58

Applications of Switchgear

58.1. LOW-VOLTAGE INSTALLATIONS

58.1.1. Switchgear apparatus

Low-voltage switchgear is used for switching and protecting electrical equipment. The various devices are selected according to their required function, e.g. isolating, disconnecting loads, short-circuit breaking, switching motors, protecting against overloads and danger to human life. The switching functions can also be performed by a combination of several devices. Fig. 58.1 gives some of the devices used for low voltage switchgear.

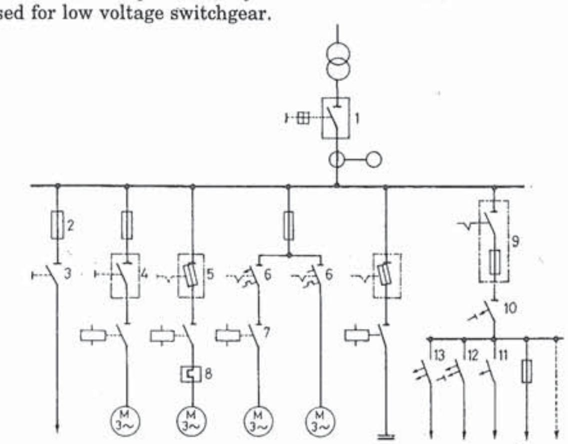


Fig 58.1 : 1 Circuit-breaker, 2 Fuse, 3 disconnector, 4 Loadback switch, 5 Fused switch-disconnector, 6 Motor starter (motor protection switch), 7 Contactor, 8 Overload relay, 9 Switch-disconnector with fuses, 10 Residual current circuit-breaker (r.c.c.b.), 11 Miniature circuit-breaker (MCB), 12 Residual current circuit-breaker with overcurrent trip, 13 miniature circuit-breaker, MCCB.

58.1.2. Technical Requirements of Various devices

1. Circuit-Breakers. Circuit-breakers must under normal operating conditions be able to make, carry and break currents and, under specified abnormal conditions up to a short circuit, be able to make the current, carry it for a defined length of time and interrupt it. Circuit breakers with instantaneous overload and short-circuit trips are used for routine switching and for overload protection of apparatus and parts of systems having a low operating frequency. Circuit-breakers without overcurrent releases, but with a special open-circuit shunt release (0.1 to $1.1 \times U_N$) are employed as "network protectors" to prevent reverse voltages.

Circuit-breakers are available for dependent or independent manual actuation and also for actuation by dependent power or energy-storage devices (operation by motor, electromagnetic,

electropneumatic). The breakers can be opened manually, electrically by a motor or electromagnet, or by releases e.g., open-circuit, overcurrent, undervoltage, reverse power or reverse current. Circuit-breakers are classified according to their design principle i.e. "current-zero breakers" and "current limiters".

Current-zero breakers interrupt the switching arc at the natural zero transition of the a.c. current. The current paths are arranged so that during the peak short-circuit current the contact pressure is reinforced by the electrodynamic forces, and the contacts do not separate until the short-circuit current has settled. These switches and all subsequent parts of the system must be able to carry the full peak short-circuit current. Current limiters are fast-acting circuit-breakers which operate before the current maximum is reached. The peak short-circuit/s is limited to a cut-off current l_p, thus reducing the mechanical and thermal stresses on the system which would occur if the short-circuit current were not restricted.

2. Contactors. Contactors are remote-controlled switches with restoring force which are actuated and held by their operating mechanism. They are used mainly with high operating frequencies for switching equipment under fault-free conditions. Including normal overloads. Contactors are not always suitable for isolating function and they must be preceded by a protection device to guard against short circuits.

Besides the widely used electromagnetic operating mechanism, contactors are also actuated pneumatically or electropneumatically.

To prevent thermal overloading of motors, contactors are fitted with current-dependent protection devices. To guard against motor overload or failure of a phase conductor, e.g., a wire breaks or only one fuse blows, the overcurrent relays are set to the rated current of the motor. Modern overcurrent relays have a temperature-compensating facility which offsets the influence of different ambient temperatures on the tripping times of the bimetal releases.

The contactor must be able to work satisfactorily within the limits of 85% and 110% of the nominal control voltage (with the control current flowing).

If the control lines are long, it is possible that the contactor will not respond to a command on closing because the voltage drop is too large (a.c. and d.c. actuation). or on opening because the capacitance of the line is too high. A voltage drop of 5% max is permitted for calculating the length of control lines.

3. Motor starters. The term motor starter are the devices necessary for starting and stopping a motor. These are provided with appropriate overload protection.

Motor starters, are also called motor protection switches if these are suitable for switching short-circuit currents.

Motor starters can be operated by hand or motor, electromagnetically, pneumatically or electropneumatically. They can be used in conjunction with open-circuit shunt releases, undervoltage relays or undervoltage releases, time-delay overload relays, instantaneous overcurrent relays and other relays or releases.

The rated operational current of a motor starter depends on the rated operational voltage, the rated frequency, the rated duty, the application and the type of enclosure.

4. Other switchgear apparatus

(*a*) **Disconnectors (isolators).** A switch which for safety purposes when open provides isolating distances (safety clearances) in compliance with specified requirements. A disconnector can open and close a circuit only if the current to be disconnected or connected is negligible, or if there is no perceptible voltage difference between the two contacts of each current path. For a defined length of time it can carry service currents under normal conditions, and also higher currents under abnormal conditions, e.g. short-circuit currents. Disconnectors can also have a certain making and/or breaking capacity.

Negligible currents can be capacitive currents occurring at bushings and busbars and very short cables, and also the currents of voltage transformers and dividers used for measuring purposes.

No perceptible voltage difference exists, for example, when induced voltage regulators or circuit-breakers are shunted.

(*b*) **Switch-disconnector.** A switch which in the open position satisfies the isolating requirements.

(*i*) *Switches (load switch).* A switch which under normal conditions, where specified also certain overload conditions, is able to connect, carry and interrupt currents and which under defined abnormal conditions such as short circuits, can carry these currents for a specified length of time. It has a short-circuit making capacity, but not a short-circuit breaking capacity.

(*ii*) *Fuse combination unit.* A switch, disconnector or switch-disconnector and one or more fuses assembled as a unit.

(*iii*) *Disconnector-fuse.* An integral assembly of a disconnector and fuses where a fuse is connected in series with the disconnector in one or more current paths.

(*iv*) *Fuse-disconnector.* A disconnector in which a fuse line or fuse carrier with fuse link constitutes the moving contact.

(*v*) *Fuse-switch.* A switch in which a fuse line or a fuse carrier with fuse link constitutes the moving contact.

(*vi*) *Switch-fuse.* An integral assembly of switch and fuses in which a fuse is connected in series with the switch in one or more current paths.

5. Protective switchgear for wiring systems. The switchgear protecting lines/cables apparatus and people are now available in modular construction. These are either snap-mounted (channel mounted) or fastened with screws. They are used for wiring,. switching, control and measuring in building installations and commercial and industrial plants. The various devices used in such switchgear include :

(*a*) **Miniature circuit-breakers.** Miniature circuit-breakers are manually operated, current-limiting switches with permanently set, undelayed electromagnetic releases and delayed thermal releases. They automatically disconnect the circuit from the network if the specified current is exceeded.

Miniature circuit-breakers for line protection are available in one, two and three-phase form, and also in one- and three-phase versions with connected neutral, together with auxiliary switches if required. Current ratings for voltages of 415 VAC and 440 VDC extend up to 63 A, the commonest ratings being 6, 10, 16, 20, 25, 32, (35).

(*b*) **Residual current-operated circuit-breakers (leakage current).** Residual current-operated circuit-breakers are used for protecting people, livestock and property (fire) against alternating and pulsating direct fault currents. They trip within 0.2 s if a defined fault current is exceeded, e.g., due to damaged insulation. They are usually protected against short circuits by an overcurrent device.

Residual-current breakers are available in two-and four-phase versions for 500 V a.c. and current ratings up to 63 A. Common rated currents are 16, 25, 40 and 63 A for nominal fault currents $l_{\Delta n}$ of 10, 30, 100, 300 and 500 mA.

(*c*) **Residual-current circuit-breakers with overcurrent trip.** These-breakers are with switch combinations which automatically disconnect all phases from the supply network, irrespective of mains and auxiliary voltages, if the values set for fault, overload or short-circuit current are exceeded.

(*d*) **Miniature circuit-breakers with differential trip.** Such breakers are combinations of switches which automatically disconnect the circuit from the supply if the set values for overcurrent or differential current are exceeded. The differential current trip can be independent of mains or auxiliary voltages. Versions in two- three- and four-phase (3 or 4 protected phases) and single-phase breakers with continuous neutral for fixed installation and two-phase breakers for plug connection with a rated differential current of 10 mA for current ratings of 10 and 16 A are available.

58.1.3. Selectivity of devices

There are a number of overcurrent protective devices between the power source and an item of equipment requiring protection against short circuits. These devices must respond selectively in order to restrict any fault as far as possible to the affected part of the system. For this proper selection of the device & the area to be covered under the protection has to be made to ensure that :

— routine current spikes do not cause disconnection

— when operating properly, only the protective device nearest to the fault in the supply direction responds.

— if this device fails, the one next to it in sequence comes into action.

The selectivity of protective devices can be established by comparing their time/current characteristics. Attention has to be paid to the following :

— zone of overcurrents: long tripping times, effective range of thermal overcurrent release.

— Zone of small short-circuit currents : short tripping times, effective range of electro- magnetic release.

— Zone of large short-circuit currents : tripping time within one half-wave, effective range of current limitation.

Various examples of selectivity are :

(*i*) **Vity fuse.** Fuses generally function selectively if their time/current characteristics do not overlap. With large short-circuit currents it is no longer sufficient to merely state the melting time. In this case selectivity is assured only if the critical value $l^2 \,.\, t_a$ of the smaller fuse is lower than the value $l^2 \,.\, t_s$ of the preceding fuse. This condition is normally satisfied by grading the fuse current ratings in a ratio 1 : 1.6.

(*ii*) **Circuit-breaker.** Selective short-circuit protection is not possible by grading the response values of the electromagnetic releases, but requires additional time grading independent of current. The total break time t_A of the downstream breaker must be shorter than the minimum command time t_m of the upstream breaker. The grading times between two breakers are 100 ms approx.

58.2. LOW-VOLTAGE SWITCHGEAR ASSEMBLIES

The term low-voltage switchgear assemblies covers all configurations with rated voltages up to 1000 VAC at frequencies up to 1000 Hz or 1500 VDC, except for small distribution boards. Also included are combinations of electromechanical and electronic equipment and also construction with solely electronic equipment.

For the same level of safety, a distinction is made between

"Type-tested switchgear assemblies" and

"Partially type-tested switchgear assemblies".

The manufacture can choose the manner of testing on grounds of production or economy.

Type-testing must demonstrate the following :

— Adherence to upper limit temperature

— Dielectric strength

— Short-circuit strength

— Flawless connection between parts of switchgear assembly and protective conductor by inspection or resistance measurement.

— Short-circuit strength of protective conductor

— Creepage distances and clearances

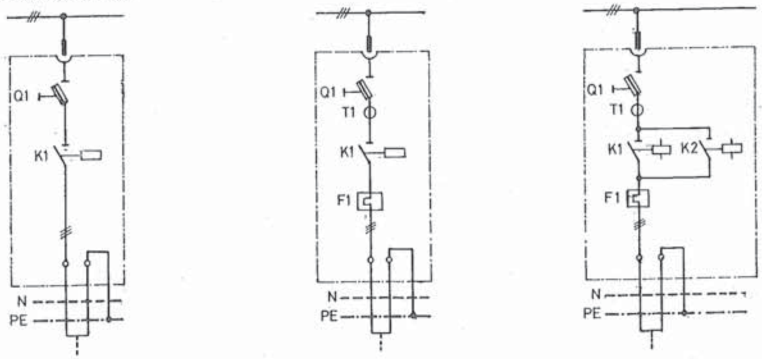
— Mechanical functioning

— IP protection class.

58.3. LOW-VOLTAGE SWITCHGEAR INSTALLATIONS AND DISTRIBUTION BOARDS

Low-voltage switchgear installations and distribution boards are used for power distribution, motor control centres and as combinations of these. They contain equipment for protecting, switching, converting, controlling and measuring. Different constructions and combinations are required for the widely varied applications and requirements, and from operation by the unskilled to locked electrical premises. The switchgear is Suitable for Surface-mounting flush-mounting, without removable cover or without door, with removable cover or with door.

Distribution boards for mounting in hollow walls are also available. Small distribution boards can include meter positions also examples of different available switchgear assemblies are given in Fig. 58.2 (*a*), (*b*), (*c*).



(*a*) (*b*) (c)

Fig. 58.2. Examples of standard assemblies with circuit diagrams (draw-out units with fuse switch-disconnectors) (*a*) without thermal protection, (*b*) with thermal protection, one direction, (*c*) with direction reversal

58.4. MEDIUM-VOLTAGE INSTALLATIONS

Switchgear apparatus is basically more or less the same except that characteristics, technical parameters are different.

1. Disconnectors. Disconnectors used in medium-voltage installations are mainly of the knife-contact type (Fig. 58.3). Special attention must be paid to the pivoting movement of the isolating blades when deciding the cubicle dimensions, to ensure the required clearances. Switchgear cubicles with knife-contact disconnectors require more mounting depth than those with slide-in disconnectors.

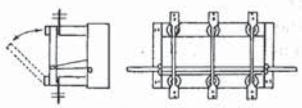


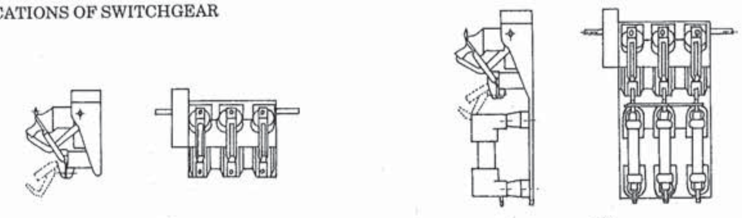
Fig. 58.3. Medium-voltage knife-contact disconnector

The blades of knife-contact disconnectors mounted standing or suspended have to be appropriately prevented from moving spontaneously under their own weight.

Disconnectors with rated voltages of up to 36 kV are usually operated by hand. In remote-controlled installations they are actuated by a motor or compressed air. Earthing switches can be fitted, including those with full making capacity.

Disconnectors rated voltages of up to 36 kV must satisfy the test conditions according IEC 129 (DIN VDE 0670 Part 2)

2. Switch-disconnectors. Switch-disconnectors are increasingly being used in medium-voltage switching stations. Switch-disconnectors have full making capacity and can handle all fault-free routine switching operations. Switch-disconnectors are load-break switches with visible isolating distances.



(*a*) (*b*)

Fig. 58.4. Knife-contact switch-disconnector : (*a*) without and (*b*) with fuse assembly

(*a*) (*b*)

Fig. 58.5. Slide-in type switch-disconnector : (*a*) without and (*b*) with fuse assembly

Knife-contact switch-disconnectors and slide-in type switch-disconnectors can be operated in two ways.

(*a*) Snap-action mechanism. With this form of operating mechanism, a spring is tensioned which is released shortly before the switching angle is completed, and its force is used to move the contacts. The procedure is employed for both closing and opening.

(*b*) Stored-energy mechanism. This system has one spring for closing and a second spring for opening. During the closing operation the opening spring is tensioned and latched. The stored energy for the opening operation is released by means of a magnetic trip or H.V. (H.R.C.) fuse.

3. Earthing switches. Depending on the construction of the switching installation, earthing switches are mounted separately ahead of the switchgear, e.g., in the cable basement (Fig. 58.6 c) or contained in the base of the switch disconnector (Fig. 58.6 a) or factory-assembled immediately underneath the circuit-breaker (Fig. 58.6 b). Earthing switches are disconnectors or switch-disconnectors (with full making capacity). Knife-contact and slide-in types are available. For safety reasons - e.g. accidental closure of the earthing switch on a live incoming or outgoing feeder earthing switches with full making capacity are recommended for conventional switching installations.

4. H.R.C. fuse links. The protection of capacitors and transformers must include provision for inrush currents. In capacitor installations. The rated current of the fuse link must be at least 1.6 times the capacitor current rating, to take into account the possible network harmonics and voltage rise.

When selecting fuse links for protecting high-voltage motors, attention must be paid to the motors starting current and starting time. The frequency of starting must also be considered if this is so high that the fuses cannot cool down in between. Fuse links are available with rated voltages and currents graded for fuse-bases of different sizes.

Current-limiting capacity. The maximum current that a fuse will let through depends on its rated current and on the prospective short-circuit current. The fuse's melting characteristics is indicated by the manufacturer for the range of breaking currents, for each rated current one can read off the peak value of the let-through current to which the fuse limits a symmetrical short-circuit current. Plotted on the horizontal axis are the r.m.s. symmetrical short-circuit current occurring when a fuse is shunted out. At a symmetrical short-circuit current of 40 kA, for example, with

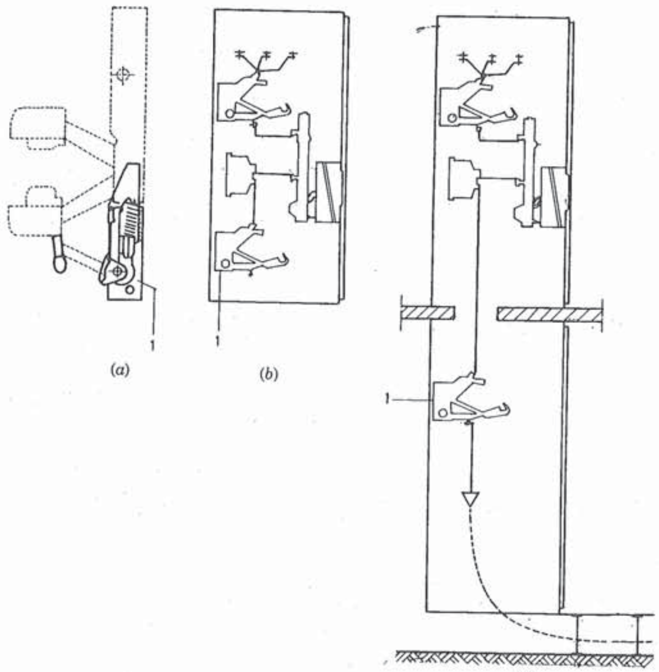


Fig. 58.6. Arrangements for earthing switches (1) : (*a*) mounted on switch-disconnector ; (*b*) in cubicle underneath of circuit-breaker and (*c*) in cable basement/compartment

a 16 A link the let-through current is only 3 kA as against a prospective impulse short-circuit current of about 100 kA with full asymmetry. This current limitation effectively protects the installation against damage due to thermal and dynamic stresses.

5. Peak current I_s limiters. Peak current I_s limiters are switching devices which interrupt circuits very quickly after tripping, commutate the current to a special quartz fuse arranged in parallel, and there extinguish it. As can be seen in Fig. 58.7. The I_s limiter consists of an insulating housing (3) containing two pieces of tube (1) provided with lengthwise slits and having one end connected to the terminals while the other ends are soldered together. Inside these tubular contacts is a detonator (2) which is fired with an igniter by discharging a capacitor.

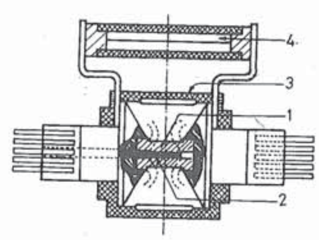


Fig. 58.7. Design of an I_s limiter, 1 Contact pieces, 2 Detonator, 3 Insulating housing, 4 Fuse

The high pressure caused by the detonation spreads the contact fingers, so interrupting the main circuit. The fuse (4), which is designed for a small rated current, limits and quenches the computated short-circuit current while it is still rising. Since the opening time of the I_s limiter is well below 1 ms, its let-through current is small, making it a very effective current-limiting device (Fig. 58.9)

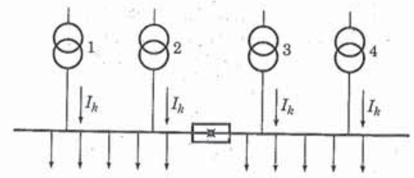


Fig. 58.8. Two switching stations coupled through an I_s limiter (a) to limit the short-circuit current

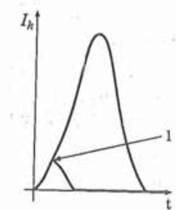


Fig. 58.9. Limitation of short-circuit current (1) by melting of fuse link

I_s limiters are used in medium-voltage installations up to 36 kV. They are employed for quickly sectionalizing busbars in installations with high-fault powers (Fig. 58.8), for re-connecting short-circuited current-limiting reactors and for directly disconnecting faulted circuits.

I_s limiters are manufactured for the rated voltages and currents shown in the Table below :

Rated voltages and currents for I_s limiters.

For higher current ratings the limiters can be connected in parallel.

Rated voltage *kV*	*Rated current* *A*		
12	1000	2000	3000
24	1000	1600	2000
36	1000	2000	

6. Circuit-breakers. Circuit-breakers for medium voltages are nowadays mainly of the oil-free type. Breakers with current ratings of 400 A to 3150 A are available for voltage ratings of 7.2 kV to 36 kV and rated short-circuit breaking currents up to 40 kA. They are either fixed or truck-mounted together with the appropriate interlocks. Draw-out breakers on extending rails are also available in standard forms for rated currents up to 1250 A.

Circuit-breakers conform essentially to IEC Publication 56-2.

Compared with minimum-oil designs, oil-free circuit-breakers (vaccum, SF_6) have the advantages of being largely maintenance-free and having a high long-term breaking capacity. Construction features, merits/demerits of each type have been covered separately.

7. Vaccum Contactors. Vaccum contactors are particularly suitable for the routine switching of motors which start and stop frequently, e.g. medium-voltage motors for pumps, compensators, capacitors or fans. Short-circuit protection for the motor feeders is provided by current-limiting h.r.c. fuses, or by a circuit-breaker.

Vacuum contactors have generally a life expectancy of 1×10^6 switching cycles and can handle switching frequencies of up to 1200 on/off operations per hour.

Rated voltage	*kV*	*3.6*	*7.2*	*12*
Rated current	A	450	450	250
for motors up to	kW	1500	2000	4000
for capacitors up to	kVar	2000	4000	4000

8. Switchgear with fully-insulated busbar. Medium-voltage installations with high power rating connections for currents of up to 5000 A because of the limited space fully phase-insulated, capacitor-controlled busbar connections are manufactured and especially where the busbar system has to meet stringent thermal and dynamic requirements.

They are generally suited for :

— connecting transformers is switchgear assemblies for voltages 0.4 to 72.5 kV
— coupling busbars for duplex switching stations
— section ties between switching stations and busbars
— incoming connection to inverter installations

Construction of such a bus-bar is given in Fig 58.10.

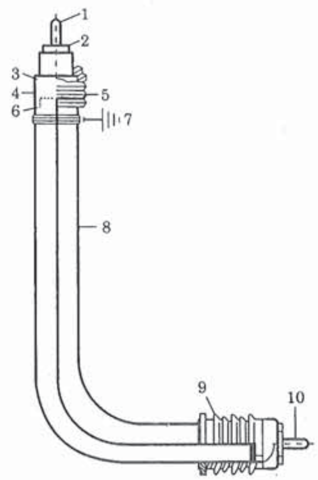


Fig. 58.10. Construction of insulated busbar for indoor or outdoor application : 1 indoor connection, 2 Conductor, 3 insulation, 4 Busbar termination with standard creepage distance, 5 Busbar termination with increased creepage distance, 6 Earth potential layer, 7 Earth connection, 8 Surface design for indoor; without protection cover, optional with protection tube, for outdoor; with protection tube, 9 Porcelain insulating cover, 10 Outdoor connection.

9. High-Current Switchgear associated with a generator.

Generator circuit-breakers are switching devices in the high-current connection between generator and main transformer. The main applications and the resulting advantages are listed below.

Function	*Advantages*
Isolate generator from station services infeed	Station services fed via generator transformer. No need for starting transformer and associated switchgear and change-over facilities (see Fig. 9-1a).
Synchronize on low-voltage side of main transformer	Eliminates voltage transformers on h.v. side of main transformer. Possibility of connecting two generator to one over-head line via 2 separate transformers or a three-winding tranformer.
Efficient power plant layout (particularly hydro plants)	Possibility of connecting two or more generators to a two or three-winding transformer and thence to an overhead line (see Fig. 9-1e).
Isolate fault in generator transformer or in station service transformer	Effects of fault very much less than with rapid de-excitation as disconnection takes less than 100 ms.
Isolate fault in generator	Station services remain continuously connected to network, thus increase of availability.
Isolate fault on line from power plant to next transformer or switching station	No need for high-voltage breaker in generating station.
Use in nuclear power stations.	Considerably improves security of no break station services power supply.
Use in pumped storage plants.	Straightforward switching between pump and generator mode.
Power plant automation.	Only 1 switching operation to synchronize or disconnect the generator, instead of 5-7 operations when synchronizing on the HV side.

Fig. 58.11 shows examples of unit-connected arrangements with generator breakers. The various alternatives show that with large units having several generator and station services transformers, these breakers ensure to a very high degree that the service supply remains available in the event of a fault.

Generator breakers are ideal for use in conventional and nuclear power plants with high unit ratings and stringent requirements as regards safety and availability.

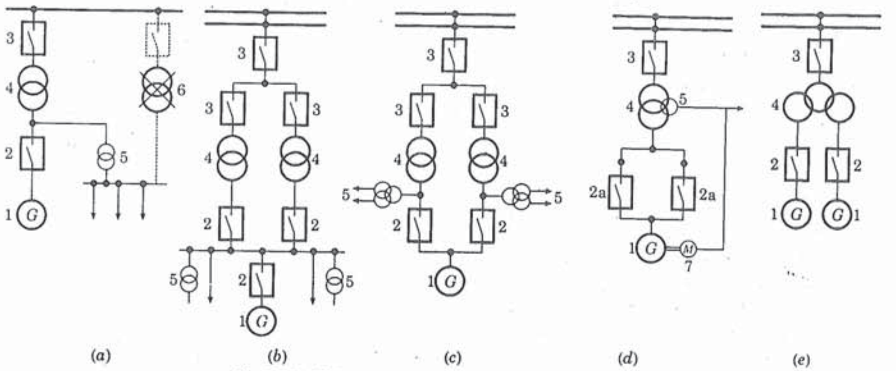


Fig. 58.11. Unit connection arrangements in power stations
(*a*) Basic diagram, (*b*) and (*c*) Large generators with part-load transformers,
(*d*) Pumped storage unit, (*e*) Hydro plant :
1 Generator, 2 Generator breaker, 2a 5-pole generator breaker for switching between motor and generator mode,
3 High-voltage circuit-breaker, 4 Main transformer, 5 Station services transformer,
6 Starting transformer, 7 Starting motor

There are three types of generator Circuit Breaker :

(*i*) SF_6 generator circuit-breakers. The type SF_6 generator breaker is designed for generator ratings from 50 MVA to about 400 MVA. The breakers are of three-phase construction, either single-phase enclosed or unenclosed for the 24 kV voltage class. It can be installed in metal-enclosed or open high-current busducts. Unenclosed generator breakers of type are installed in a room which can be locked or surrounded by an aluminium enclosure to prevent touch contact.

The basic model has 1 extinction chamber. It can be extended on the modular principle by 1 disconnector, 1 or 2 earthing switches and 1 or 2 current transformers, all mounted on the same baseframe.

(*ii*) Air-blast generator circuit-breakers. (*a*) *Closed Type Busbars.* Breakers of this type are intended for unit ratings of about 400-2000 MVA and above. The breaker is operated by compressed air. It incorporates a separate isolating distance, for which compressed air is the quenching medium. The necessary high-quality compressed air is produced in a self-contained compressor station.

This type of generator breakers are of single-phase metal-enclosed construction and can be incorporated directly into the high current busduct. Both the breaker enclosure and the active parts are connected to the busduct by flexible copper straps.

The series covers load-break switches and circuit-breakers of modular construction, so providing a range of models using the same basic components and suitable adapted cooling systems.

(*b*) *Open Type Bus-bars.* This type of air-blast breaker is preferably used in open, unenclosed busbars. These breakers are available in single or 3-phase versions, depending on their size.

Such generator circuit-breakers should be installed in a room which can be locked. Alternatively, the breakers can be surrounded by an aluminium enclosure or grille to protect against contact.

Breakers standing directly on the floor do not need any lifting gear : built-in castors enable them to be moved in any direction.

Their open construction, with the isolating distance visible, makes them particularly easy to check and service.

58.5. HIGH-CURRENT ISOLATED PHASE BUSDUCTS (GENERATOR BUSDUCTS)

The high-current isolated phase busducts and their branches are an important part of the electrical installation in a power plant.

The high-current busducts and switchgear are connected as shown in (Fig. 58.12): The purpose & function of such bus-ducts are :

— Connection between generator and the main transformer (s), including the generator neutral.

— Branch connections to station services transformer, excitation transformer and voltage transformer cubicle,

— Mounting and connection of measuring, signalling and protective devices for current, voltage and other parameters,

— Installation and connection of switching devices such as generator breakers, high-current disconnectors and earthing switches.

— Additional facilities relating, for instance, to protective and maintenance earthing, pressure-retaining systems or forced cooling.

Modern generator design, with rated voltages up to 27 kV and powers up to 1600 MVA, gives rise to service currents of up to 36 kA. For the high-current busduct this means that it has to withstand the temperature rise in conductor and enclosure and also the effects of substantial magnetic fields in the installation and its surroundings.

Unit capacities of this magnitude in conjunction with the high network powers can result in short-circuit currents of up to about 750 kA in the busducts and switchgear. Short-circuit currents of more than 1000 kA can occur in the branches. Furthermore, the safety and availability of a high busduct must conform to the high standard of the other station components.

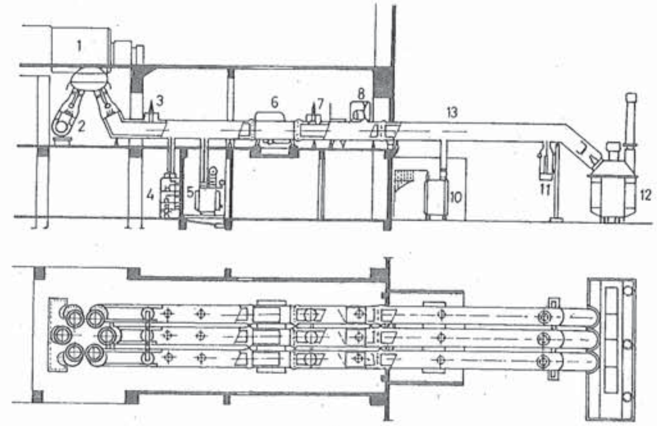


Fig. 58.12. High-current switchgear installation, 1 Generator, 2 Generator neutral, 3 Earthing switch with short-circuiter, 4 Voltage transformer cubicle, 5 Excitation transformer, 6 Generator circuit-breaker, 7 Earthing switch (optional), 8 Voltage transformer and capacitor compartment, 9 Expansion joint, 10 Station services transformer, 11 Lightning arrester, 12 Main transformer, 13 High-current busduct.

High-current busducts have to satisfy the following requirements :

— Adherence to specified temperature limits,

— Adequate short-circuit strength (thermal and mechanical strength in the event of short circuits),

— Adequate magnetic screening,

— Safe insulation, i.e., protection against overvoltages, moisture and contamination.

58.5.1. Types & Constructional features

Up to about 5 kA the generator connections are generally shaped like ordinary busbars. The simplest form consists of flat or U-section aluminium or copper bars (sometimes also tubes, but only Al). Exposed bars are used only with small generator ratings, because the area then has to be locked. On the other hand, placing the bars in a common square aluminium duct (nonsegregated phase busduct) protects them against contact and contamination. Added protection is provided by partitions between the phases (segregated phase busduct), thus preventing phase-to-phase short circuits and reducing the dynamic forces ; For higher ratings, isolated phase bus-ducts (each phase in separate enclosure) is provided.

Both the conductor and the enclosure arranged concentrically round it are in the form of aluminium tubes and are insulated each other by air and moulded-resin insulators.

Three insulators construction is commonly used for higher ratings as shown in Fig 58.13 for lower ratings, single insulator type bus-ducts are used.

An important technical feature is that the enclosures of each phase are short-circuited across the three phases at both ends. The current flowing in the enclosure-in the opposite direction to the conductor current-attains some 95% of the conductor current, depending on the system configuration and the impedance of the short-circuit connection between the enclosures (Fig. 58.13).

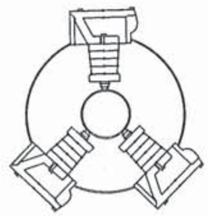


Fig. 58.13. (a) BBC high-current isolated-phase busduct, single-phase arrangement

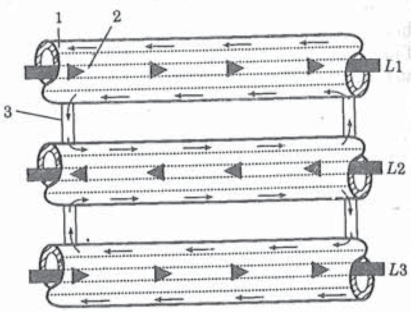


Fig. 58.13. (b) Principle of high-current busduct with electrically continuous enclosure : 1 Enclosure current. 2 Conductor current, 3 Short-circuit connection between enclosures.

The magnetic field outside the enclosure is almost completely compensated, so eliminating losses to the surroundings.

This design has the following important features :

— Proof against contact, so locked electrical premises are unnecessary.
— Protection against dirt and moisture, maintenance is limited to visual inspection,
— No magnetic field outside the enclosure (no inductive losses in nearby conducting material, such as grilles, railings, concrete reinforecements, pipes, etc.),
— Less likelihood of earth faults and short circuits.
— Single-phase high-current breakers can be incorporated in each busduct.

58.5.2. Design Considerations

The design of a high-current isolated-phase busduct is based on :

— Rated voltage
— Current
— Insulating level
— Short-circuit current
— Operating temperatures
— Climatic conditions
— Other requirements concerning components and ancillaries

Dielectric strength (rated power-frequency any lightning impulse withstand voltages) is provided by standard type sizes with air clearances between conductor and enclosure conforming to the minimum clearances specified in IEC 71.2, and by standard insulators complying with IEC and the respective voltage levels with test voltages to IEC 694/298.

58.5.3. Construction

Conductor and enclosure are generally of Al 99.5% rolled aluminium sheet into tubes and submerged-arc. The prefabricated assemblies can be up to 12 m long. Their length depends on transport and site lonstrain.

Each support consists of three post insulators—four in exceptional cases—which are mounted from outside. Sliding surfaces or fixed pins on all insulators of each support, and as spring arrangement on one of them, allow relative axial movement between conductor and enclosure.

The bearing elements for the enclosure are arranged independently of the conductor supports. They are of sliding or fixed type and bolted direct to the base structure. The tubular shape allows foot supports at distances of 10-20 m, depending on the system.

All connections to generator, transformers and switchgear not only provide sure electrical contact but also allow adjustment, the accommodation of thermal movement and access to the junction

points. Careful construction of the enclosure in particularly important in the vicinity of the generator terminals, owing to the small space between them. With small and medium-sized installations, three-phase terminal and neutral compartments with hatches and windows enable the connections to be reached and inspected. At higher current ratings, only the isolated-phase busduct construction provides adequate magnetic-field compensation, avoids eddy currents and so ensures controlled temperature conditions.

Flexible pressure-welded copper straps are used to bolt the conductors to the generator and switchgear terminals. Strong and highly resilient washers ensure the necessary contact pressure and so prevent excessive heat build-up. The contact surfaces are silver-coated if the maximum permitted conductor temperature so warrants.

Current tranformers for measurement and protection are of the bushing type of annular core type integrated into the busduct at a suitable place. To install or remove them, detachable connections have to be provided along the duct. Voltage transformers can be incorporated in the busduct or contained in separate instrument cubicles connected by way of suitable branches. The same applies to protective capacitors for limiting capacitively transmitted voltages.

Surge arresters protect busduct and generator in the event of flashover in the transformer, but are then usually stressed beyond the resealing voltage. Personnel and equipment can be safeguraded by using explosion-proof arresters and a suitably designed and tested arrester housing with means of pressure relief.

The earthing system of the isolated-phase busduct utilizes the enclosures of the three phases as an earth conductor. The other earth connections needed are restricted to connecting the enclosure to the earth terminals of the generator and the transformers, and coupling to the station earth.

58.5.4. Earthing Switch

Short-circuit-proof earthing switches and short-circuiting devices are necessary in the vicinity of high-current busducts, for safety reasons. With small unit ratings, manually fitted jumpers and straps can be used. For higher unit ratings it is advisable to employ motordriven earthing switches.

Fig. 58.14 shows the basic diagram of a high-current busduct with earthing switch.

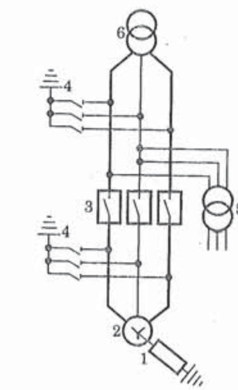


Fig. 58.14. Basic diagram of high-current busduct 1 Neutral earth, 2 Generator, 3 Generator breaker, 4 Earthing switch type E 36.150, 5 Station services transformer, 6 Main transformer.

58.5.5. Switchgear Installations

A switchgear installation contains all the apparatus and auxiliary equipment necessary to ensure reliable operation of the installation and a secure supply of electricity. High-voltage switchgear installations with operating voltages up to 800 kV are used for distributing electricity in towns and cities, regions and industrial centres, and also for power transmission. The voltage level employed is determined by the transmission capacity and the short circuit capacity of the power system.

Distribution networks are operated predominantly up to 132 kV. Power transmission systems and ring mains round urban areas operate with 33, 66, 132, 220, or 400 kV rated voltage, depending on local conditions. Over very large distances, electrical power is transmitted at 765 or 800 kV or by high-voltage direct-current systems.

Switchgear installations can be placed indoors or outdoors. SF_6 gas-insulated switching stations have the important advantage of taking up little space and being unaffected by pollution and environmental factors.

Indoor installations are built both with SF_6 gas-insulated euipment for all voltage ratings above 36 kV and also with conventional, open euipment up to 132 kV. SF_6 technology, requiring very little floor area and building volume, is particularly suitable for supplying load centres in cities and industrial complexes. This kind of equipment is also applied in underground installations.

Outdoor switching stations are used for all voltage levels from 33 kV to 765 kV. They are built outside cities, usually at points along the cross-country lines of bulk transmission systems. Switchgear for HVDC applications is also predominantly of the outdoor type.

Transformer stations comprise not only the h.v. equipment and power transformer but also medium-and low-voltage switchgear and a variety of auxiliary services.

Depending on the intended plant site, the construction of a switchgear installation must conform to IEC requirements of particular national codes, like BIS in our country.

The starting point for planning a switchgear installation is its single-line diagram. This indicates the extend of the installation, such as the number of busbars and branches, and also their associated apparatus.

The brief summary of Technical Particulars of HV switchgear is given subsequently for reference of both students as well as practising engineers.

58.6. HIGH-VOLTAGE SWITCHGEAR

58.6.1. Definitions and electrical characteristics for HV switchgear apparatus

Disconnectors are mechanical switching devices which in the open position provide an isolating distance. They are able to open or close a circuit if either a negligible current is switched or if no significant change occurs in the voltage between the terminals of the poles. Currents can be carried for specified times in normal operation and under abnormal conditions (*e.g.* short circuit). Negligible current have values ≤ 0.5 A; they include the capacitive charging currents of bushings, busbars, connections, very short lengths of cable and the currents of voltage transformers.

Isolating distances are gaps of specified dielectric strength in gases or liquids in the open current paths of switching devices; as protection for people and equipment they must satisfy special conditions and their existence must be clearly perceptible when the switching device is open.

Load switches are switching devices a switching capacity equivalent to the electrical stresses occurring when connecting and disconnecting equipment and sections of installations in the fault-free condition.

Load disconnectors are load switches which in the open position provide a visible isolating distance.

Circuit-breakers are switching devices able to close on the current occurring in a circuit under specified normal and abnormal conditions, to carry them for a specified time, and interrupt them.

Earthing switches are mechanical switching devices for earthing and short-circuiting circuits: they are able to carry currents for a specified time under abnormal conditions.

Fuses are switching devices in which the circuit is interrupted by the melting of specified parts under the influence of heat generated within the device when the current exceeds a given value for a specified time.

Auxiliary switches, auxiliary circuits. Auxiliary switches must be designed for a continous current of at least 10 A and be able to interrupt the current in control circuits. Details must be started by the manufacturer. If this information is not available, auxiliary switches must be able to interrupt at least 2 A at 220 V d.c. with a minimum time constant of the control circuit of 20 ms. The terminals and wiring in auxiliary circuits must be designed for a continuous current of at least 10 A.

58.6.2. Electrical characteristics

Making current. Peak value of the first large half-wave of the current in one pole of a circuit-breaker during the transient reaction after current starts to flow on closing.

Peak current. Peak value of the first large half-wave of the current during the transient occurrence after current begins to flow which a switching device withstands in the closed position under specified conditions.

Breaking current. Current is one pole of a circuit-breaker at the instant the arc occurs during an opening operation.

Making capacity. The value of the maximum prospective peak current which at a given voltage a circuit-breaker can interrupt under specified conditions; for load switches the value of the prospective service current.

Short-line fault. A short circuit on an overhead line at a short, not negligible distance from the terminals of the circuit-breaker.

Switching capacity (Making or breaking) under asynchronous condition. Making or breaking capacity when synchronism is lost or absent between the network sections before and after the circuit-breaker under specified conditions.

Normal current. The current that the main current path of a switching device can carry continuously under specified conditions. For standardized rated normal currents, see below.

Short-time current. The rms value of the current which a switching device in the closed position can carry for a specified short time under specified conditions. For standardized rated short-time currents. see below.

Rated voltage. The maximum voltage of a network for which a switching device is designed. For standardized rated voltages, see below.

Applied voltage. The voltage between the terminals of a circuit-breaker immediately before making of the current.

Recovery voltage. The voltage occuring between the terminals of a circuit-breaker after the current is interrupted.

Opening time. The time interval between the beginning of the opening time of a circuit-breaker and the end of the arcing time.

Closing time. The time interval between commencement of the closing movement and the instant at which current begins to flow in the main current path.

Rated value. The value of a characteristic quantity used to define the operating conditions for which a switching device is designed and built, and which the manufacturer must guarantee.

Withstand value. The maximum value of a characteristic quantity that a switching device will tolerate with no impairment of function. The withstand value must be at least equal to the rated value.

Standard value. A value defined in official specifications on which the design of a device is to be based.

Standardized rated voltages. 3.6, 7.2, 12, 17.5, 24, 36, 52, 72.5, 100, 123, 145, 170, 245, 300, 362, 420, 525, 765 kV.

Standardized rated normal currents. 200, 400, 630, 800, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300 A.

Standardized rated short-time currents. 8, 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80, 100 kA.

Rated power-frequency withstand voltage. The value of the power-frequency voltage which the insulation of a device must withstand for a time of 1 minute.

Rated lightning impulse withstand voltage. The value of the unipolar standard 1.2/50 μs impulse voltage which the insulation of a device must withstand.

Rated switching impulse withstand voltage. The value of the unipolar standard 250/2500 μs switching impulse voltage which the insulation of a device with a rated voltage of 300 kV and above must withstand.

NOTE :

1. Under the new standards, the isolating distances of disconnectors for rated voltages of 300 kV and above are tested by applying the power-frequency voltage to one terminal and, when the peak value is reached, applying to the other terminal the reversed-polarity lightning or switching impulse voltage. This bipolar test is called the bias test.

   Table 10-1 below lists the dielectric values for disconnectors, switches, earthing switches and circuit-breakers for the respective rated voltages. In the case of circuit breakers, tests are conducted across the contact stroke in the open position with the voltages in columns 2, 4 and 6.
2. Up to 72.5 kV one can choose between list 1 (which covers equipment in networks and industrial installations not connected to overhead lines, or through transformers) or list 2 (in all other cases or if increased security is required).

   At the higher voltages the related values are selected from the same line.

Table 58-1

Standardized* values for disconnectors, load switches, circuit-breakers and earthing switches.

Rated voltage (rms value)	*Rated power-frequency withstand voltage 50 Hz / 1 min (rms value)*		*Rated lightning impulse withstand voltage 1.2/50 μs (peak value)*	
	To earth	*Across isolating distance*	*To earth*	*Across isolating distance*
(kV)	*(kV)*	*(kV)*	*(kV)*	*(kV)*
1	*2*	*3*	*4*	*5*
—	—	—	List 1 List 2	List 1 List 2
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	165 — 195
52	95	110	250 — 250	290 — 290
72.5	140	160	325 — 325	375 — 375

* Minor variations in various standards exist.

Table 58-1 (Continued Figures in brackets are peak values of the power-frequency voltage applied to the opposite terminal.

Rated voltage (rms value)	*Rated power-frequency withstand voltage 50 Hz / 1 min (rms value)*		*Rated lightning impulse withstand voltage 1.2/50 μs (peak value)*		*Rated switching impulse withstand voltage 250/2500 μs (peak value)*		
	To earth	*Across isolating distance*	*To earth*	*Across isolating distance*	*To earth*	*Across isolating distance Class A*	*Class B*
(kV)	*(kV)*	*(kV)*	*(kV)*	*(kV)*	*(kV)*	*(kV)*	*(kV)*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
100	150	175	380	440	—	—	—
	185	210	450	520			
123	185	210	450	520			
	230	265	550	630			
145	230	265	550	630			
	275	315	650	750			
170	275	315	650	750			
	325	375	750	860			
245	360	415	850	950			
	395	460	950	1050			
	460	530	1050	1200			
300	380	435	950	950 (+170)	750	850	700 (+ 245)
			1050	1050 (+170)	850		
362	450	520	1050	1050 (+205)	850	950	800 (+295)
			1175	1175 (+205)	950		
420	520	610	1300	1300 (+240)	950	1050	900 (+345)
			1425	1425 (+240)	1050		
525	620	760	1425	1425 (+300)	1050	1175	900 (+430)
			1550	1550 (+300)	1175		
765	830	1100	1800	1800 (+435)	1300	1550	1100 (+625)
			2100	2100 (+435)	1425		

58.7. DISCONNECTORS AND EARTH SWITCHES

Various types of disconnectors/isolators are :

1. Rotary disconnectors.

(*a*) *Two-column rotary disconnectors*. These are general-purpose disconnectors for voltages from 72.5 to 420 kV, used mainly in small substations or larger switchyards as incoming-feeder or sectionalizing disconnectors. Earthing switches can be mounted on either side.

As can be seen in Fig. 58.15, the two rotating bases are mounted on a sectional-steel frame and linked by a braced tie-rod. The post insulators are attached to the rotating bases and at the top carry the swivel heads with their arms and high-voltage contacts. When actuated, both arms turn through 90 degrees. In the open position, two-column centre-break disconnectors create a horizontal isolating distance.

The rotating bases are weather-proofed and are provided with roller bearings. The insulators are mounted on stay bolts which allow precise adjustment of the contact system once the lines are rigged, and also take care of the insulator tolerances.

The swivel arms are of welded aluminium construction with non-corroding contact pieces, so minimizing any long-term change in resistance. An interlocking device (pawl and pin) prevents the arms from separating in the event of high short-circuit currents. Current transfer to the rotating heads, which are fully protected and need no maintenance, is by way of contact fingers arranged in tulip shape round two contact pins or, for service currents > 2500 A, via tapered roller contacts. The high-voltage terminals can turn through 360 degrees, enabling the tube or wire runs to be connected in any direction. The contact system is a composite copper/steel construction with separately sprung contact fingers (none of them exposed), it has permanent dry lubrication, and thus needs minimum maintenance.

Both disconnector and earthing switch have an operating mechanism with a deadcentre interlock. This prevents them from changing service position under extreme circumstances such as short circuits, earthquakes or high winds.

Disconnector and earthing switch have separate operating mechanisms. One mechanism operates the two- or three-pole group, the individual poles of a group being mechanically linked by a connecting rod.

The actuating force from the drive is transmitted to one rotating base, and turns it through 90 degree; at the same time the tie-rod rotates the second base. When opening and closing, the contacts of the disconnector both rotate and execute a sliding movement, so easily break even severe icing.

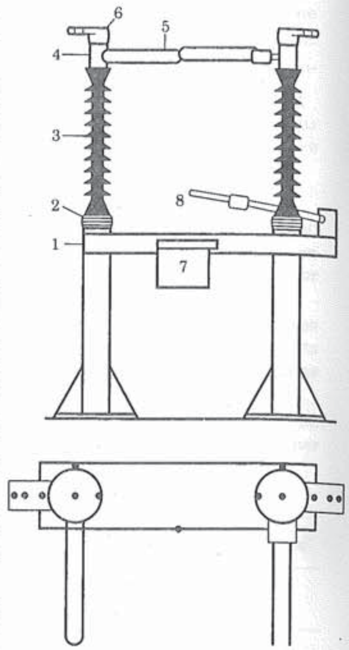


Fig. 58.15. Two-column rotary disconnector type SEF 123 kV. 1 Rotating base, 2 Frame, 3 Insulator, 4 Rotating head, 5 Swivel arm, 6 High-voltage terminal, 7 Actuator, 8 Earthing switch

The force of the operating mechanism is passed to the shaft of the earthing switch. When the disconnector closes, the arm of the earthing switch swings up and engages the earthing contact on the swivel arm.

(*b*) *Three-column rotary disconnectors*. These disconnectors are used usually for lower voltages. Compared with two-column disconnectors they allow smaller distances between phases and higher static terminal pull.

The two outer insulators are fixed to the baseframe and carry the contact system (Fig. 58.16). The middle insulator stands on a rotating base and supports the one-piece arm which, when operated, turns through about 60 degrees and engages the contact systems on the outer insulators.

The contacts for the earthing switches, which can be mounted on either side, are located at the fixed contact system.

2. Single-column (pantograph) disconnectors. In installations for higher voltages and multiple busbars, the single-column disconnector (also pantograph or vertical-reach disconnector) shown in Fig. 58.17 are provided. These require, less ground area than other kinds of disconnector. It is widely used for this reason and because of the clear station layout.

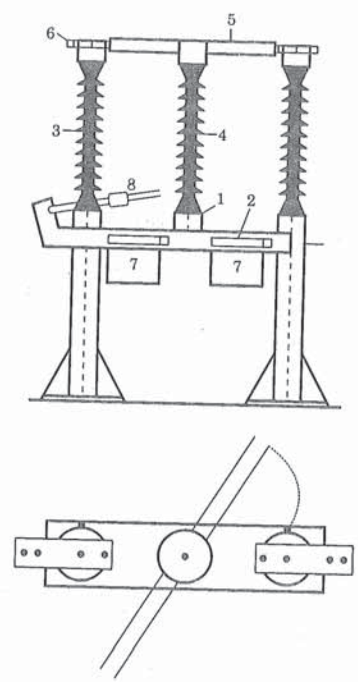


Fig. 58.16. Three-column rotary disconnector type TDA, 145 kV, 1. Swivel base, 2 Frame, 3 Fixed insulator, 4 Rotating insulator, 5 Contact arm, 6 High-voltage terminal, 7 Operating mechanisms, 8 Earthing switch.

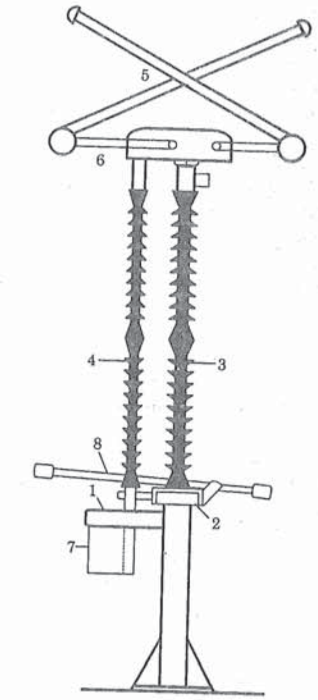


Fig. 58.17. Single-column insolator 245 kV. 1 Rotary bearing, 2 Frame, 3 Post insulator, 4 Rotating insulator, 5 Pantograph, 6 Gearbox, 7 Operating mechanism, 8 Earthing switch, 9 Suspended contact.

The base of the disconnector is the frame on which is installed the post insulator carrying the head piece with the pantograph and gearbox. The actuating force is transmitted to the gearbox by a rotating insulator. The suspended contact is mounted on the busbar situated above the disconnector. On closing it is gripped between the pantograph arms. The feeder line is connected to the high voltage terminals on the gearbox.

If desired, each disconnector pole can be equipped with a rotary/linear earthing switch as described under single column earthing switch.

The frame with its attached rotary bearing for transmitting the actuating force from the operating mechanism to the gearbox is fastened to the support by four stay bolts. These allow exact adjustment of the disconnector relative to the suspended contact, an advantage when installing and servicing. Any slight discrepancies in the foundation heights can be compensated by adjusting the stay bolts.

The pantograph assembly is a welded aluminium construction (the same for all types up to peak currents of 200 kA) which is fixed and pinned to the pantograph shaft in the gearbox. This unit is thus unable to shift. It also ensures consistently high contact pressure between the upper ends of the pantograph arms and the stirrup contact. The contact pressure of 70-150 kp (according to design) not only guarantees efficient current transfer, but also helps to break even severe icing. Contact between the gearbox and the pantograph arms and also from the lower to the upper arms is provided by flexible, multi-layer links of silver-coated copper strip or tapered roller contacts.

The contact bars at the top of the arms and also the suspended contact are of silver-plated copper, or with an inlay of high-purity silver for heavy duty or special cases. Contact erosion is therefore slight, ensuring good current transfer and long servicing intervals.

Disconnectors for high short-circuit currents have a damping device between the arm joints. In the closed position these limit the distance between the two arms to prevent any reduction in contact pressure and damping any vibration of the contact arms caused by a short-circuit current.

Single-column disconnectors have a dead-centre interlock in the gearbox, so that their position does not alter spontaneously. The setting is retained even if the rotating insulator breaks or extreme vibration due to earthquakes or short-circuit forces occurs. Anti-corona fittings at the tips of the arms act as a stop for the suspended contact if it moves vertically. The stirrup remains firmly held in the contact zone even when subject to high tensile forces due to a short circuit.

The assembly comprising pantograph and gearbox is mechanically set in the factory, greatly reducing on-site erection time.

A compensating spring in the gearbox assists the actuating force on closing, while on opening it returns the arms to the folded position.

Special versions of the single-column disconnector have been in use for many years in high-voltage direct-current (HVDC) installations.

Each disconnector pole has its own operating mechanism.

When the disconnector closes the pantograph arms execute a wide catching movement and so are sure to engage the suspended contact. The forces acting on one point and the high contact pressure together ensure reliable current transfer and can also overcome severe icing. The anti-corona fittings at the ends of the pantograph arms prevent the stirrup contact from slipping out of their grip.

Special Technical Consideration. In outdoor switching stations, a change of busbars without interruption of current supply gives rise to commutation currents during the switching operation, and these can cause increased burning at the disconnector contacts and at the fixed contact. How high these currents are depends on the distance of the switching location from the infeed or the manner of changeover, i.e., busbar or switching bay, the latter producing the higher stress.

Commutation phenomena occur both on closing and opening. Closing gives rise to bouncing between disconnector arms and stirrup contact which result in little arcing and hence slight contact wear. On opening, however, an arc is drawn between the separating arm contacts and this persists until the inverse voltage needed to extinguish the arc has been generated. Since at first the contacts move slowly this can take several cycles, severely damaging the disconnector contact elements. High-power 420 kV switchyards can experience commutation voltages up to 300 V and commutation currents up to 1600 A.

The suspended commutating contact developed by some manufacturers for single-column disconnector has two enclosed auxiliary switching systems which act independently of each other. This ensures proper operation every time, regardless of which pantograph arm is first to touch or last to leave the suspended contact. The principal components are shown in Figs. 58.18 (*a*) and (*b*). The auxiliary switch system is contained in an anti-corona hood and consists esssentially of a snap contact (coupled to the auxiliary contact bar by a toggle lever) and a deion arc-quenching device. The snap contact opens and closes regardless of switching speed when the auxiliary contact bar is in a particular position.

Since on opening th arc duration lasts only about 25 ms, wear on the snap contact system is slight and the current is safely interrupted before separation of the disconnector contact bar. By separating the main and auxiliary contact systems, no forces are exerted on the latter in the event of a fault. Short-circuit testing has demonstrated an impulse withstand strength of 200 kA. Each

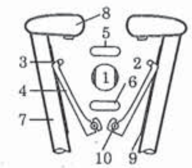


Fig. 58.18. (*a*) Commutating suspended contact, operating principle of guide strips, 1 Main contact support, 2 Main contact bar, 3 Auxiliary contact bar, 4 Toggle lever, 5 Upper guide strip, 6 Lower guide strip, 7 Pantograph arm, 8 Catch device, 9 Pantograph contact piece, 10 Insulated pivot with resetting spring.

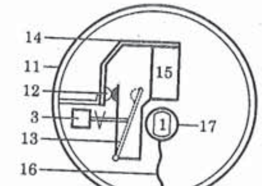


Fig. 58.18 (*b*). Commutating suspended contact, schematic of auxiliary switching chamber, 1 Main contact support, 3 auxiliary contact bar, 11 Anti-corona hood, 12 Fixed contact, 13 Snap contact, 14 Arc-deflecting baffle, 15 Deion arc-quenching plates, 16 Flexible bonding connection, 17 Rotary bearing

switching system can perform at least 350 switching cycles with commutation currents of up to 1600 A and commutation voltages up to 330 V.

Installing commutating suspended contacts thus provides the system operator with flexibility and reliability. Also these contacts can be fitted to upgrade existing installations.

3. Two-column vertical centre-break disconnectors. Higher voltages mean large isolating distances & thus long contact arms. The vertical centre-break disconnector with two-piece contact arms for voltages ≥ 400 kV is a better choice in case of space constraints.

As shown in Fig. 58.19, the two post insulator-column are mounted on a frame, Attached to them are the gearboxes with the contact arms and the high-voltage terminal Rotating insulators link the rotary bearings in the frame to the top bearings in the gearboxes. Below the frame centre, the operating mechanism is provided, the force of which is transmitted to the two rotary bearings by tie-rods.

Either side of the disconnector can be fitted as required with a rotary-linear earthing switch. The earthing contacts are mounted on a holder between the post insulator and the gearbox.

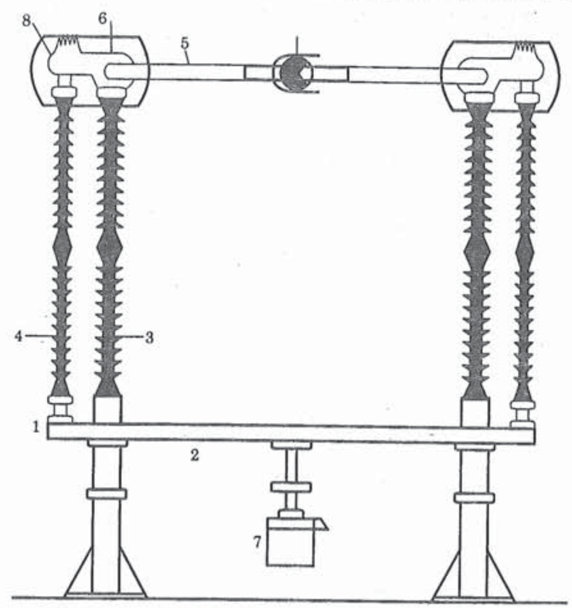


Fig. 58.19. Vertical centre-break disconnector for HV. 1 Rotary bearing, 2 Frame, 3 Post insulator, 4 Rotary insulator, 5 Contact arm, 6 High-voltage terminal, 7 Operating mechanism, 8 Gearbox.

Advantages & other Technical features : The vertical centre-break disconnector requires less force to operate than types with one-piece contact arms. The strain substation portals need not be so high and so the fundation costs are lower. The mechanical construction of the disconnector is simple because the current arms rotate only in a vertical plane without additional rotary movement to achieve the necessary contact pressure.

Like the other kinds of disconnector, the post insulators stand on stay bolts which, after the lines are rigged, allow precise adjustment of the contact arms and compensation for insulator tolerances. The rotary insulators have universal bearings at the gearbox end, and tramsmit the actuating force without distortion. Gearbox and contact half-arm form a mechanical assembly unit.

The contact arms are made up of components from the range of two-column rotary disconnectors, a welded aluminium construction with only a few bolted joints. Tapered roller contacts transfer the current in the weatherproof, cast aluminium gearbox. Dry, permanent (and maintenance-free) lubrication is used for the separately sprung, copper/steel composite contact fingers. Low contact pressures also reduce wear at the contact points. An interlocking device prevents the contact arms from separating in response to high short-circuit currents and ensures trouble-free operation even under extreme conditions.

Diagonal tie-rods transmit the actuating force from the operating mechanism to the two bottom bearings and via rotary insulators to the bearings in the gearboxes. The diagonal tie-rods and the actuating rods at the gearbox pass through a dead-centre point shortly before reaching the open position, and block the current arms in this position. Each contact arm rotates vertically through 90 degrees. In the open position they point vertically upwards, creating a horizontal isolating distance.

4. Single-column earthing switch. In outdoor switchyards earthing switches are required not only directly at the disconnectors but also at other positions, e.g., for earthing individual busbar sections. The single-column earthing switches employed for this duty can also be used as supports for tubular busbars.

Earthing switches for mounting on disconnectors or separately on a single column have the same components. The only exceptions are the frame and support for the earthing contact.

A baseframe containing the operating mechanism supports the insulator (Fig. 58.20), to which are attached the contact holder and the earthing contact.

Two types of such switches are manufactured are available, to meet different requirements : (a) vertical-reach earthing switches for low rated voltages and peak currents, (b) rotary/linear earthing switches for higher voltages and peak currents. The differences lie in the design of the operating mechanism, and hence in the movement executed by the contact arm.

The contact arm of the vertical-reach earthing switch is able to swivel on a shaft and executes only a rotary movement with an angle of about 90 degree. In the closed position the earthing contact lies between the contact fingers, and these in turn against a spring stop. The mechanics of the rotary/linear earthing switch allow increased performance: the contact arm at first rotates, but towards the end of this rotation moves in a straight line into the earthing contact. The contact blade mounted on the contact arm is thus fixed in the earthing contact, making a joint which can withstand high peak currents.

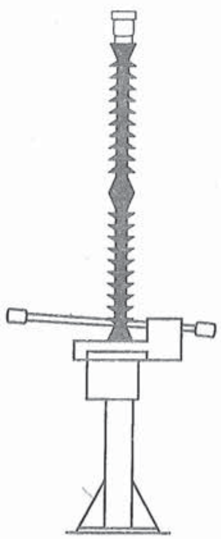


Fig. 58.20. High-voltage single-column earthing switch 420 kV

Disconnectors and earthing switches can be actuated by motor-driven, compressed-air or manual operating mechanisms. Air-powered mechanisms are now used only where a source of compressed air is already available. Motorized systems are usually simpler and less costly to install and connect.

The operating mechanism is generally mounted direct on the baseframe of the disconnector or earthing switch. However, disconnector situated well of the ground, e.g., on a portal, can also have the operating mechanism positioned within reach. The actuator unit then requires a bearing and additional like rods. Emergency manual operation is possible with all operating mechanisms if the power source should fail, or for making adjustments.

The operating mechanisms also incorporate annunciator switches for indicating the switching position and for control and interlock purposes: motor-driven units also include contactors and control devices. The control system is arranged so that only one switching pulse is needed and the actuators switch off automatically when the end-position is reached. In the event of emergency manual operation a safety contact interrupts the motor circuit so that simultaneous actuation from the control room is not possible. Motor-driven systems can also be equipped for local and remote control.

To prevent maloperation the operating mechanisms of disconnectors and earthing switches can be interlocked relative to each other: motorized systems electrically, compressed-air systems electro-pneumatically and manual systems mechanically. Manual and motorized systems can also be equipped with a locking solenoid which when the interlock voltage is dead prevents actuation by hand. Local operation is then possible only if the interlock voltage is present and the specified interlocking conditions are satisified. For instance, a disconnector can only be closed or opened if its related circuit-breaker is open. Various kinds of key-operated interlocks are also fitted.

The actuating systems of disconnectors and earthing switches have a dead-centre interlock so that the switching position cannot change spontaneously under extreme conditions such as short circuit, earthquakes or hurricane.

5. Load switches. High-voltage load switches are mechanical switching devices which are able to make carry and break the currents - which may also include a specified operating overload-occurring in the network under normal conditions, and also to carry currents under specified abnormal system conditions, e.g., short circuits, for a certain time. A load switch may also be able to close on short-circuit currents, but not interrupt them.

Load switches are designed for both indoor and outdoor installation. According to their switching function or application, these switches are classified as :

— general-purpose switches — transformer off-load switches
— single-capacitor-bank switches

Also used are switch-disconnectors with a visible isolating distance in the open position.

Load switches are increasingly being used in gas insulated switchgear installations.

58.7.1. Circuit Breakers Function

High-voltage circuit-breakers are mechanical switching devices able to make, continuously carry and interrupt currents under normal circuit conditions and also for a limited time under abnormal circuit conditions e.g. short circuits. Circuit-breakers are used for switching overhead lines, cable branches, transformers, reactors and capacitors. They are also used in bus and section-ties in multiple-busbar installations so that power can be transmitted from one bus bar to the other.

Specially designed breakers are used for specific duties such as railways, where in 16 2/3 Hz networks they have to extinguish longer-burning arcs, (longer half-wave).

Breakers for use with melting furnaces operate frequently and so require smaller actuating forces and lower breaking capacity. They therefore experience less wear, despite the high switching rate, and so servicing intervals are long.

(*b*) **Selection.** The principal points to consider when selecting circuit-breakers are :

— maximum operating voltage at location
— height of installation above sea level
— maximum operating current occurring at location
— maximum short-circuit current occurring at location
— system frequency
— duration of short-circuit current
— switching cycle
— particualr operational and climatic conditions

(c) **Selection.** Rated values can be selected with the aid of Tables 10-1 and 10-2.

(d) **Reference standards.** Important national and international standards for circuit breakers are :

IEC	VDE
56-1	0670 Part 100/2.78 General and definitions
56-2	0670 Part 102/2.82 Classification
56-3	0670 Part 103/2.78 Design and construction
56-4	0670 Part 104/11.78 Type and routine testing
56-5	0670 Part 105/3.79 Selection
56-6	0670 Part 106/3.79 Information in enquiries, tenders and orders
56-7	0670 Part 107/7.80 Testing under asynchronous conditions
427	0670 Part 108/5.79 Synthetic testing
	0670 Part 1000/8.84 Common clauses for HV switchgear and controlgear

ANSI (American National Standards Institution)

C 37.04 — 1979 Rating structure
C 37.06 — 1979 Preferred ratings
C 37.09 — 1979 Test procedure
C 37.010 — 1979 Application guide
C 37.011 — 1979 Application guide for transient recovery voltage
C 37.012 — 1979 Capacitance current switching
C 37.11 — 1979 Requirements for electrical control

Table 1.

Table for coordinating rated values of circuit-breakers to DIN VDE 0670 Part 102, IEC 56-2

Rated voltage	*Rated short-circuit breaking current*	*Rated operating current*				
kV	*kA*	*A*				
123	12.5	800	1250			
	20		1250	1600	2000	
	25		1250	1600	2000	
	40			1600	2000	
145	12.5	800	1250			
	20		1250	1600	2000	
	25		1250	1600	2000	
	31.5		1250	1600	2000	3150
	40			1600	2000	3150
	50				2000	3150
170	12.5	800	1250			
	20		1250	1600	2000	
	31.5		1250	1600	2000	3150
	40			1600	2000	3150
	50			1600	2000	3150
245	20		1250	1600	2000	
	31.5		1250	1600	2000	
	40			1600	2000	3150
	50				2000	3150

Rated voltage	*Rated short-circuit breaking current*	*Rated operating current*				
kV	*kA*	*A*				
300	16	1250	1600			
	20	1250	1600	2000		
	31.5	1250	1600	2000	3150	
	50		1600	2000	3150	
362	20			2000		
	31.5			2000		
	40		1600	2000	3150	
420	20		1600	2000		
	31.5		1600	2000		
	40		1600	2000	3150	
	50			2000	3150	4000
525	40			2000	3150	
765	40			2000	3150	

Table for coordinating rated values of circuit-breakers to ANSI C 37.06.1979

Rated voltage	*Maximum rated voltage*	*Rated short-circuit breaking current*	*Rated operating current*			
kV	*kV*	*kA*	*A*			
34	38	22	1200			
69	72.5	37				
115	121	20	1200		2000	
		40		1600	2000	3000
		63				3000
138	145	20	1200			
		40		1600	2000	3000
		63			2000	3000
		80				3000
161	169	16	1200			
		31.5		1600		
		40			2000	
		50			2000	
230	245	31.5		1600	2000	3000
		40			2000	3000
		63				3000
345	362	40			2000	3000
500	550	40			2000	3000
700	765	40			2000	3000

(e) **Design.** The main subassemblies of HVCB include : operating mechanism, insulators, extinction chamber, capacitor and resistor.

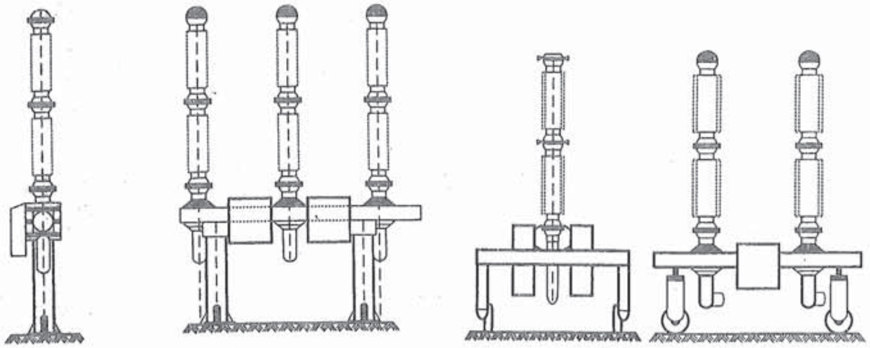
HV circuit-breakers are built on the modular principle. The number of interrupting chambers is increased to cope with higher voltages and capacities.

Single-chamber breakers are used for voltages up to 245 kV and breaking currents of 40 kA. Multiple-chamber breakers are preferred for higher currents within this voltage range.

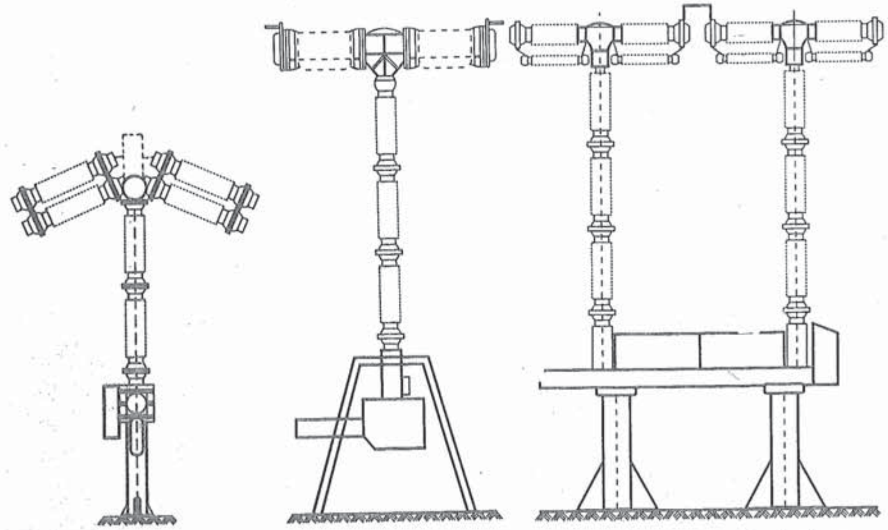
Only multiple-chamber breakers are used for voltages ≥ 245 kV. Up to 525 kV and a breaking current of 50 kA they have two chambers. With higher voltages or capacities the number of chambers can be four or more.

All breakers can be installed as individual poles, each with its own operating mechanism. For the lower voltages and three-phase auto-reclosure the 3 poles are best mounted on a common frame. HV circuit-breakers can also be mounted on trolleys with sprocket-type or plain wheels.

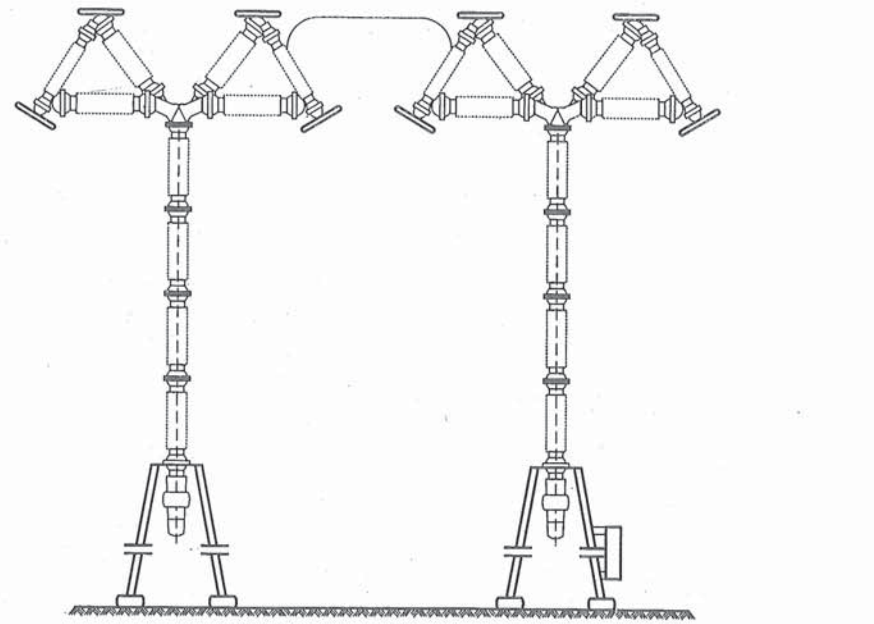
Typical arrangement of various voltage rating breaker is given in Fig. 58.21.



(a) 132 kV Three-pole arrangement (b) 132 kV two-pole with trolley



(c) 245 kV Single-pole (d) 420 kV Two chamber (e) 420 kV 4-chamber A without Pre-Insertion resistors



(f) 800 kV 4 chamber with closing resistors

Fig. 58.21

Typical arrangements of Various rating SF6 Outdoor Circuit breaker

Brief Arc extinction process of a cricuit Breaker

The arc-extinction process can take two basic forms.

Direct-current extinction, Fig. 58.22.

A d.c. arc can be extinguished only when the arc voltage U_s is greater than the voltage present at the breaker LS. A sufficiently high arc voltage can be built up - at reasonable measures — only in low and medium-voltage d.c. circuits (magnetic blowout breakers). To extinguish the d.c. arc in d.c. high-voltage circuits the voltage must be lowered accordingly and/or artificial current zeroes must be created by inserting a resonant circuit.

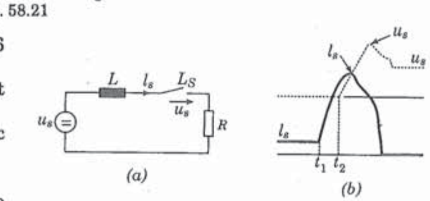


Fig. 58.22 Direct-current extinction, (a) simplified equivalent circuit, (b) curves of current I_s and arc voltage U_s, t_1 initiation of short-circuit, t_2 contact separation

Alternating-current extinction, Fig. 58.23 a.c. arcs are extinguished at each current zero. In high-voltage circuits, and without extra measures the arc re-ignites after passing current

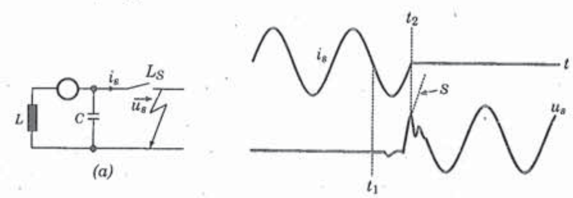


Fig. 58.23 Alternating-current extinction, (a) simplified equivalent circuit, (b) curves of short-circuit current i_s and recovery voltage U_s, t_1 contact separation, t_2 arc extinction, S rate of rise of recovery voltage

zero, and so continues to burn. In high-voltage breakers, the arc plasma is intensively cooled in the extinction chambers thus reducing its electrical conductivity at current zero so the recovery voltage is insufficient for re-striking.

Voltage stresses on the breaker. While Interrupting different types of loads :

(*a*) On interrupting an inductive load (Fig. 58.24 a) the breaker voltage oscillates to the peak value of the recovery voltage. The breaker must be able to cope with the recovery voltage's rate of rise and its peak value. The dielectric strength between the arcing contacts must built up faster than the recovery voltage rises, if re-striking is to be prevented.

(*b*) When interrupting a purely resistive load (Fig. 58.24 b) current zero and voltage zero coincide. The recovery voltage at the breaker rises sinusoidally with the service frequency. The gap between the contacts has sufficient time to recover.

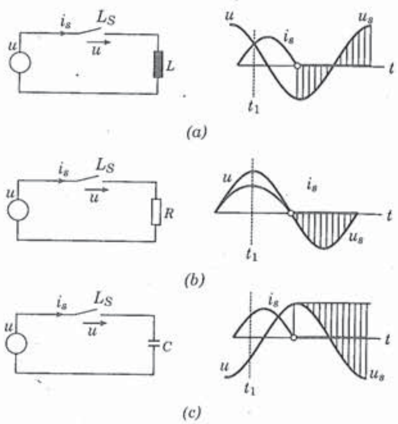


Fig. 58.24. Recovery voltage U_s when interrupting (*a*) inductive load, (*b*) resistive load, (*c*) capacitive load

(c) When switching a capacitive load (Fig. 58.24 c) following interruption of the current the supply-side voltage (infeed C.B. terminal) oscillates at system frequency between ± μ, while the breaker terminal on the capacitor side remains charged at + μ.

Different Switching Conditions for which breaker has to be designed/developed. Depending on their location, circuit-breakers have to cope with a variety of conditions which in turn impose different requirements on the breaker. *e.g.*

(*i*) **Terminal fault (symmetrical short-circuit current).** Fig. 58.25. A terminal fault is a short circuit on the consumer side of a breaker in the immediate vicinity of the breaker terminals. The short-circuit current is symmetrical if the fault takes place at the voltage maximum. The recovery voltage settles to the value of the driving voltage. Rate of rise and amplitude of the transient voltage are determined by the network parameters.

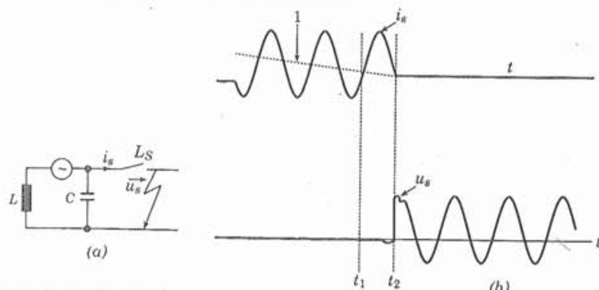


Fig. 58.25. Terminal fault, (*a*) simplified equivalent circuit, (*b*) curves of recovery voltage U_s and short-circuit

(*ii*) **Terminal fault (asymmetrical short-circuit current).** In addition to the symmetrical short-circuit current, a d.c. component also has to be interrupted, its magnitude depending on the breaker's mechanical opening time. The d.c. component of the short-circuit current depends on the moment of short circuit initiation (max. at voltage zero) and on the time constants of the network's supply-side components such as generators, transformers, cables and h.v. lines.

(*iii*) **Short-line fault, Fig. 58.26.** Short-line faults are short circuits that occur on overhead lines not far (a few kilometres) from the breaker. They impose a particularly severe stress on the breaker because two transient voltages are superimposed: the transient voltage of the feeder network and the transient voltage on the line side. The cumulative effect is a particularly steep rate of rise of voltage, with only a minor reduction in the short-circuit current. The critical distance of the short-circuit depends on current, voltage and arc-quenching medium.

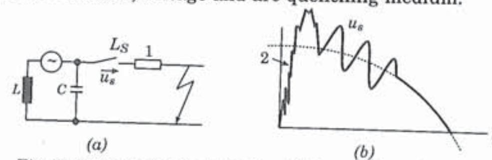


Fig. 58.26. Short-line fault, (*a*) simplified equivalent circuit, (*b*) recovery voltage U_s across breaker, 1 Line, 2 Sawtooth shape of U_s

(*iv*) **Phase opposition.** The (power frequency) voltage stress is severe if the phase-angles of the systems on either side of the breaker are different (system components fall out of step or generator breakers incorrectly synchronized).

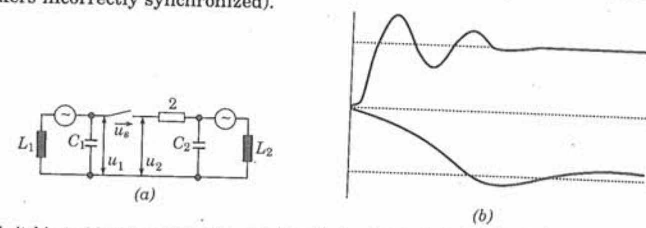


Fig. 58.27 Switching with phase opposition, (*a*) simplified equivalent circuit, (*b*) voltage stress on circuit-breaker

(*v*) **Interruption of small inductive currents, Fig. 58.28.** Depending on network configuration, the interruption of small inductive currents, such as reactors or transformer magnetizing currents, can cause a rapid rise of recovery voltage and also high overvoltages as a result of current chopping (forced extinction) before the natural zero passage.

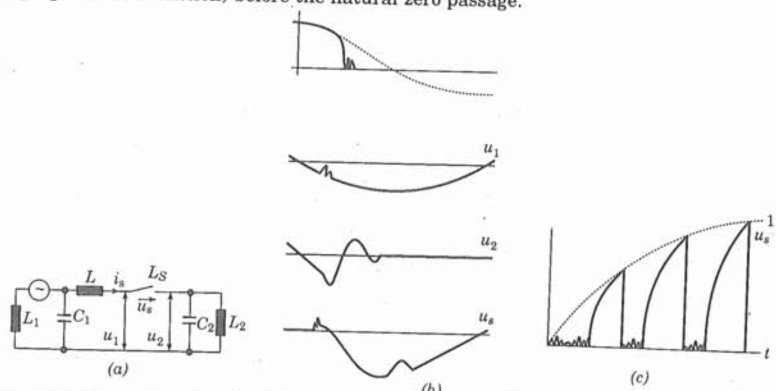


Fig. 58.28. Interruption of small inductive currents, (*a*) simplified equivalent circuit, (*b*) curves of current and voltages with current chopping without re-striking, (*c*) curve of voltage in response to re-striking

(*vi*) **Switching capacitive currents, Fig. 58.29.** This situation imposes no severe stresses, as breakers that prevent re-striking are generally available (Fig. 58.29). Theoretically, however, repeated re-striking can increase the voltage stress to a multiple peak value of the driving voltage.

Switching of open-circuit lines and cables :

The capacitance per unit length of line or cable imposes similar conditions as to the switching of capacitors.

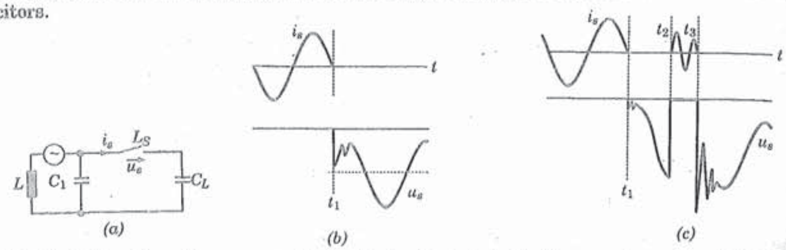


Fig. 58.29. Switching of capacitive currents, (*a*) simplified equivalent circuit, (*b*) curves of current and voltage, (*c*) curves of current and voltage when re-striking occurs

(*vii*) Stresses on contacts when connecting an inductive circuit, see Fig. 58.30.

Closing on inductances and capacitances can produce overvoltages of up to 100%. Circuit-breakers for high voltages and very long lines (approx. 300 km) are therefore fitted with closing resistors.

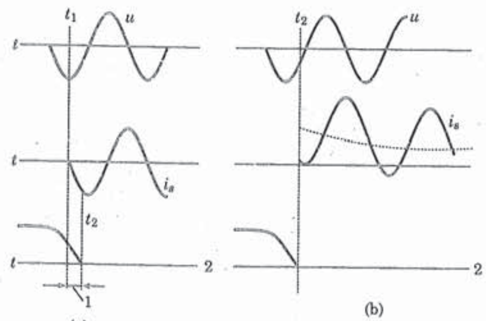


Fig. 58.30. Contact stress when connecting an inductive circuit: (*a*) with pre-arcing (*b*) without pre-arcing

58.7.2. Quenching Medium and Operating Principle for Different Insulating & Quenching Medium

(*i*) **SF_6 gas.** Circuit-breakers using SF_6 gas as the insulating and quenching medium have been operating successfully throughout the world for a number of years. This gas is particularly suitable as a quenching medium because of its high dielectric strength and high thermal conductivity.

Fig. 58.31 shows the design and operating principle of the extinction chamber of a SF_6 circuit-breaker. The extinction unit consists of the fixed contact and the moving contact with its blast cylinder. During the opening movement the volume of the blast cylinder diminishes steadily and hence the pressure of the gas inside it increases until fixed and moving contacts separate. Separation of the contacts causes an arc to be drawn which further raises the pressure of the SF_6 gas in the blast cylinder. When the pressure is high enough the compressed gas is released and blows the arc, so depleting its energy and causing it to extinguish. The nozzle shape of both contacts results in optimum flow and quenching characteristics.

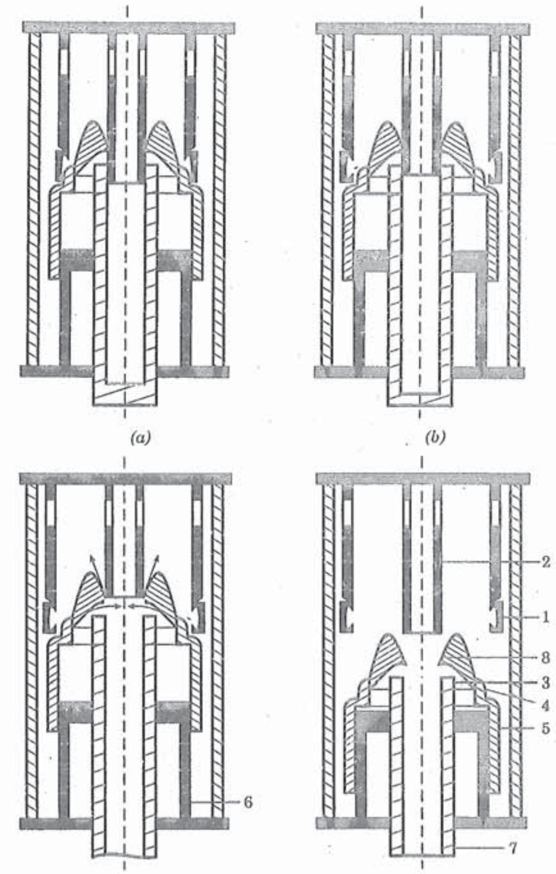


Fig. 58.31. Principle of SF_6 breaker for outdoor installation, 4 positions of opening process, (*a*) closed position, (*b*) opening movement begins, (*c*) arc contacts separate, (*d*) open position.
1 Fixed continuous current contact, 2 Fixed arcing contact, 3 Moving arcing contact, 4 Moving continuous current contact, 5 Compression cylinder, 6 Compression piston, 7 Actuating rod, 8 Quenching nozzle

(*ii*) **Oil.** Up to about 1930 high-voltage breakers were of the bulk-oil type. The oil was used as insulation and to extinguish the arc. The arc heats the oil in its vicinity, so causing it to flow and extinguish the arc. The bulk oil breaker, which contains a large amount of oil, was gradually replaced by the minimum-oil breaker in which the extinction chamber contains a small volume of oil. With these breakers, too, the arc heats the oil and so brings about its own extinction. When switching small currents, quenching of the arc is assisted by a pump effect.

(*iii*) **Compressed air.** Air-blast breakers using compressed air as the quenching, insulating and actuating medium were widespread up to the end of the seventies. Here the quenching medium is held in an air receiver at pressures up to some 30 bar, and inside the breaker. As the contacts separate, compressed air is blown through the nozzle-shape contacts, so quenching the arc and establishing the insulating gap. Air compressor, storage and distribution systems provide air-blast breakers with clean, dry, compressed air.

58.7.3. Different types of Operating mechanisms of HV, CB

(*i*) *Spring-powered operating mechanism.* The spring-operated mechanism is a mechanical system in which energy is stored by a powerful spring. The spring is tensioned with an electric motor and held ready by a latch arrangement. When the breaker trips, a magnet releases the latch and the force of the spring is used to move the contact.

(*ii*) *Hydraulic spring operating mechanism.* The hydraulic spring mechanism is a combination of hydraulic and spring systems. Energy is transmitted by an incompressible medium, usually oil, and stored with the aid of a spring. A pump feeds oil into a high-pressure cylinder in which a piston tensions a strong spring. Solenoid pilot valves allow the oil to pass to the master valve and from here to the actuator cylinder for closing, or to the low-pressure tank for opening. All dynamically stressed seals are between the high and low-pressure volumes. In the event of a leak, therefore, oil can pass only into the low-pressure volume, but not to the outside.

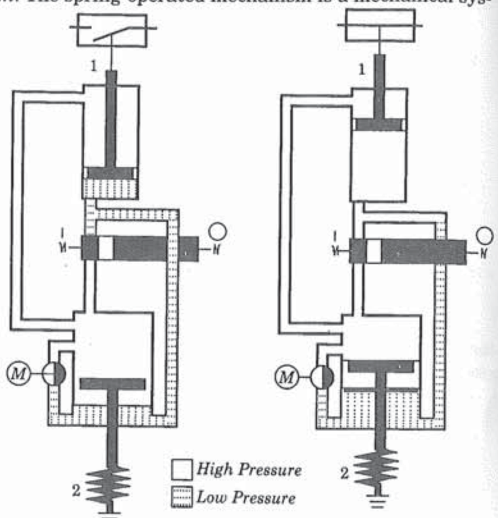


Fig. 58.32 Principle of hydraulic spring operating mechanism, (*a*) OPEN position, (*b*) CLOSED position, 1 Breaker actuating rod. 2 Disc-spring column.

The principle of the hydraulic spring operating mechanism is given in Fig. 58.32.

The system works on the differential piston principle. The OPEN (piston rod) side is smaller than the CLOSED (piston face) side by the cross-section area of the piston rod. The piston rod side is permanently under system pressure. The piston face side, on the other hand, is subjected to system pressure on closing, and relieved on opening.

(*iii*) *Pneumatic operating mechanism.* The pneumatic system uses compressed air contained in a receiver directly on the breaker. Solenoid valves allow the compressed air to pass to the actuator cylinder (on closing) or to atmosphere (on opening).

58.7.4. Electrical control of H.V. Circuit breakers

(*a*) *Phase-discrepancy monitoring for breakers with single-pole actuation.* If a TRIP circuit of a breaker pole is disturbed, this pole does not respond to an TRIP command, and the three breaker poles adopt different positions. The phase-discrepancy monitoring system detects this difference and after a preset waiting time of 2 s actuates the joint OPEN operation of all three breaker poles.

Breakers with three-pole auto-reclosure do not need phase-discrepancy supervision because the three poles are mechanically linked and so cannot achieve different positions.

(*b*) *Anti-pumping control.* Anti-pumping control prevents repeated, undesired operation of one or more breakers if an existing OPEN command is followed by repeated CLOSE commands. The breaker must then close no more than once, followed by lock-out, *i.e.* it must stay in the OPEN position, regardless of whether control commands are applied, or for how long.

(*c*) *Non-stop motor operation.* Depending on the system design and the switching cycle performed, the pump or compressor requires a certain time to restore the energy expended. If there is a leak in the pressure system the motor starts more often or runs continuously. Non-stop running is interpreted as a disturbance and signalled.

(*d*) *SF_6 gas monitoring.* The breaking capacity of a circuit-breaker depends on the density of the gas in the breaking chamber, and this is measured with a temperature-compensated pressure gauge. An alarm is given if the gas density falls to a preset value, and if it falls further to a specified minimum the breaker is blocked.

(*e*) *Local / remote control.* To allow work to be done on the breaker, it can usually be controlled from the local cubicle; control can be set from remote to local by means of a selector-switch.

(*f*) *Pressure monitoring.* Control and supervision of pressure is required particularly with pneumatic and hydraulic operating mechanisms that use nitrogen to store energy. A multipole pressure switch performs the following functions:

— close replenishment valve, *i.e.* stop pump or compressor
— open replenishment valve, *i.e.* start pump or compressor
— interlock auto-reclosure if pressure is insufficient
— interlock CLOSE operation, prevents breaker closing if it then cannot open because pressure is insufficient
— interlock OPEN operation, prevent breaker opening if pressure is insufficient

Hydromechanical operating mechanisms are controlled by means of a gate system. These mechanisms depend not on pressure, but on travel.

(*g*) *Auto-reclosure.* Single or three-pole auto-reclosure is selected according to the kind of system earth, the extent of network interconnection, the length of the lines and the amount of infeed from large power plants. Tripping commands from the network protection system (overcurrent and line protection) are accordingly evaluated differently for the respective circuit breakers.

In circuit breakers for single-phase auto-reclosure each pole has a separately controlled operating mechanism. Any pole can thus be tripped independently. However, all three poles close together, and the auxiliary power system for the three poles is supplied from a single unit. The clearance of transient faults can then be limited in time and location, without taking out larger parts of the network. Single-phase tripping improves system stability; the network remains in synchronism. The three poles of breakers with single-phase auto-reclosure can also be controlled so that they open and close together.

Circuit-breakers for three-phase auto-reclosure have a single actuator cylinder for all three poles. The three poles are mechanically linked to each other and to the operating mechanism. They can therefore only be closed and opened all together. In stable networks (where loss of synchronism is unlikely) breakers with three-phase auto-reclosure shorten possible outage times.

58.7.5. Instrument transformers for switchgear installations.

Instrument transformers to transform high voltages or currents to values which are unified or can be measured safely, while incurring low internal losses. In the case of current transformers the primary winding carries the operating current, while with voltage transformers it is connected to the operating voltage. The voltage or current of the secondary winding is identical to the value on the primary side in phase and ratio, except for the error of the transformer. Current transformers operate under almost short-circuit conditions, while voltage transformers operate at no-load. Primary and secondary sides are nearly always electrically independent and insulated from each other as required by the operating voltage.

Instrument transformers are used either for measuring purposes when connected to measuring instruments, meters and the like, or for protection purposes, in which case they are connected to protective devices.

Instrument transformers are divided into classes according to their accuracy of measurement. Their applications are summarized in Table.

Table Applications and classes of instrument transformers

Application	*VDE class*	*IEC class*	*ANSI class*
Precision measurements and calibration	0.1	0.1	0.3
Accurate power measurement, tariff metering	0.2	0.2	0.3
Tariff metering, accurate measuring instruments	0.5	0.5	0.6
Industrial meters: voltage, current, power, etc.	1	1	1.2
Ammeters or voltmeters, overcurrent or voltage relays	3	3.5	1.2
Protection cores of current transformers	5 P, 10 P		C, T

Definition according to DIN VDE 0414

1. *Current transformers :*

— Primary and secondary rated current are the primary and secondary currents stated on the nameplate.

— Rated transformation ratio is the ratio of the primary rated current to the secondary rated current.

— Burden is the impedance of the secondary circuit expressed in terms of its modulus and power factor cos β.

— Rated burden is the burden to which specifications regarding error limits are referred.

— Rated output is the apparent power in VA at rated secondary current and rated burden.

— Current error is the deviation in percent of the secondary current, multiplied by the nominal transformation ratio, from the primary current.

— Phase displacement is the difference in phase angle of the secondary current relative to the primary current.

— Composite error of a current transformer is the ratio in per cent having as divisor the rms value of the primary current and as dividend the rms value taken over one cycle of the difference between the instantaneous values of the secondary current multiplied by the rated transformation ratio and the instantaneous values of the primary current.

$$F_g = 100 \frac{\sqrt{\frac{1}{T}\int_0^T (K_N \cdot i_2 - i_1)^2 dt}}{I_1}$$

Here : F_g Composite error in %,
T Duration of one cycle in s,
K_N Rated transformation ratio,
I_1 rms value of primary current in A,
i_1 Instantaneous value of primary current in A,
i_2 Instantaneous value of secondary current in A.

— Primary rated accuracy limit current is a current at which at rated burden the composite error specified for instrument transformers for protection purposes is not exceeded and at which the composite error for instrument transformers for measuring purposes is greater than 15%.

— Rated accuracy limit factor is a defined number by which the primary rated current must be multiplied to obtain the primary rated accuracy limit current.

— Rated continuous thermal current is 1.2 times the rated current, and 1.5 or 2 times this current in the case of current transformers with extended range.

— A current transformer with extended range is a transformer whose rated continuous thermal current is greater than 1.2 times the rated current and which complies with the specified error limits.

— Rated short-time thermal current (I_{th}) is stated on the nameplate as the rms value of the primary current of one second duration which the current transformer can withstand without suffering damage when the secondary winding is short-circuited.

— Rated dynamic current (I_{dyn}) is the value of the first current crest the related forces of which a current transformer can withstand without damage with the secondary winding short-circuited.

2. *Voltage transformers :*

— Primary rated voltage is the value of the primary voltage stated on the nameplate. In the case of phase-insulated transformers connected in three-phase networks between phase and earth it is stated in the form $U/\sqrt{3}$, U being the voltage between the phase conductors.

— Secondary rated voltage is the value of the secondary voltage stated on the nameplate, also stated as $U/\sqrt{3}$. In the case of earth-fault detection windings it is stated in the form $U/3$.

— An earth-fault detection winding for three-phase networks consists of a set of three phase-isolated transformers.

— Rated transformation ratio is the ratio of the primary to the secondary rated voltage.

— Burden is the admittance of the secondary circuit expressed in terms of its value and burden power factor cos β.

— Rated burden is the burden to which the specifications regarding error limits are referred.

— Rated output is the apparent power at secondary rated voltage and rated burden.

— Voltage error of a voltage transformer at a given primary voltage is the difference in per cent between the secondary voltage, multiplied by the rated transformation ratio and the primary voltage. The voltage error is taken to be positive if the actual value of the secondary voltage is greater than the desired value.

The voltage error of a voltage transformer is :

$$F_u = 100 \cdot \frac{U_2 \cdot K_N - U_1}{U_1}$$

Here : F_u Voltage error in %, U_1 Primary voltage in V,
U_2 Secondary voltage in V, K_N Rated transformation ratio.

— Error angle is the phase displacement of the secondary voltage relative to the primary voltage.

— Rated long-duration current is the current in an earth-fault detection winding which this can withstand for 4 or 8 hours in the event of an earth fault at 1.9 times the primary voltage and with the other windings simultaneously connected to rated burden, without the permitted temperature rise being exceeded by more than 10°C.

— Short-time load rating is determined by the rated voltage factors and duration of the load at elevated voltages.

58.7.6. Current transformers

The primary winding is incorporated in the line and carries the current flowing in the network. It is provided with various secondary cores. The purpose of current transformers is to transform the primary current in respect of magnitude and phase angle within prescribed error limits. The main source of transformation errors is the magnetizing current. So that this and the transformation errors remain small, all current transformers are equipped with high-grade core magnets. The cores are made of silicon-iron or high-alloy nickel-iron. Fig. 58.33 shows the magnetizing curves of different core materials. In special cases cores with an air gap are used in order to influence the core's behaviour in the event of transients.

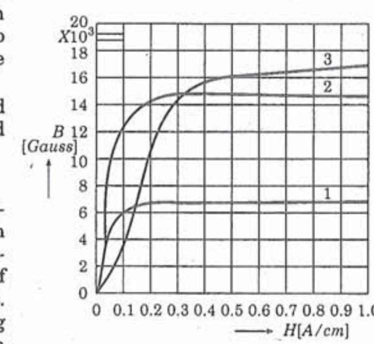


Fig. 58.33. Magnetizing curves of different core materials. Material 1 is used mainly for measuring cores, and material 3 for protection cores. H = field strength [A/cm], B = peak flux density [gauss], 1 = nickel-iron with approx. 75% Ni, 2 = nickel-iron with approx. 50% Ni, 3 = mill-patterned cold-rolled silicon-iron.

Current transformers are divided in single-turn transformers and wound-type transformers depending on the construction of the primary winding. Single-turn transformers are made in the form of outdoor inverted-type transformers, straight-through transformers, slipover and bar transformers. Wound-type transformers can be bushing transformers, post-type and miniature transformers and also outdoor post-type and tank transformers with oil-paper insulation. Fig. 58.34 shows the basic construction of an inverted-type transformer (Fig. 58.34 a) and a tank-type transformer (Fig. 58.34 b).

The different designs of current transformer according to insulating medium are shown in Table 10-5.

Table 10-5 Design of current transformers

Insulation	*Type*	*Voltage range*	*Application*
Dry	Slipover, wound and cable-type transformers	Low voltage	Indoors
Cast resin	Post-type and bushing transformers	Medium voltage	Indoors and SF_6-installation
Oil-impregnated paper/porcelain	Tank and inverted-type transformers	High and very high voltage	Outdoors

If required, current transformers can be provided with reconnecting facilities for two or more different primary currents. The following versions are possible :

Primary changeover. Changeover takes the form of switching two or more partial primary windings in series/series-parallel or parallel. The rated output and rated overcurrent factor remain unchanged. The rated thermal short-time current and rated dynamic current decrease in direct proportion to the primary current.

Secondary tappings. Changeover is performed with the aid of tappings on the secondary winding.

When the primary rated current is reduced in this way, the rated output in classes 0.1 to 3 decreases approximately as the square of the reduction in primary current, and in protection classes 5 P to 10 P roughly in direct proportion to this reduction.

The absolute values of the thermal rated short-circuit current and rated dynamic current also remain the same for all ratios.

Selection of current transformers. The factors determining the choice of current transformers are the values of the primary and secondary rated currents, the rated outputs of the different cores for a given accuracy class, and the rated overcurrent factor. The rated current of the transformer has to be adapted to suit the operating current.

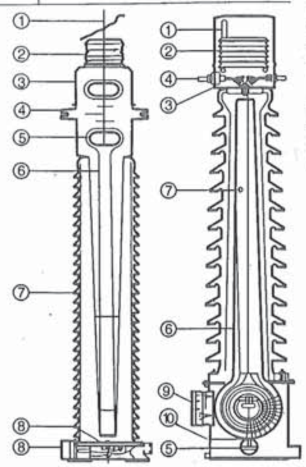


Fig. 58.34 (*a*) Inverted-type current transformer AOK for 300-525 kV, 40-6000 A, (*b*) Tank-type current transformer AOT for 300-765 kV, 40-4000 A, 1 Oil level indicator, 2 Bellow, 3 Terminal head, 4 Primary terminals, 5 Cores with secondary winding. 6 Core-and-coil assembly with main insulation, 7 Insulator. 8 Base plate, 9 Terminal box, 10 Tank

According to DIN VDE 0414, current transformers can be continuously overloaded by 20%. With an operating current of 120 A, for example, this means a transformer for 10% A can be used. Current transformers for wide-range use can be loaded continuously the 1.5. I_N (ext. 150%) or 2.0 . I_N (ext. 200%).

Determining the output of a current transformer. The sec. output of a current transformer is governed by the number of ampere-turns the core material and the construction of the core. The output varies approximately at the square of the number of ampere-turns (roughly linear with

protection cores). However, it also decreases roughly as the square of the difference between operating current and the rated current of the transformer (approximately linearly in the case of protection cores), so that with a transformer rated 30 VA and loaded with half the rated current, the output is reduced to a quarter, *i.e.* to about 7.5 VA.

The rated output of a current transformer is the product of the nominal burden Z and the square of the rated secondary current I_{2N}, i.e.: $S_N = XZ\, I_{2N}^2$ in VA. A current transformer with a secondary current of I_{2N} = 5A and a connected burden of 1.2 Ω thus has a rated output of 1.2. $5^2 = 30VA$. The transformer may be loaded with the rated output stated on the nameplate, without exceeding the limits of error. This means that a series-connected current paths of measuring instruments, meters and protective relays in the secondary circuit, including the resistance of their associated connection wires and cables, must not in total exceed this nominal burden (Table 58.6).

Table 58.6
Rated outputs and nominal burdens of current transformers (for 50 Hz)

Rated output in VA	5	10	15	30	60
Nominal burden at 5 A in Ω	0.2	0.4	0.6	1.2	2.4
Nominal burden at 1 A in Ω	5	10	15	30	60

For 162/3 Hz the transformer output must be multiplied by a factor of approximately 0.33 and for 60 Hz by 1.2.

When selecting current transformers, attention must be paid to the rated overcurrent factor, as well as to the output. The rated overcurrent is stated on the nameplate.

For measuring and metering cores, the rated overcurrent factor should be as small as possible, *e.g.* M 5 or M 10, to protect the connected measuring instruments from excessive overcurrents or short-circuit currents. Since the rated overcurrent factor is valid only for the nominal burden, while the actual overcurrent factor increases roughly in inverse proportion to the decrease in burden or transformer loading, care must be taken to ensure that the operating burden of the connected measuring instruments, including the necessary connecting wires and cables, is as close as possible to the nominal burden of the transformer, to prevent the instruments from being damaged. Otherwise, an extra burden should be included in the secondary circuit.

Example 58.1. Current transformer to 100/5 A, 30 VA class 0.5 M 5

Power requirement :	1 ammeter	...	2.5 VA
	1 wattmeter	...	3 VA
	25 m cable of 2.5 mm^2	...	4.5 VA
	Total power requirement	...	10 VA

Since the product of the core output and rated overcurrent factor is almost constant, in the example we have 30 VA . 5 = 150. With a burden of only 10 VA this then gives an overcurrent factor of 150 : 10 = 15. The measuring instruments are then insufficiently protected. If a transformer of only 15 VA is selected, the overcurrent factor is 7.5. The transformer output could thus be even smaller, or an additional burden would have to be provided.

Protection cores for connection to protective relays must unlike measuring cores, be so chosen that, depending on the settings of the relays, their total error in the region (short-circuit currents) where the relays have to function reliably, *e.g.* between 6 and 8 times the rated current, is not too large. The protection core must therefore be so designed that the product of rated output and rated overcurrent factor is at least equal to the product of the secondary circuit power requirement at rated current and the necessary rated overcurrent factor. This must be considered especially if verification of the thermal short-circuit stress indicates an enlarged conductor cross-section on the primary side. In this case one can either choose a current transformer for a higher rated current, whereupon the number of primary turns will be smaller (but so will the output because the operating current is lower than the rated current), or one can use a special transformer.

Example 58.2.

Current transformer for 400/5 A, 15 VA class 5 P 10

Power requirement:	overcurrent relays	...	8 VA
	differential relays	...	1 VA
	cable	...	3 VA
	Total power requirement	...	12 VA

The overcurrent factor is then $\frac{15VA \,.\, 10}{12VA} = 12.5$

i.e. the transformer has been chosen correctly.

An overcurrent relay set to 8 I_N will trip because in the present case the current rises in direct proportion to the primary current, up to 12.5 × rated current.

In the event of a fully displaced short-circuit current, the d.c. component occurring at the beginning of the short circuit gives rise to transmission errors owing to saturation of the core. This can be remedied by using linearized cores with a high rated overcurrent factor (*e.g.* 200), or by selecting a high transformation ratio for the protection core.

The above selection criteria relate as well to current transformers in metal-enclosed switching installations.

The selection of current transformers in accordance with international standards (IEC) and the major foreign standards (*e.g.* ANSI) is generally based on similar criteria. The following short summary and Tables 10-7 to 10-11 are intended to assist in selecting transformers to the above standards.

Definitions and standard ratings to IEC Publication 185 (1966)

Measuring cores Rated output : 2.5 – 5.0 – 10 – 15 – 30 VA ; Burden power factor cos β = 0.8

Classes : 0.1 – 0.2 – 0.5 – 1 valid between 25% and 100% of rated power.
0.25 – 0.5 only for 5 A secondary current
3 – 5 valid between 50% and 100% of rated power

Designation Measuring cores are designated by a combination of rated output and class, *e.g.*
15 VA class 0.5
15 VA class 0.5 ext. 150% (wide-range transformer).

Table 58-7
Error limits for measuring cores

Class	± *Current error in % referred to per cent of rated current*					± *Phase displacement referred to per cent of rated current*							
						Minutes				*Centiradiant*			
	10	*20*	*50*	*100*	*120*	*10*	*20*	*100*	*120*	*10*	*20*	*100*	*120*
0.1	0.25	0.2	—	0.1	0.1	10	8	5	5	0.3	0.24	0.15	0.15
0.2	0.5	0.35	—	0.2	0.2	20	15	10	10	0.6	0.45	0.3	0.3
0.25; 0.5	0.35	0.2	—	0.2	0.2	—	—	—	—	—	—	—	—
0.5	1.0	0.75	—	0.5	0.5	60	45	30	30	1.8	1.35	0.9	0.9
1	2.0	1.5	—	1.0	1.0	120	90	60	60	3.6	2.7	1.8	1.8
3	—	—	3	—	3	—	—	—	—	—	—	—	—
5	—	—	5	—	5	—	—	—	—	—	—	—	—

Current transformers of classes 0.1 – 1 are also defined as wide-range transformers for 120%. 150% and 200% of rated primary current.

Phase displacement limits are not defined for classes 3 and 5.

Protection cores Rated output : preferred 10 – 15 – 30 VA

Classes : 5 P and 10 P; here the numbers denote the maximum permitted composite error at the error limit current; the letter P stands for protection.

Error limit factor : 5 – 10 – 15 – 20 – 30

Table 58-8
Error limits for protection cores

Class	*Current error in % at rated primary current*	*Phase displacement at rated primary current Minutes Centirad.*		*Composite error in % at error limit factor*
5 P	± 1	± 60	± 1.8	5
10 P	± 3	—	—	10

Designation : The rated output and class is followed by the error limit factor, *e.g.* 30 VA class 5 P 10.

58.7.7. Inductive voltage transformers

Inductive voltage transformers are low-power transformers in which the secondary voltage is for all practiced purposes proportional to and in phase with the primary voltage. The purpose of voltage transformers is to transform network voltage to be measured into a secondary voltage which is fed to measuring and protective devices. The primary and secondary windings are galvanicly separated from each other.

Inductive voltage transformers are manufactured in the following forms :

1. Voltage transformers with two-phase insulation for connection between two phases, ratio 6000/100 V, for example. Two voltage transformers in vee connection are normally used for measuring power in three-phase networks.
2. Voltage transformers with single-phase insulation for connection between one phase and earth, ratio *e.g.* 110 000/$\sqrt{3}$/100/$\sqrt{3}$ V.

   For measuring power in three-phase networks one needs three voltage transformers connected in star. If single-phase insulated voltage transformers include an auxiliary winding for signalling earth faults, in three-phase networks this winding must be sized for 100/3 V. The "open triangle" in the three-phase set can also be provided with a fixed resistor to damp relaxation oscillations (caused by ferroresonance in insulated networks with small capacitances).
3. Three-phase voltage transformers with the measuring windings connected in star and an auxiliary winding on the 4th and 5th limb for signalling earth faults. In the event of an earth fault the auxiliary winding has a voltage of 100 V.

Inductive voltage transformers are selected according to the primary and secondary rated voltages and also the accuracy class and rated output of the secondary windings so as to meet the requirements of the devices they are connected to.

If there is a winding for detecting earth faults, its rated long-duration currents must be stated. For the short-time load rating it is necessary to state the rated voltage factor and the duration of stress at elevated voltage.

58.7.8. Capacitive voltage transformers

For higher system voltages up to 765 kV it is also possible to use voltage transformers that work on the capacitive divider principle. Capacitive voltage transformers can be connected to all customary measuring instruments and protection relays; they are also authorized for tariff metering purposes.

The basic diagram of a capacitive voltage transformer is shown in Fig. 58.35. Capacitive transformers also provide a reliable supply to system protection relays with transistorized circuitry for very short switching times, especially if the transformers are provided with an electronic damping device which very quickly attenuates any transient oscillation of the transformer.

Capacitive voltage transformers have the added advantage that they can be used for coupling high-frequency power-line carrier systems, *e.g.* for telephony, telecontrol, and so on. The necessary additional components (reactor, lightning arrester) can be contained in the terminal box.

The essential features to consider when selecting voltage transformers are the primary and secondary rating, rated frequency, rated output and class. However, account must also be taken of the rated long-duration current of any earth-fault detection winding, rated voltage factor and the duration of stress at elevated voltage.

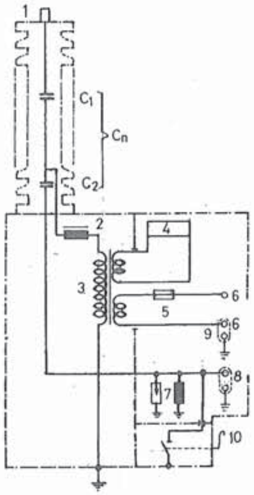


Fig. 58.35. Basic diagram of a capacitive voltage transformer

1 High-voltage terminal, 2 Medium-voltage choke, 3 Transformer, 4 Protection device, 5 Fuses (optional), 6 Secondary terminals, 7 Earthing reactor and lightning arrester (optional), 8 PLC terminal, 9 Earthing strap, 10 PLC earthing switch (optional), 11 Earthing terminal, C_n, C_1, C_1 capacitive voltage divider

Capacitive voltage transformers are selected in the same way as inductive types, except that the rated capacitance must also be defined. An example of determining the main technical data of a capacitive voltage transformer is given below :

Rated primary voltage	$\frac{110\,000}{\sqrt{3}}$ V
Rated secondary voltage of measuring winding	$\frac{110}{\sqrt{3}}$ V
of earth-fault detection winding	$\frac{100}{3}$ V
Rated output	75 VA, Kl, 0.5
Rated voltage factor	1.9 U_N, 4h
Rated long-duration current of earth-fault detection winding	9 A, 4h
Rated capacitance	4.400 pF ± 10%
Rated frequency	50 Hz

With capacitive transformers the rated capacitance and behaviour under transient conditions (interaction with network protection system) are also important.

Inductive and capacitive voltage transformers are used in SF_6-insulated switching stations. They are described more fully in Section 11.2.4.

58.8. SURGE ARRESTERS

58.8.1. Types of Surge arresters

(*i*) Arresters with plate-type spark-gaps and silicon carbide (SiC) resistors (valve-type arresters) are used in distribution systems with overhead lines. They provide a relatively high protection level against atmospheric overvoltages.

(*ii*) Arresters with magnetically blown spark-gaps and SiC resistors (also valve-type arresters) afford protection at lower levels. Their energy absorption capacity is about 3 times higher than that of plate-type arresters. They are used in high-voltage networks and at central points in distribution systems.

(*iii*) Surge arresters with no spark gap and using non-linear metal-oxide resistors (MO-arresters) usually, Zno are suitable for all voltage levels.

58.8.2. Application and selection

Surge arresters are used to protect costly and critical equipment and installations (especially power transformers HV cables etc.) against atmospheric overvoltages and switching overvoltages. They are selected according to the rules of insulation coordination. Valve-type arresters are selected according to their resealing voltage, the rules of insulation coordination, surge (discharge) current, line discharge class and short-circuit strength. For gap-less metal oxide arresters, the criteria are: maximum permitted continuous operating voltage, surge current, strength against transient overvoltages, line discharge class and short-circuit strength.

The resealing voltage is the voltage across the arrester at which the follow current is still definitely interrupted after sparkover. According to DIN VDE 0675 it is chosen equal to, or greater than, the maximum permissible continuous power-frequency voltage at the arrester. Account must be taken of the most unfavourable conditions. For phase arresters (connected between phase and earth) the resealing voltage is governed by the maximum phase-to-earth voltage. This is calculated as the product of the maximum power-frequency voltage and the earth-fault factor c_E.

With metal oxide arresters the maximum continuous operating voltage U_c is the highest power-frequency voltage that the arrester can withstand permanently. The strength T against transient overvoltages is the maximum temporary increase in the power-frequency voltage, referred to U_c for time t.

Selection of U_c for MO arresters: In networks with insulated or inductively earthed neutral the continuous operating voltage U_c is chosen the same as the maximum operating voltage U_m.

If networks with insulated neutral are provided with earth-fault protection, lower values of U_c are permissible: $U_c \geq U_m/T$.

Strength T as a function of time t for which the transient overvoltage persists is a characteristic of the arrester design and is usually represented in a diagram.

With non-earthed transformers the neutral is normally brought out. & an arrester is used to protect this neutral.

Strength T against transient overvoltages can be called upon when MO arresters are used for the neutral point. The continuous operating voltage U_c is selected in terms of the highest possible neutral-point voltage divided by T. Factor T depends on the type of arrester and will be found in the appropriate literature.

58.8.3. Typical values of surge arresters for the major voltage ratings

Recommended values of valve-type arresters for the principal voltages are summarized given in Table 58.13.

With gap-less MO arresters the continuous operating current U_c must be selected according to the earth-fault c_E. Table 14 shows typical values for low impedance-earthed networks ($c_E = 1.4$) and non-earthed systems ($c_E = \sqrt{3}$) without any other transient overvoltage.

Table 58.13.
Recommended values for valve-type arresters

Rated system voltage U_m *kV*	*Treatment of system neutral*[1)]	*Phase arrester Resealing voltage* U_1 *kV*	*Neutral arrester Resealing voltage* U_1 *kV*
10	f, l	12	—
20	f, l	24	—
30	f, l	36	—
110	n	120	85
110	l	132	85
138	e	128	60
220	e	216	120
220	e[2)]	234	120
345	e	321	151
380	e	360	195
380	e[2)]	420	175
500	e	467	219

1 f system with insulated neutral

l system with earth-fault compensation

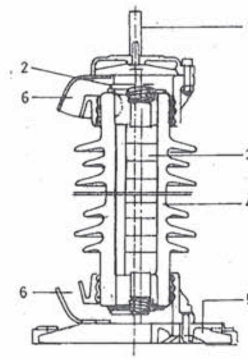
e system with low impedance-earthed neutral, earth-fault factor ≤ 1.4

n 110 kV system with low impedance-earthed neutral, earth-fault factor ≤ 1.7

2 for generator transformers

Table 10-14.
Selection of MO arresters
for maximum permitted continuous operating voltage U_c
(assuming that no other transient overvoltages occur)

Rated system voltage	*Phase arrester*		*Neutral arrester*	
U_m *kV*	U_c *for* $c_E = 1.4$ *kV*	U_c *for* $c_E = \sqrt{3}$ *kV*	U_c *for* $c_E = 1.4$ *kV*	U_c *for* $c_E = \sqrt{3}$ *kV*
10	—	12	—	—
20	—	24	—	—
30	—	36	—	—
110	71	123	34	71
138	84	—	41	—
220	142	—	68	—
345	209	—	102	—
380	243	—	116	—
500	304	—	147	—



Metal oxide surge arrester
1. Primary terminal,
2. Pressure relief device,
3. Stack of MO resistors,
4. Insulator,
5. Earth-side terminal,
6. Pressure relief exhaust

Fig. 58.36. Construction of MO arrester.

Arresters for up to 30 kV in distribution networks (*e.g.* for tower-mounted transformers) are usually designed for a rated surge current of 5 kA; arresters for 10 kA are used in networks seriously at risk due to thunderstorms. A rated surge current of 10 kA must always be selected for arresters before cable runs.

Arresters for voltages above 30 kV always have rated surge currents of 10 kA.

Under extreme fault conditions it is possible for lightning arresters to be overloaded. In such cases, e.g. a voltage rise from one level to the next, a single-phase earth fault occurs in the resistor assembly of the arrester. The pressure relief system prevents the porcelain housing from exploding. The system earth-fault current at the arrester's location must be smaller than the guaranteed current of the arrester's pressure relief device.

Lightning arresters are fitted in parallel with the object protected, generally between phase and earth. Because of their limited spatial protected zone, the arresters must be connected as close as possible to the protected item, e.g. a transformer.

Table 10-15
Approximately values of Protected zone of lightning arresters, reference values

Maximum voltage of equipment U_m *kV*	*Protected zone* I_{max} *m*	*Length of lead to arrester* *a* *m*
≤ 36	8	2
123	15	5
245	20	10
420	20	15

In medium-and high-voltage installations with cable entry, overvoltages due to reflection must be taken into account, despite limitation of the travelling wave by the cable. The arresters must therefore be located as close as possible to the transformer.

Surge counters are used to monitor lightning arresters. These are connected in the earth-wire of the arrester; the arresters are therefore, insulated against earth.

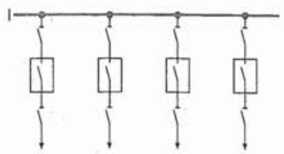
58.8.4. Circuit configurations for high- and medium-voltage switchgear installations

The circuit configurations for high- and medium-voltage switchgear installations are governed by operational considerations. Whether single or multiple busbars are necessary will depend mainly on how the system is operated and on the need for sectionalizing, to avoid execessive breaking capacities. Account is taken of the need to isolate parts of the installations for purposes of maintenance and also of future extensions.

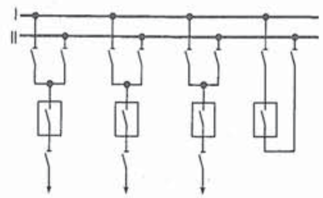
When drawing up a single line-diagram a great number of possible combinations of incoming and outgoing connections have to be considered. The most common ones are as described below.

(*i*) *Single busbars*. Suitable for smaller installations. A sectionalizer allows the station to be split into two separate parts and the parts to be disconnected for maintenance purposes.

(*ii*) *Double busbars*. Preferred for larger installations. Advantages: maintenance without interrupting supply. Separate operation of station sections possible from bus I and bus II. Busbar sectionalizing increases operational flexibility.



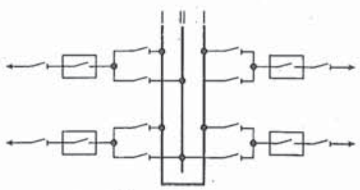
Single busbars



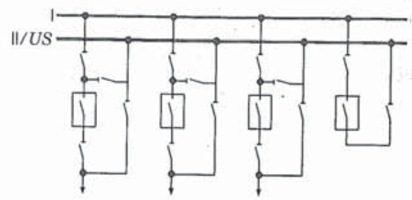
Double busbars

(*iii*) *Double busbars in U connection*. Low-cost, space-saving arrangement for installations with double busbars and branches to both sides.

(*iv*) *Composite double bus / bypass bus*. This arrangement can be adapted to operational requirements. The station can be operated with a double bus, or with a single bus plus bypass bus.



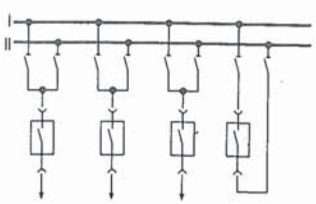
Double busbars in U connection



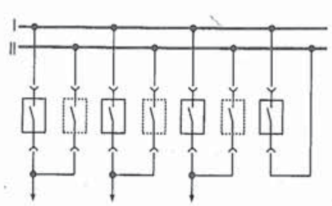
Composite double bus/bypass bus

(*v*) *Double busbars with draw-out circuit-breakers*. In medium-voltage stations, draw-out breakers reduce downtime when servicing the switchgear; also a feeder isolator is eliminated.

(*vi*) *Two-breaker method with draw-out circuit-breakers*. Draw-out circuit-breakers result in economical medium-voltage stations. There are no busbar isolators or feeder isolators. For station operation the draw-out breaker can be inserted in a cubicle for either bus I or bus II.



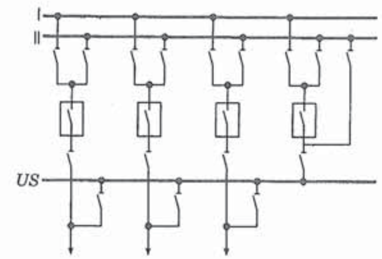
Double busbars with draw-out circuit-breakers.



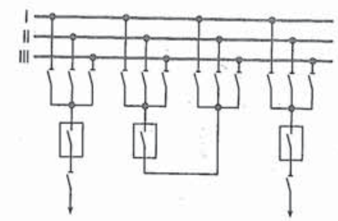
Two-breaker method with draw-out circuit-breakers.

(*vii*) *Double busbars with bypass busbar*. The bypass bus is an additional busbar connected via the bypass branch. Advantage; each branch of the installation can be isolated for maintenance without interrupting supply.

(*viii*) *Triple (multiple) busbars*. For vital installations feeding electrically separate networks or if rapid sectionalizing is required in the event of a fault to limit the short-circuit power. This layout is frequently provided with a bypass bus.



Double busbars with bypass busbar

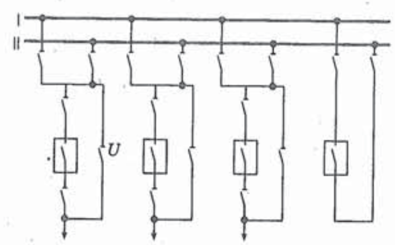


Triple (multiple) busbars.

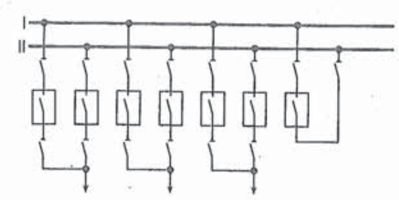
(*ix*) *Special configurations.*

(*a*) *Double busbars with shunt disconnector*. Shunt disconnector "U" can disconnect each branch without supply interruption. In shunt operation the tie breaker acts as the branch circuit-breaker.

(*b*) *Two-breaker method with fixed switchgear*. Circuit breaker, branch disconnector and instrument transformers are duplicated in each branch. Busbar interchange and isolation of one bus is possible, one branch breaker can be taken out for maintenance at any time without interrupting operation.



Double busbars with shunt disconnector

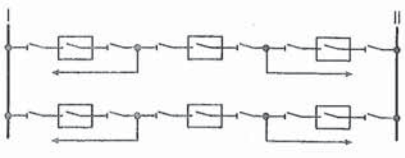


Two-breaker method with fixed switchgear

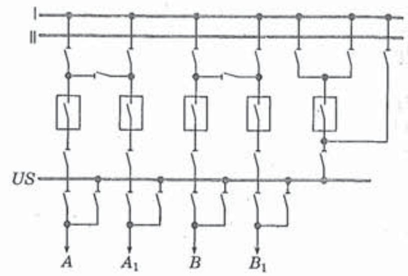
(*c*) *1 1/2-breaker method*. Fewer circuit-breakers are needed for the same flexibility as above. Isolation without interruption. All breakers are normally closed. Uninterrupted supply is thus maintained even if one busbar fails.

(*d*) *Cross-tie method*. With cross-tie disconnector "DT" the power of line A can be switched to branch A_1, bypassing the busbar. The busbars are then accessible for maintenance.

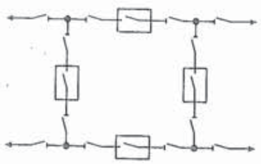
(*e*) *Ring busbars*. Each branch requires only one circuit-breaker, and yet each breaker can be isolated without interrupting the power supply in the outgoing feeders. The ring busbar layout is often used as the first stage of 1 1/2-breaker configurations.



1 1/2-breaker method

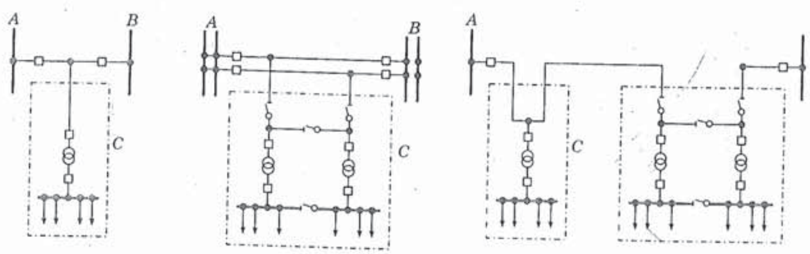


Cross-tie method



Ring busbars

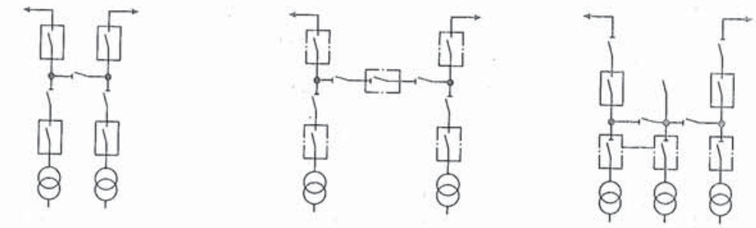
(*x*) *Configurations for load-centre substations.* A and B = Main transformer station, C = Load-centre substation, □ = Circuit-breaker or load disconnector. The use of load disconnectors instead of circuit-breakers imposes operational restrictions.



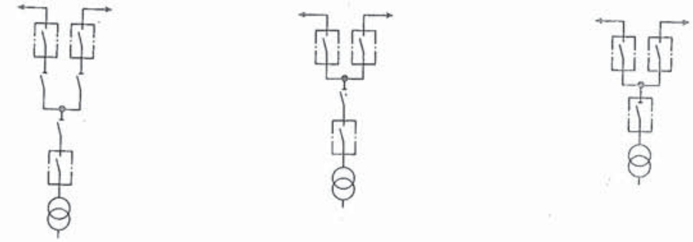
Single-feed station Double-feed station Ring stations

A and B = Main transformer station, C = Load-centre substation, □ = Circuit-breaker or load disconnector. The use of load disconnectors instead of circuit-breakers imposes operational restrictions.

Load disconnectors are frequently used in load-centre substations for line/cable branches or transformer feeders. Their use is determined by the operating conditions and economic considerations.

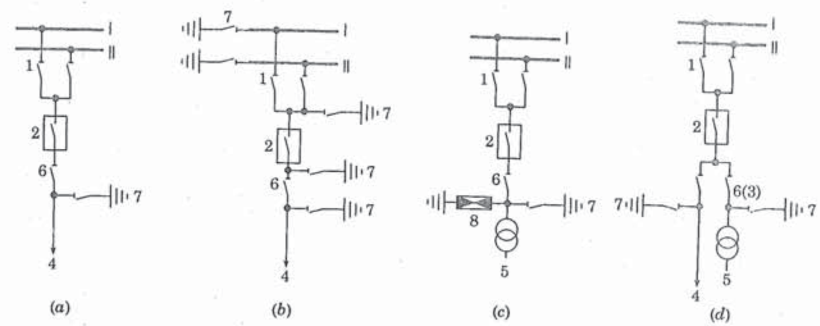


H connection with circuit-breakers — H connection with load disconnectors — H connection with 3 transformers



Ring main cable connection allowing isolation in all directions — Simple ring main cable connection — Cable loop

(*xi*) *Branch connections, variations (a) to (d)*



1. Busbar disconnector, 2. Circuit-breaker, 3. load disconnector, 4. Overhead-line or cable branch, 5. Transformer branch, 6. Branch disconnector, 7. Earthing switch, 8. Surge arrester

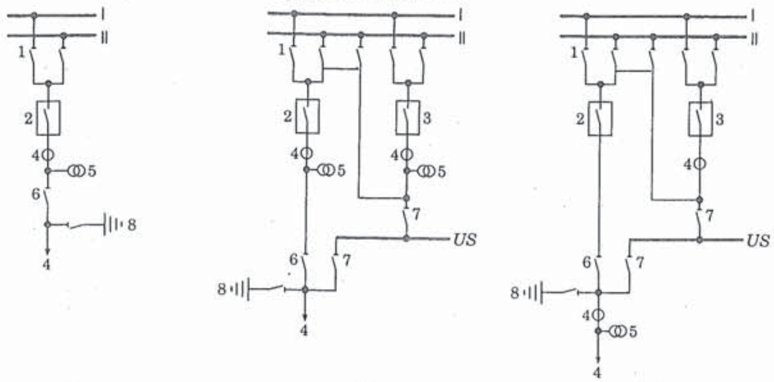
(*a*) *Overhead-line and cable branches.* Branch disconnector 6 allows circuit-breaker 2 to be isolated for maintenance purposes, even in installations with feedback voltage. Earthing switch 7 eliminates capacitive charges and provides protection against atmospheric charges on the overhead line.

(*b*) *Branch with unit earthing.* Station earthing switches 7 are made necessary by the increase in short-circuit powers and (in impedance-earthed systems) earth-fault currents.

(*c*) *Transformer branches.* Feeder disconnectors can usually be dispensed with in transformer branches because the transformer is disconnected on both h.v. and l.v. sides. For maintenance work an earthing switch 7 is recommended.

(*d*) *Double branches.* Double branches for two parallel feeders are generally fitted with branch disconnectors 6. In load-centre substations, by installing load disconnectors 3 it is possible to connect and disconnect, and also through-connect, branches 4 and 5.

(*xii*) *Connections of instrument transformers, variations*



(*a*) (*b*) (*c*)

1. Busbar disconnectors, 2. Branch circuit-breaker, 3. Bypass circuit-breaker, 4. Current transformers, 5. Voltage transformers, 6. Branch disconnector, 7. Bypass disconnectors, 8. Earthing switch

(*a*) *Normal branches.* The instrument transformers are usually placed beyond the circuit-breaker, 2. with voltage transformer 5 after current transformer 4. This is the correct arrangement for synchronizing purposes. Some kinds of operation require the voltage transformer beyond the branch disconnectors, direct on the cable or overhead line.

(*b*) *Station with bypass busbar.* Instrument transformers within branch. The instrument transformers cease to function when the bypass is in operation. Line protection of the branch must be provided by the instrument transformers and protection relays of the bypass. This is possible only if the ratios of all transformers in all branches are approximately equal. The protection relays of the bypass must also be set for the appropriate values. Maintenance of the branch transformers are used which also act as coupling capacitors for a high-frequency telephone link, this link is similarly inoperative in the bypass mode.

(*c*) *Station with bypass busbar.* Instrument transformers outside branch.

In bypass operation the branch protection relays continue to function, as does the telephone link if capacitive voltage transformers are used. It is only necessary to switch the relay tripping circuit to the bypass circuit-breaker 3. Servicing the transformers is more difficult since the branch must then be out of operation.

The decision as to whether the instrument transformers should be inside or outside the branch depends on the branch currents, the protection relays, the possibility of maintenance and, in the case of capacitive voltage transformers, on the h.f. telephone link.

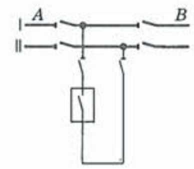
Busbar coupling connections

A and B = Busbar sections, LTR = Busbar sectioning disconnector

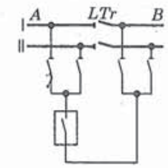
More complex coupling arrangements are usually needed in order to meet practical requirements concerning security of supply and the necessary flexibility when switching over or disconnecting. This greater complexity is evident in the layouts for medium and high-voltage installations.

Division into two bays is generally required in order to accommodate the equipment for these tie-breaker branches.

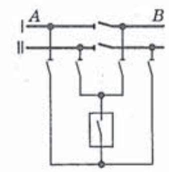
Double busbars



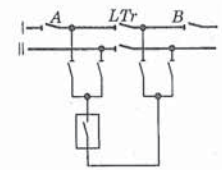
Bus coupling I/II for A or B



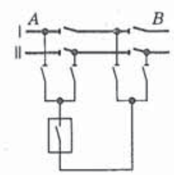
Section coupling for A-B Bus coupling I/II via disconnector LTR



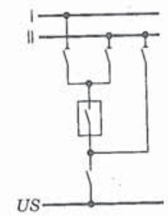
6-tie coupling Section coupling for A-B Bus coupling I/II for A or B



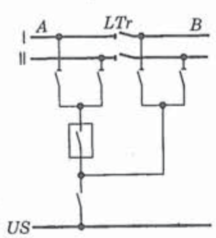
Section coupling for A-B Bus coupling I/II for A or B via tie-breaker bus II



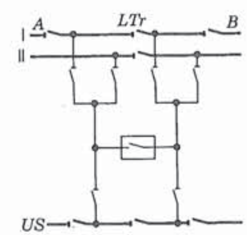
8-tie coupling Section coupling for A-B Bus coupling I/II for A or B



Bus coupling I/II Bypass (US) coupling I or II to bypass

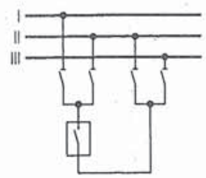


Section coupling for A-B Bus coupling I/II via LTR Bypass coupling A direct. B via LTR to bypass

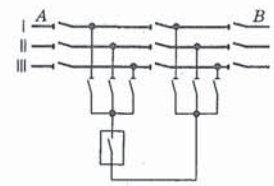


13-tie coupling Most flexible method of section, bus and bypass coupling

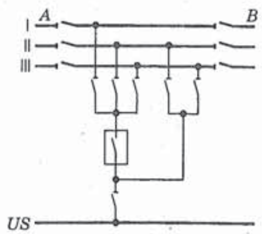
Triple busbars



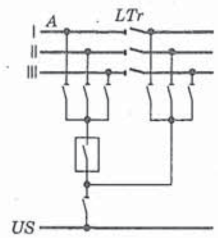
Bus coupling I/II/III



Section- and bus coupling for all possible ties between the 6 sections A-B



Bus coupling I/II/III for A or B Bypass coupling I/II/III to bypass (US) for A or B



Section coupling for A-B. Bus coupling I/II/III via LTR. Bypass coupling A I/II/III to bypass. Bypass coupling B bypass via LTR.

59

Electrical Safety

59.1. INTRODUCTION

While electricity has made life full of comfort and ease, it has also the potential to create heavy destruction if adequate precautions against its potential dangers are not taken care of. This brings into focus the safety to be exercised in the entire process of generation, transmission, distribution and the end use of electrical energy. Safety management & monitoring system has to ensure:

— Safety to self
— Safety to fellow workman
— Safety to consumer
— Safety to the public
— Safety of equipment apparatus & buildings
— Continuous and reliability of supply.

The concept of electrical safety as applied to the present day environment has taken deep roots so as to evolve as a discipline in itself in which specialists from all essential walks of life contribute towards devising ways and means to ensure safety in dealing with electrical energy. Safety includes safety of the equipment as well as the safety of the personnel. It is rather difficult to visualize any well-designed electrical system where these two aspects have not been taken into consideration. The safety of the equipment is generally provided by the use of protective devices such as switchgear and controlgear, fuses, relays etc. Safety of the personnel is ensured not only by employing protective devices but also by educating them about the safety precautions and practices that are required for installation, maintenance and operation of the electrical equipment. In addition, requirements to ensure a safe design of the equipment coupled with the reliability are specified in its product specification at the time of formulation of the relevant standard. For ensuring safety, a suitable statutory & institutional mechanism has been provided.

59.2. REQUIREMENTS FOR ELECTRICAL SAFETY

Personnel involved in the electrical work are normally called for to attend to installation and maintenance work, be it in a substation or in the factory premises or in commercial or domestic dwelling where electrical energy is being put to use. It is essential for these personnel to be conversant with Indian Standard and Codes of practices dealing with procedures for use of electricity and for various maintenance activities of electrical installations. The safety codes specify the precautions to be taken in ensuring safe use of electricity for the personnel working on them. In the Standards on personnel safety, various requirements on design and constructional details of the equipment have been laid down with a view to ensure protection from shock as well as protection from fire hazards under abnormal conditions. For ensuring a safe electrical environment, it is essential that the product conforms to these specified requirements and the instructions and guidelines laid down in Standards codes are known and practiced at all times by all concerned. The safety instructions are to be regarded as normal routine and not as involving extra and laborious efforts. Some of the important factors against which safety is ensured and requirements laid down in the Standards are: