7th code of social law, §15.

Note on BGI³⁰: BG information describes typical solutions for applying BG regulations. Unlike UVV rulings, BG information does not have to be obligatorily applied.

²⁷ An EU Council Recommendation need not obligatorily be implemented in applicable law in EU member states. In Germany this has taken place in the form of 26. BImSchV.

²⁸ An EU Directive must be implemented in national law in EU member states. However, only respective national legislation is legally binding.

²⁹ BGV = BG regulation

³⁰ BGI = BG information

J 2 Generic standards for switching devices and switchgear

=> Listed according to the number of the international standard

International standard	German standard	Title (English / German)
EN 50110	VDE 0105-100 ³¹	Operation of electrical installations Betrieb von elektrischen Anlagen
IEC 60071	VDE 0111	Insulation coordination Isolationskoordination
IEC 60376	VDE 0373-1	Specification and acceptance of new sulphur hexafluoride Bestimmung für neues Schwefelhexafluorid SF ₆
IEC 60480	VDE 0373-2	Guide to the checking of SF ₆ taken from electrical equipment Prüfung von aus elektrischen Geräten entnommenem SF ₆
IEC 60529	VDE 0470-1	Degrees of protection provided by enclosures (IP Code) Schutzarten durch Gehäuse (IP-Code)
IEC 62271-1	VDE 0671-1	High-voltage switchgear and controlgear – Common specifications Gemeinsame Bestimmungen für Hochspannungs-Schaltgeräte
IEC 60865	VDE 0103	Short-circuit currents - Calculation of effects Kurzschlußströme – Berechnung der Wirkung
IEC 60909	VDE 0102	Short-circuit current calculation in three-phase a.c. systems Kurzschlußströme in Drehstromnetzen
IEC 62271-303	VDE 0671-303	High-voltage switchgear and controlgear - Use and handling of sulphur hexafluoride (SF ₆) Hochspannungs-Schaltgeräte und -Schaltanlagen - Teil 303: Gebrauch von und Umgang mit Schwefelhexafluorid (SF ₆)
IEC 61936-1	VDE 0101-1	Power installations exceeding 1 kV ac Starkstromanlagen mit Nennwechselspannungen über 1 kV
EN 50522	VDE 0101-2	Earthing of power installations exceeding 1 kV Erdung von Starkstromanlagen mit Nennwechselspannungen > 1 kV

³¹ Part 1 of EN 50110 contains minimum requirements applicable in all CENELEC countries. The respective currently valid safety requirements for the individual countries are described in national addenda. In Germany, the details of Parts 1 and 100 (VDE 0105-1 and -100) are significant.

J 3 Product standards for switching devices

=> Listed according to the number of the international standard

International standard	German standard	Title (English / German)
IEC 60044	VDE 0414	Instrument transformers Meßwandler
IEC 60099	VDE 0675	Surge arresters Überspannungsableiter
IEC 60282	VDE 0670-4	High-voltage fuses - Current-limiting fuses Hochspannungssicherungen – Strombegrenzende Sicherungen
IEC 60644	VDE 0670-401	Specification for high-voltage fuse-links for motor circuit applications Anforderungen an Hochspannungs-Sicherungseinsätze für Motorstromkreise
IEC 60787	VDE 0670-402	Application guide for the selection of fuse-links of high-voltage fuses for transformer circuit applications Wechselstromschaltgeräte für Spannungen über 1 kV – Auswahl von strombegrenzenden Sicherungseinsätzen für Transformatorstromkreise
IEC 62271-100	VDE 0671-100	High-voltage switchgear and controlgear - High-voltage alternating-current circuit-breakers Hochspannungs-Wechselstrom-Leistungsschalter
IEC 62271-102	VDE 0671-102	High-voltage switchgear and controlgear - High-voltage alternating current disconnectors and earthing switches Wechselstromtrennschalter und Erdungsschalter
IEC 62271-103	VDE 0671-103	High-voltage switches - Part 1: Switches for rated voltages above 1 kV and less than 52 kV Hochspannungs-Lastschalter – Teil 1: Hochspannungs-Lastschalter für Bemessungsspannungen über 1 kV und unter 52 kV
IEC 62271-105	VDE 0671-105	High-voltage alternating current switch-fuse combinations Hochspannungs-Lastschalter-Sicherungs-Kombinationen
IEC 62271-106	VDE 0671-106	High-voltage alternating current contactors and contactor-based motor-starters Hochspannungs-Wechselstrom-Schütze und -Motorstarter mit Schützen
IEC 62271-110	VDE 0671-110	High-voltage alternating current circuit-breakers - Inductive load switching Hochspannungs-Schaltgeräte und -Schaltanlagen – Schalten induktiver Lasten

J 4 Product standards for switchgear and accessories

=> Listed according to the number of the international standard

International standard	German standard	Title (English / German)
EN 50181	DIN EN 50181	Plug-in type bushings above 1 kV up to 36 kV and from 250 A to 1,25 kA for equipment other than filled transformers Steckbare Durchführungen über 1 kV bis 36 kV und von 250 A bis 1,25 kA für Anlagen anders als flüssigkeitsgefüllte Transformatoren
EN 50187	VDE 0670-811	Gas-filled compartments for a.c. switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV Gasgefüllte Schotträume für Wechselstrom-Schaltgeräte und –Schaltanlagen mit Bemessungsspannungen > 1 kV bis einschließlich 52 kV
IEC 61219	VDE 0683-200	Live working – Earthing or earthing and short-circuiting equipment using lances as a short-circuiting device – Lance earthing Arbeiten unter Spannung – Erdungs- oder Erdungs- und Kurzschließvorrichtung mit Stäben als kurzschließendes Gerät – Staberdung
IEC 61230	VDE 0683-100	Live working – Portable equipment for earthing or earthing and short-circuiting Arbeiten unter Spannung – Ortsveränderliche Geräte zum Erden oder Erden und Kurzschließen
IEC 61243-1	VDE 0682-411	Life working – Voltage detectors Capacitive type to be used for voltages exceeding 1 kV a.c Arbeiten unter Spannung – Spannungsprüfer Kapazitive Ausführung für Wechselspannungen über 1 kV
IEC 61243-5	VDE 0682-415	Live working - Voltage detectors Voltage detecting systems (VDS) Arbeiten unter Spannung – Spannungsprüfer Spannungsprüfsysteme (VDS)
IEC 62271-200	VDE 0671-200	A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV Metallgekapselte Wechselstrom-Schaltanlagen für Bemessungsspannungen über 1 kV bis einschließlich 52 kV
IEC 62271-201	VDE 0671-201	A.C. insulation-enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 38 kV Isolierstoffgekapselte Wechselstrom-Schaltanlagen für Bemessungsspannungen über 1 kV bis einschließlich 52 kV
IEC 62271-202	VDE 0671-202	High-voltage/low-voltage prefabricated substations Fabrikfertige Stationen für Hochspannung/Niederspannung

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