9 High-current switchgear

9.1 Generator circuit-breaker

Generator circuit-breakers are switchgear in the high-current connection between generator and generator transformer. The electrical requirements on generator circuit-breakers are higher in many respects than for breakers in the network. These requirements are specified in the (unique in the world) "IEEE" C37.013 standard in detail (ANSI). The following list summarizes the most important areas of application and the advantages.

Functions	Advantages
Isolate generator from station services infeed	Station services fed via main transformer. No longer requires the formerly standard starting transformers and the associated switchgear components and changeover facilities (see Fig. 9-1a).
Synchronization on the low voltage side of the main transformer	Eliminates voltage transformers on the h.v. side of the main transformer. Possibility of connecting two generators via two separate transformers or one three-winding transformer to one overhead cable simplifies power-plant design (see Fig. 9-1).
Disconnection of a fault in the main transformer or in the station service transformer.	Effects of faults much more restricted than with high-speed de-excitation because it trips in less than 60 ms.
Disconnection of a fault in the generator	Station services remain on the network without interruption, resulting in higher availability. Safe handling of load imbalances.
Disconnection of faults on the overhead lines from the power plant to the next transformer station or substation.	HV circuit-breaker no longer required in power plant if transformers or switchgear installations are near power plant.
Implementation in nuclear power plants.	Significantly improved security of uninterruptable station services supply.
Implementation in pumped-storage power stations.	Switching between pump and generator operation without problem.
Automation of the power plant.	Only 1 switching operation to synchronize or disconnect the generator, instead of 5-7 switching operations when synchronizing on the HV side, resulting in reduction of the danger of switching faults.

In specific cases there can be economic, operational and technical reasons for implementing such breakers.

Fig. 9-1 shows examples of unit connections with generator circuit-breakers. The various types show how these breakers ensure maximum possible availability of station services in the event of a fault for large units with several main and station transformers.

Conventional power plants and nuclear power plants with high unit capacity and special requirements for safety and availability are preferred areas of application for generator circuit-breakers.

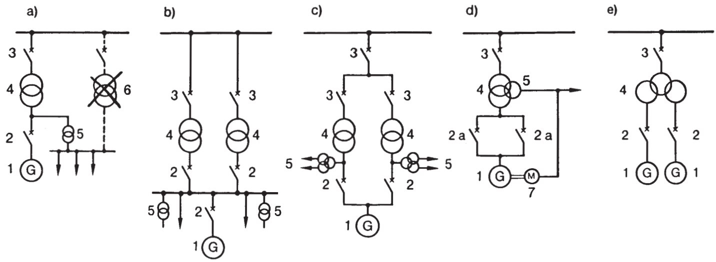


Fig. 9-1

Unit connections of power plants
a) Basic circuit diagram, b) and c) Large generators with part-load transformers, d) Pumped storage block, e) Hydro power plant;
1 Generator, 2 Generator breaker, 2a 5-pole generator breaker for switchover between motor and generator operation, 3 High-voltage circuit-breaker 4 Main transformer, 5 Station services transformer, 6 Starting transformer, 7 Starting motor

The use of generator circuit-breakers must be considered in the early stages of designing a power plant. The following requirements are important when designing the structure:

a) Space required for breaker
Breaker dimensions; phase spacing (note minimum clearances); transport; access and space for maintenance. Expansion of air-pressure wave (DR-breaker type only).

b) Space required for auxiliaries
Cooling unit (5-10 m^2, at higher rated currents)
Control cubicle (2.5-5 m^2)
Air-compressor plant (10-30 m^2)(DR-breaker type only).
The auxiliaries must be in the immediate vicinity of the generator circuit-breaker.

c) Structural requirements
Stable foundation (attend to reaction forces)
Maintenance pit (under DR-breaker only)
Lifting gear for installation and maintenance.

Today, generator circuit-breakers are not generally offered as single unit but as a functional unit, which contains the current and voltage transformers required for generator and unit protection inside single-phase enclosures, with disconnectors, shorting links and earthing switches, and also start-up disconnectors, surge arresters and protection capacitors.

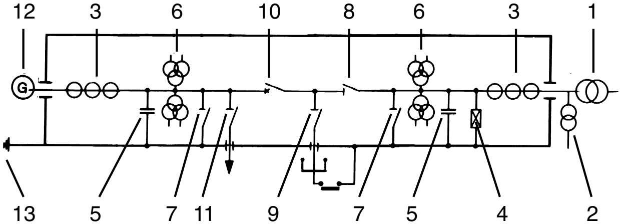


Fig. 9-2

Single-line diagram of a generator circuit-breaker system
1 Main transformer, 2 Station services transformer, 3 Current transformer, 4 Surge arrester, 5 Protection capacitor, 6 Voltage transformer with 1 or 2 secondary windings, 7 Earthing switch, motor-actuated, 8 Series disconnector, motor-actuated, 9 Short-circuit connection with clip for earth connection, 10 Circuit-breaker, 11 Starting circuit-switch, motor-actuated, 12 Generator, 13 Earth

9.1.1 Selection criteria for generator circuit-breakers

Apart from the rated voltage, the most important criteria are the rated current and the rated breaking current of the power unit. ABB supplies several types of generator circuit-breaker, which can be used depending on the unit capacity. They include the SF_6 breakers of the HG and HE range, the DR type air-blast breaker and the type VD4G vacuum breaker.

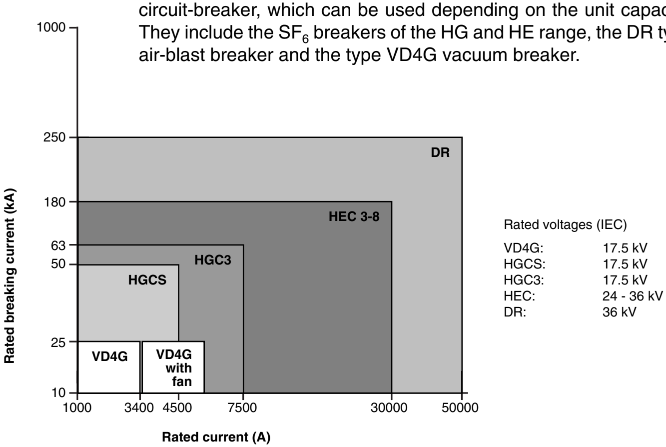


Fig. 9-3 Selection table for generator circuit-breakers

9.1.2 Generator circuit-breaker type ranges HG... and HE...(SF_6 gas breaker)

These breaker systems are designed for generator capacities of 100-1000 MVA and – depending on the type – can be used for the voltage levels 17.5-36 kV.
They are suitable for both indoor and outdoor installation.

The power-interruptor chambers of these breakers are filled with SF_6 gas as the quenching and insulation material. The arc is interrupted with the proven ABB self-blasting principle: The arc that is generated when the contacts open heats the SF_6 gas, increases the pressure and generates a stronger gas flow, which blasts the arc and extinguishes it.
The rotating arc reduces the contact erosion.

The contacts, which carry current continuously, are placed separately from the interrupting contacts, guaranteeing optimum current transfer at all times.

The voltage-carrying components are air-insulated against earth.
The 3-pole design on a common base frame makes installation very simple. Special foundations are not required.

The power chambers are actuated by the proven ABB type AHMA spring mechanism. The energy storage capacity is rated for 2 switching cycles ON-OFF. Disconnector, earthing switch and start-up switch have electric motor-operated mechanisms. They are controlled in accordance with the current requirements in power plant design with conventional relay technology.

The modular design makes it possible to expand the generator circuit-breakers to very compact functional systems with disconnectors, earth switches, transformers etc. (see Figs. 9-2, 9-4). Production and testing of the complete system in factoy greatly reduces the time and expense of assembly and testing at the construction site.

The service intervals, in compliance with the demands of modern power plant design, have been extended to 15 years operational life or 10,000 switching cycles (mechanical). The single-line breaker enclosure is welded to the busduct enclosure. The live parts are bolted to the high-current busduct conductor by way of flexible copper extension straps.

Table 9-1

Technical data for generator circuit-breakers type
HG ... and HE ... (SF_6 gas breaker)

Type designation	kV	HGCS	HGC3	HEC3	HEC4	HEC5	HEC6	HEC7	HEC8	HGI2	HGI3	HEK3
Rated voltage as per IEEE/ANSI	kV	15.8	15.8	27.5	27.5	27.5	27.5	27.5	27.5	15.8	15.8	24
Rated voltage as per IEC	kV	17.5	17.5	24	24	24	24	36	36	17.5	17.5	
Rated short-time power frequency withstand voltage 50/60 Hz 1 min, against earth	kV	50	50	60	60	60	60	80	80	50	50	80
over isolating distance [1]	kV	55	55	70	70	70	70	88	88	–	–	–
Rated lightning impulse withstand voltage 1.2/50 µs against earth	kV	110	110	125	125	125	125	150	150	110	110	150
over isolating distance [1]	kV	121	121	145	145	145	145	165	165	–	–	–
Rated current,[2) 3)] natural cooling, 50 Hz	A	4,500	7, 500	12,000	13,000	12,000	13,000	24,000	–	6,300	8,000	11,000
Rated current,[2) 3)] natural cooling, 60 Hz	A	4, 500	7,300	11,500	12,500	11,500	12,500	24,000	–	–	–	11,000
Rated current,[3)] with forced ventilation, at 50 +60 Hz	A	–	–	–	24,000	–	24,000	–	28,000	–	–	16,500
Breaking current	kA	50	63	100	100	120	120	160	160	50	63	100
Making current	kA	138	173	300	300	360	360	440	440	138	170	300

1) Only valid for models with disconnector
2) Rated current information corresponding to ambient temperature: max. 40 °C
3) Temperature of the high-current bus ducts at the breaker terminals: conductor max. 90 °C; encapsulation max. 65 °C

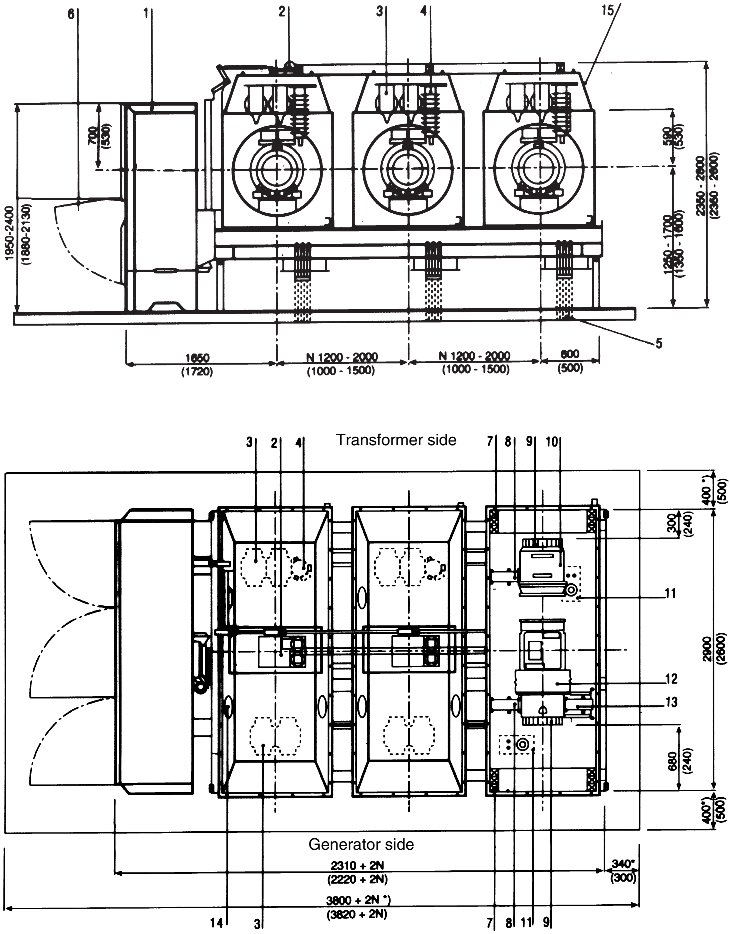


Fig. 9-4

Generator circuit-breaker systems of the HGC (dimensions in parentheses) and HEC range – outline drawing
1 Control cubicle, 2 Short-circuit connection with disconnector, 3 Voltage transformer, 4 Surge arrester, 5 Cable feed to start-up feed, 6 Opening shutter panel to mechanism compartment, 7 Toroidal-core current transformer, 8 Earthing switch, 9 High-current terminal, 10 Series disconnector, 11 Capacitor, 12 SF_6 circuit-breaker, 13 Disconnector to start-up feed, 14 Inspection glass for visual position check, 15 Removable covers for breaker encapsulation, N Variable phase clearance

The HGCS generator circuit-breaker system has a different design from the other systems of this range. It has a switchbay compartmented by phases with all apparatus permanently installed. The circuit-breakers can be slid out.

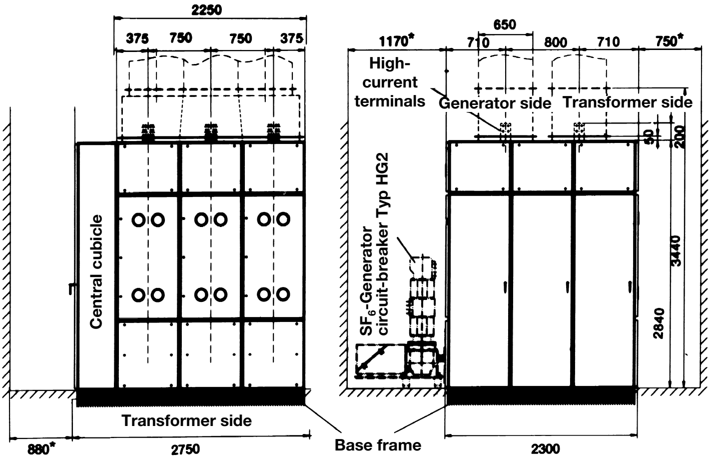


Fig. 9-5 HGCS generator circuit-breaker system/outline diagram
**= Minimum clearances*

The generator circuit-breaker of the **HEK 3** type is particularly well suited for integration into encapsulated busbar systems when retrofitting existing installations. The generator circuit-breakers of the **HGI 2** and **HGI 3** types are available when retrofitting open indoor busbar systems.

9.1.3 Generator circuit-breaker type DR (air-blast breaker)

This breaker type is designed for very large unit capacities up to 2000 MVA and above. The type DR generator circuit-breaker is single-line metal-clad and can be directly integrated into the high-current bus ducts. Both the breaker encapsulation and the breaker live parts are connected to the high-current bus ducts with flexible copper expansion straps.

The cooling components are 100% redundant, so in the event of faults, they can be switched immediately to the standby unit and the power plant can continue operating.

Table 9-2

Technical data for generator circuit-breaker type DR
(see Fig. 9-6)

Type designation		DR 36 v 1750 D
Rated voltage	kV	36
Rated short-time power-frequency withstand voltage 50 Hz, 1 min. against earth	kV	75
Over open isolating distance	kV	100
Rated lightning impulse withstand voltage 1.2/50 μs against earth	kV	170
Over open isolating distance	kV	195
Rated frequency	Hz	50/60
Rated current		
– self-cooling	A	up to 11 000
– forced cooling	A	up to 50 000
Breaking current	kA	250
Making current (peak value)	kA	400-750

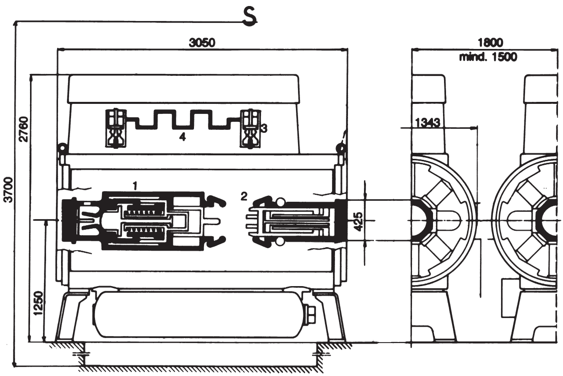


Fig. 9-6
Generator circuit-breaker type DR/outline diagram

1 Circuit-breaker, 2 Linear-travel disconnector, 3 Auxiliary chamber, 4 Low-resistance resistivity

9.1.4 Generator circuit-breaker type VD 4 G (vacuum breaker)

Vacuum circuit-breakers from standard ranges can also be used as generator circuit-breakers with smaller generators (up to 100 MW). These breakers allow very compact solutions. They are used as a fixed-mounted single unit or as a draw-out device within a functional system with metallic compartment walls, earthing switch and disconnector function (segregation) (Fig. 9-5). Current and voltage transformers and surge arresters can also be integrated.

The technical data listed in the following table are based on testing in accordance with ANSI standard IEEE C 37.013-1997.

Table 9-3

Technical data generator circuit-breaker type VD4 G

Type designation		VD4G	
Rated voltage (IEC)		kV	17.5
Rated voltage (ANSI/IEEE)		kV	15.8
Rated short-time power-frequency withstand voltage		kV	50
Rated lightning impulse withstand voltage		kV	(95) 110
Rated current (at 40°C max.)	without fan	A	3400
	with fan	A	5000
Rated breaking current	(system source, symm.)	kA	40
	(generator source)	kA	25/18.5
Rated making current		kA	110

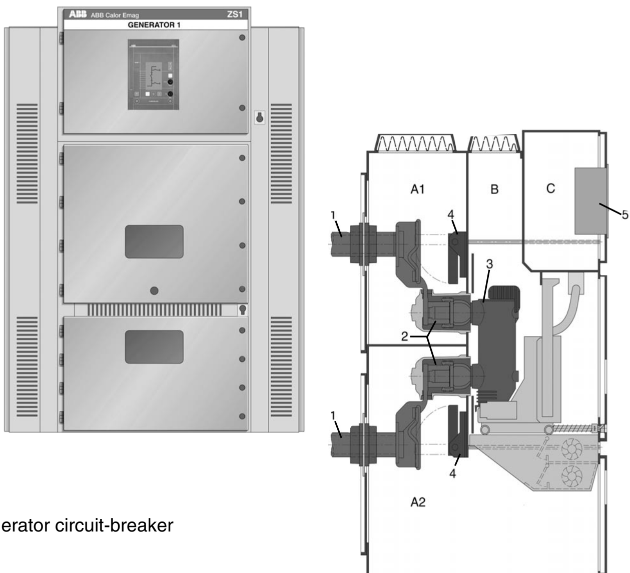


Fig. 9-7 Generator circuit-breaker VD4G

A1 Upper terminal compartment (e.g. transformer)
A2 Lower terminal compartment (e.g. generator)
B Circuit-breaker compartment
C Low-voltage compartment

1 Terminal lead
2 Isolating contacts
3 Circuit-breaker
4 Earthing switch
5 Bay control and protection unit REF 542

9.2 High-current bus ducts (generator bus ducts)

9.2.1 General requirements

The high-current bus ducts with all their branches are a component of the electrical installation in the power plant.

The high-current bus duct and switchgear generally serve the following functions (Fig. 9-8).

– Connection between generator and main transformer(s) including generator neutral.
– Branch connections to station services and excitation transformers as well as voltage transformer cubicles.
– Design and connection of measuring, signalling and protection devices for current, voltage and other operating data.
– Installation and connection of high-current switching devices such as generator circuit-breakers with high-current disconnectors and earth disconnectors.
– Additional facilities, e.g. for protection and working earthing, pressure-retaining systems or forced cooling.

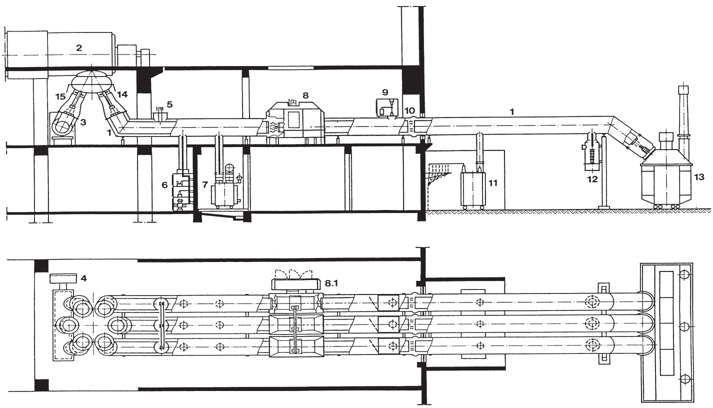


Fig. 9-8 High-current switchgear installation

1 High-current bus duct, 2 Generator, 3 Generator neutral point, 4 Neutral earthing cubicle, 5 Short-circuiting facility (temporary), 6 Voltage transformer cubicle, 7 Excitation transformer, 8 Generator circuit-breaker, HEC type with 8.1 control cubicle, 9 Voltage and capacitor cubicle, 10 Expansion joint, 11 Station auxiliary transformer, Main transformer, 14 Current transformer / feeder side, 15 Current transformer/neutral side

Note: The voltage transformers (6 and 9), the capacitors (9), the earth switch, the short-circuiting facility (5) and the surge arrester (12) can also be installed in the generator terminals.
The configuration of the current transformers (14) must be specified: a) at the generator feed, b) in the busbar run or c) in the generator circuit-breaker, to enable the short-circuiting facility to be located at the proper position.
Consultation with the supplier of the generator circuit-breaker is required.

Technical requirements

The design of the largest generators with nominal voltages of up to 27 kV and power up to 1600 MVA yields operating currents of up to 36 kA. For the high-current bus duct, this means that the generated heat in conductors and enclosure and the significant magnetic field effects in the installation and its environment must be controlled.

With the stated unit capacities and the high network outputs, short-circuit currents of up to approximately 750 kA peak value may occur in the high-current bus ducts and high-current switchgear. In the branches, peak short-circuit currents of more than 1000 kA may occur. And of course the safety and availability of a high-current bus duct must correspond with the high standard of the other power-plant components.

The high-current bus ducts must therefore comply with specified requirements:
– Adherence to preset temperature limits,
– Adequate short-circuit current carrying capability, (thermal and mechanical strength with short-circuits),
– Adequate magnetic shielding,
– Safe insulation, i.e. protection against overvoltages, moisture and pollution.

9.2.2 Types, features, system selection

Types

In smaller power plants (hydropower, CHP stations) with a load current of up to approximately 2.5 kA (5 kA), the bus ducts can still have the "classic" busbar design. The simplest designs are flat and U-shaped busbars of Al or Cu (sometimes also tubular conductors, in Al only). Exposed busbars are used with small generator ratings only because they require locked electrical equipment rooms. In contrast, laying the busbars in a common rectangular aluminium duct provides protection against contact and pollution. Aluminium partitions between the phases provide additional protection. This prevents direct short-circuits between the phases. In the event of short-circuit currents flowing, the compartment walls reduce the short-circuit forces (shielding) on insulators and busbars.

Single-phase systems can be supplied in single-insulator or triple-insulator designs.

The ABB standard is the single-phase system with the following variations:
– up to 5.5 kA in single-insulator design (type HS 5500)
– up to 40 kA in triple-insulator design (type HA)

Features

ABB high-current bus ducts in single-phase enclosure.

The single-phase enclosure is the most commonly supplied and the most technically advanced model. The conductors and the concentrically arranged enclosure around the conductor consist of aluminium tubes and are insulated from each other by an air gap and resin insulators (Fig. 9-9)

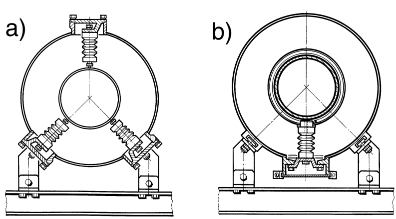


Fig. 9-9
ABB high-current bus duct

a) Single-phase design with three insulators

b) Single-phase design with one insulator

An important technical feature is the single-phase enclosure short-circuited over the three phases at both ends. This enables the enclosures to form a transformer secondary circuit to the conductors. The current flowing in the enclosure – opposite to the conductor current – reaches approximately 95% of the conductor current depending on the system configuration and the impedance of the short-circuit connection between the enclosures (Fig. 9-10)

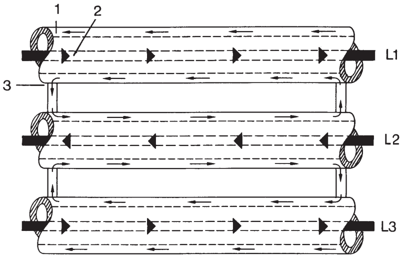


Fig. 9-10

Principle of the high-current bus duct with electrically continuous enclosure,

1 Enclosure current,
2 Conductor current,
3 Enclosure connection

The magnetic field outside the enclosure is almost completely eliminated, thereby eliminating the ambient losses.

This type has the following important features:
- Proof against contact, making locked electrical equipment rooms unnecessary,
- Protection against pollution and moisture, maintenance limited to visual checks,
- No magnetic field outside the enclosure (no induction losses in adjacent conductive material such as screens, railings, concrete reinforcement, pipes etc.),
- Reduced likelihood of ground faults and short-circuits,
- Single-phase high-current switching devices can be incorporated in the bus duct.

The HA type range includes 5 voltage levels – types HA 01 to 05 – for rated current intensities of 3 to 31 kA in self-cooling design (Table 9-5) and currents of up to about 50 kA with forced cooling.

Types HS 5500 for 2 voltage levels, rated currents intensities up to 5.5 kA (Table 9-4) Table 9-6 is applicable for structural planning.

Table 9-4 Single-phase high-current bus ducts types HS 5500

General table for system selection based on current and voltage (natural cooling)

Rated current	Conductor dia. mm	Enclosure dia. mm	Conductor/Enclosure Rated short-time p.-f. withstand voltage 50 (60) Hz 1 min in kV		Conductor/Enclosure Rated lightning impulse withstand voltage 1.2/50 µs in kV	
	Type HS 5500	Type HS 5500	Type HS 5500		Type HS 5500	
kA	01 and 02	01 and 02	01	02	01	02
5.5	150	480	28	(36) 38	75	(95) 95

Notes: For explanations, see Table 9-5
For main dimensions, see Table 9-6

Table 9-5 Single-phase high-current bus ducts type HA

General table for system selection based on current and voltage (natural cooling)

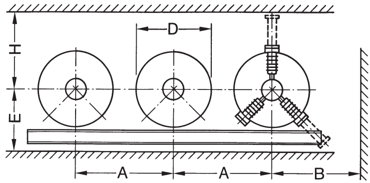
Rated current	Conductor Ø mm	Enclosure Ø mm					Conductor/enclosure Rated short-time p.-f. withstand voltage 50 (60) Hz 1 min in kV					Conductor/enclosure Rated lightning impulse withstand voltage 1.2/50 ms, in kV				
	Type HA	Type HA					Type HA					Type HA				
kA	01 to 05	01	02	03	04	05	01	02	03	04	05	01	02	03	04	05
3	100	460	460	550	640	730										
5	190	550	550	640	730	820										
8	280	640	640	730	820	910										
10	370	730	730	820	910	1 000		(36)	(60)	(80)	(80)		(95)	(110)	(150)	(150)
12	460	820	820	910	1 000	1 090	28	38	50	70	70	75	95	125	145	170
15	550	—	910	1 000	1 090	1 180										
17	640	—	1 000	1 090	1 180	1 270										
20	730	—	1 090	1 180	1 270	1 360										
22	820	—	—	1 270	1 360	1 450										
24	910	—	—	1 360	1 450	1 540										
26	1 000	—	—	1 450	1 540	1 630										
30	1 000	—	—	—	—	1 720										

Note: test voltages as per DIN EN 60071-1 (VDE 0111, Part 1), Table 2; IEC 600 71-1, Table 2;
( ) values in parentheses according to ANSI C 37.23.
A cooling system is required for currents over 31 kA.

Table 9-6

Main dimensions of the high-current bus duct

Dimension A for
HGCS breaker: 650 mm
HEK 3 breaker: 1400 mm
HEC breaker: 1200 to 2000 mm
DR breaker: 1800 mm and over



Current kA	Type HA 01 to 05 D mm	A mm	B mm	E mm	Type HA 01 H mm	02 H mm	03 H mm	04 H mm	05 H mm	05E H mm
0- 3	460	750	700	500	600	600	—	—	—	—
3- 5	550	850	750	550	650	650	650	—	—	—
3- 8	640	950	800	600	650	650	700	750	—	—
3-10	730	1 000	900	650	700	700	750	800	850	—
3-10	820	1 100	950	700	750	750	800	850	900	950
5-12	910	1 200	1 000	750	800	800	850	900	950	1 000
8-15	1 000	1 300	1 050	800	850	850	900	950	1 000	1 050
10-17	1 090	1 400	1 100	850	900	900	950	1 000	1 050	1 100
12-17	1 180	1 500	1 150	900	950	950	1 000	1 050	1 050	1 100
15-20	1 270	1 600	1 200	950	1 000	1 000	1 050	1 100	1 100	1 150
17-22	1 360	1 700	1 250	1 000	1 050	1 050	1 050	1 100	1 150	1 200
20-24	1 450	1 800	1 300	1 050	1 100	1 100	1 100	1 150	1 200	1 250
22-26	1 540	2 000	1 400	1 100	1 100	1 100	1 150	1 200	1 250	1 300
24-26	1 630	2 100	1 450	1 150	1 150	1 150	1 200	1 250	1 300	1 350
26-30	1 720	2 300	1 500	1 200	1 200	1 200	1 250	1 300	1 350	1 400
	Type HS 5500									
to 5.5	480	600	700	500	650	650	—	—	—	—

9.2.3 Design dimensions

Criteria for rating a high-current bus duct:

– service voltage
– load current
– operating temperatures
– insulation level
– short-circuit current carrying capability
– supplementary requirements for installed components and equipment
– climatic conditions

The dielectric strength (rated short-time p.-f. withstand and rated lightning impulse withstand voltage) is assured by standardized type-sized air clearances between conductor and enclosure, and by standard insulators as per VDE, DIN and IEC and the assigned voltage levels with the test voltages as per DIN EN 600 71-1 (VDE 0111 Part 1).

The test voltages for BS and ANSI are covered by the clearances provided (Table 9-4, 9-5).

The standardized type range and the connections at components of the power plant such as generator and transformer are rated for minimum clearances as per VDE and IEC. Verification by test is not required.

Computers are used for optimum and economical design of sizes and wall thicknesses for conductor and enclosure on the basis of a comprehensive heat network; with full or partial ventilation of the bus duct, this program is also used to design the cooling system. The standard rating is based on maximum limit temperatures with an ambient temperature of 40°C:

Enclosure 65 °C – 80 °C; conductor 90 °C – 105 °C.

These values comply with all corresponding VDE, IEC and ANSI standards.

The short-circuit current carrying capability of the bus duct includes adequate provision for peak short-circuit and short-time current. Only one short-circuit current – either from the generator or from the system side – can occur on the main conductor, but in the branches, the sum of the two short-circuit currents must be taken into account. The single-phase enclosure design reduces the likelihood of a short-circuit by many times.

The main duct design for the rated current inevitably has a short-circuit current carrying capability by that far exceeds the rated value dynamically and thermally.

However, the branch ducts are dimensioned primarily for peak and short-time current withstand in compliance with the ABB short-circuit calculations and the requirements of the relevant standards (Section 3 and 4). This automatically ensures compliance with the permissible temperatures at load current.

9.2.4 Structural design

Conductors and enclosure are of Al 99.5% sheet (DIN 40501), which is rolled and submerged-arc welded. Conductors of up to 370 mm diameter are used in the form of extruded aluminium tubes only. To improve thermal dissipation, the conductors are painted on the outside and the enclosures inside and outside.

The prefabricated assemblies have a maximum length of about 12 m. The length depends on the feasibility of transport and the access and installation conditions on the construction site.

Each support of the conductor consists of one or three post insulators – in exceptional cases of four –, which are mounted from outside. Sliding surfaces or fixed pins on all insulators of each support and a spring arrangement on one insulator per support allow relative axial movements between the conductor and the enclosure.

The single-insulator system has been designed to carry currents in the range of 3 to 5.5 kA with the greatest possible safety with the compact design requiring the smallest possible space. The single-insulator system offers all the advantages of single-phase enclosed bus ducts (three-insulator system). In addition, the use of one freely accessible post insulator around the enclosure makes the assembly easier in very small spaces.

Post insulators and holder ring are manufactured from moulded resin and provide support for the conductor and retain the air gap between conductor and enclosure.

The enclosure supports are independent of the support of the conductor and are designed as sliding or fixed-point, fastened directly to the support structure. The tube profile allows distances of enclosure supports of 10-20 m depending on the system.

All connections to the generator, to transformers and switchgear not only ensure secure electrical connection but also allow adjustment, accommodation of thermal movements and access to the junction points. The enclosure structure is particularly important at the generator terminals because of the small spaces between them. In small and medium-sized installations, three-phase terminal and neutral compartments with hatches and viewing windows allow inspection and access to the connections. At higher rated currents, only the single-phase enclosed bus duct construction provides sufficient magnetic field compensation, prevents eddy currents and therefore ensures controlled temperature conditions.

The conductors are connected to the generator, transformers and switchgear terminals with flexible press-welded copper straps fastened with bolts. Spring washers with high spring travel and force guarantee the required contact pressure and prevent unacceptable temperature rise. The contact surfaces are silver-coated if required by the conductor limit temperature (IEC and ANSI).

Current transformers for measurement and protection of the toroidal core type are either installed at the generator terminal bushings or integrated into the bus duct at a suitable point. Detachable connections are then to be integrated into the main conductor for installation and removal. Voltage transformers can be incorporated into the bus duct or installed in separate instrument cubicles connected by branch ducts. The same applies for protection capacitors for limiting capacitively transmitted voltages.

Surge arresters protect bus duct and generator, even in the event of flashover in the transformer, but are then usually overstressed. The use of housings with pressure relief will ensure the safety of personnel and the installation.

9.2.5 Earthing system

The design of earthing systems for high-current bus ducts is based on VDE 0141 and more recently VDE 0101, which also comply with the other national and international standards (such as IEC, ANSI, BS). The maximum anticipated double ground-fault current can be calculated as follows:

$$I''_{\text{K EE}} = \frac{\sqrt{3}}{2} \cdot I''_{\text{K 3}}$$

The minimum cross section A_E for the main earthing conductor as per VDE 0103 is calculated as follows:

$$A_{\text{E min.}} = \frac{I''_{\text{K EE}} \cdot 10^3 \cdot \sqrt{m + n}}{S_{\text{thn}} \cdot \sqrt{\frac{1}{T_K}}}$$

The earthing system of the ABB high-current bus duct uses the enclosure of the three phases as the earthing conductor. The separate conductors are restricted to connecting the enclosure to the earth terminals on the generator, the transformers and the connection to the power plant earthing system. All components outside the busbar run such as cubicles etc. are connected to the enclosure and so are earthed "by spurs". See Section 5.3 for additional information on earthing.

Note:

When installing generator circuit-breakers, the earth switch and the short-circuiting facility are integrated into the generator circuit-breaker.
For detailed information, see generator circuit-breakers in Section 9.1!

9.2.6 Air pressure/Cooling system

Operational reliability can be further improved by supplying the high-current bus duct with filtered dry air. The resulting overpressure of 500 Pa (max. 2000 Pa) allows air in the bus duct to pass from inside to outside only, preventing contamination. The dry air also prevents the formation of condensation. The incoming air is drawn through a reducing valve and a gas meter from the power plant compressed-air system with or without a dryer and water separator, or from a circuit-breaker compressor, see also Section 15.5 Compressed-air system.

Forced ventilation of the high-current bus duct at 31 to max. 50 kA is of the closed loop type with an air-water heat exchanger for cooling. The ABB cooling unit is installed under the bus duct as close to the middle as possible. The air is blown into the outer phases by fans and diverted to the middle phase at the end by control dampers and deionizing screens via a connecting duct, in which it flows back to the cooling unit at twice the speed. The closed circuit air-cooling system is 100% redundant, allowing the system to be switched to the standby fan and cooler immediately when necessary. If the cooling system fails, the availability of the high-current bus duct is still 50–70%, depending on the design. Fig. 9-11 shows the air flow diagram of a high-current bus duct.

The limited space in the generator terminal area and the requirement to be able to work with smaller dimensions may require cooling with a single-pass airflow below 31 kA.

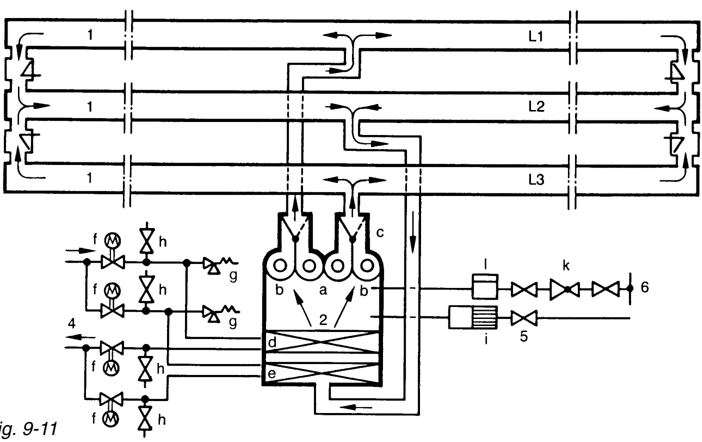


Fig. 9-11

Cooling-air flow diagram for a high-current bus duct, 1 High-current bus duct, 2 Cooling unit with fans a; Standby fans b; Dampers on standby fan c; Cooler d and standby cooler e; 3 Damper valves for flow distribution, deionization screens, 4 Cooling water circulation with motor-operated valves f for cooler and standby cooler (flow and return) with safety valves g; Vent and discharge valves h; 5 Make-up air with filter-dryer element i; 6 Alternative to 5: Make-up air from the compressed air system via reducing valve k and air meter l.