Striker Fuse

Striker is a mechanical device having enough force and displacement which can be used for closing signal/tripping/indicator circuits. A force of a few kg can be obtained.

14.21. TEST ON FUSE

Tests are necessary to provide the least characteristic and ratings of the fuse. All tests on fuses are type tests and at least three samples of each current rating are tested.

The tests conducted are the following :

(*i*) Rated current test, temperature rise.

(*ii*) Current time characteristics.

(*iii*) Determination of minimum fusing current. Determination of maximum non-fusing current.

(*iv*) Test of duty, *i.e.* satisfactory opening at rated voltages for current upto rupturing capacity.

(*v*) Cut-off characteristics.

(*vi*) Resistance measurements.

(*vii*) Various performance tests.

The manufacturer gives the ratings to the fuses on the basis of the Type Tests.

QUESTIONS

1. Compare 'HRC Fuse' and 'Circuit-Breaker' as interrupting devices.
2. What is the meaning of HRC fuse ? How does it operate ?
3. What is 'cut off'? How is it beneficial in protection of bus-bars ?
4. Explain the aspects to be considered in selecting a fuse.
5. What are the considerations in selecting fuse for
   (*a*) Motor protection (*b*) Transformer protection (*c*) Heaters (*d*) Lighting local.
6. Explain the following terms for HRC fuse :
   (*a*) Cut-off (*b*) Pre-arcing time (*c*) Arcing time.
7. Discuss the method of selecting the rating of HRC fuse for motor starter.
8. Define 'Normal Current' and 'Fusing Factor' for HRC fuse.
9. Write short notes on any two :
   — Drop-out fuse
   — Striker fuse
   — Characteristics of HRC fuse
   — Co-ordination of fuse with back-up breaker.
   — Co-ordination of circuit-breakers with back-up fuse.
   — Protection of low voltage induction motors.

15-A

Metal-enclosed Switchgear, Controlgear and Contactor

Introduction—High voltages indoor Metalclad Switchgear—Low Voltage Indoor Metalclad Switchgear—Low voltage circuit-breakers—Low voltage controlgear and Contactor—Control-panels—Control Room—Flame-proof Switchgear.

15.1. INTRODUCTION

In Conventional Outdoor Installations (rated 36 kV and above) the various substation equipment like circuit-breakers CTs, PTs, Isolator etc. are installed under open sky. Necessary clearances are provided between phases, phase and ground. The equipment for such outdoor switchgear are manufactured separately and are erected at site as per the switchyard layout.

For low voltages (below 1000 V) and medium high voltages (below 36 kV) the clearances required between phases, between phases and ground are relatively small. Hence all the components (busbars, circuit-breakers, fuses, CTs, PTs, Isolators, meters, instruments, Relays etc.) can be provided in/on *factory assembled metal enclosed units.* Such switchgear is called *Unit Type Metal Enclosed / Metal-clad switchgear.*

Circuit breakers rated below 1000 V and Switchgear rated below 1000 V are generally indoor type and are used at final load points. Unlike HV circuit-breakers, LV circuit-breakers may have to operate repeatedly at relatively low powers factor currents. Hence the design and specifications of low voltage switchgear and circuit-breakers is markedly different from HV Switchgear. *Controlgear* is used for switching and controlling power consuming device such as motors, furnaces, vehicles, *equipment, processes* etc. Contactors are used at switching devices for normal and overload currents. Short-circuit currents are interrupted by HRC fuses or circuit-breakers.

Control Panels are installed in control room. From control panel, the operator can know, what is happening in the plant. The operator can control, start, regulate or switch-off the main-circuits from control panels. The control panels are designed and assembled to customer's specifications.

15.2. TYPES OF SWITCHGEAR

Indoor switchgear is used for medium, low and high voltages. It is in a variety of forms these switchgear units and applications in industrial plants, production floors, workshops, power stations, sub-stations, electrical distribution networks. The indoor switchgear is used in industrial plants such as chemical, petrochemical cement, dairy, textile plants, floor mill etc. They are also used in power plants and in distribution sub-stations.

(1) Stationary cubicle type, in which the components occupy fixed positions.

(2) Draw-out type or truck type switchgear in which the circuit breaker is installed on a carriage which can be pulled out to provide isolation. (Ref. Fig. 15.2).

(3) Compound filled or SF_6 filled switchgear. In which certain enclosures are filled with dielectric liquid or the whole switchgear enclosure is filled with SF_6 gas. (Refer Chapter 7)

(4) Fuse switch units and ring mains.

(5) Flame-proof or Explosion-proof switchgear which is designed and built specially for hazardous locations.

(6) *Cellular type.* (Which is now obsolete). The units are separated by brick-walls and R.C.C. slabs.

(7) *Corridor switchboard.* A switchboard on which the devices are mounted on two opposite sides separated by accessible corridor.

(8) *Mimic diagram board.* A switchgear on which the mimic diagram of main circuit is reproduced.

(9) *Metal-clad switchgear.* In this switchgear, the components are arranged in separate compartments with metal-enclosures intended to be earthed. The components include : Switching device, busbars, CT, VT etc. this barriers between compartments are metallic and earthed. The shutters may be insulating or metallic. Metal-enclosed switchgear called cubicle switchgear has no internal compartments.

(10) *Indoor switchgear.* Switchgear intended for indoor use.

(11) *Switch board.* An assembly comprising switchgear, electrical connections etc. and supporting frame.

(12) *Out-door Kiosk.* An enclosed outdoor self-contained unit connections are via bushings or cables. Metal enclosure contains CB, CT, VT, Busbars, Meters etc.

(13) *Compartmented Switchgear.* A metalclad switchgear having barriers of insulating Refer Ch. 15-B.

PART A—HIGH VOLTAGE INDOOR METAL ENCLOSED SWITCHGEAR

15.3. GENERAL FEATURES OF INDOOR METAL-ENCLOSED SWITCHGEAR

The indoor switchgear is generally factory assembled and unit type. Each unit has horizontal bus-bars of standard length. The required number of units are assembled in a line. The bus-bars are connected. The components are enclosed in sheet metal enclosure or cast iron enclosures. Hence these switch-gear are called Metal clad or Metal-enclosed switchgear.

The term switchgear covers a wide range of equipment for switching, interruption, measurement, control, indication etc. In indoor switchgear there are several components. These are assembled and provided with an enclosure. The components for switching and interruption include (1) Switches, (2) Switch-fuse combinations (3) Air-break/Bulk-oil/Minimum oil/Vacuum/SF_6 circuit-breakers (4) H.R.C. Fuses, (5) Isolators, (6) Earthing switches.

The components for measurements include current and potential transformers, measuring instruments.

The items in protective system include relays, instrument transformers etc. The components are chosen to suit customer's requirement.

Bus bars are essential components of switchgear. Bus-bars are defined as conductors to which several incoming and outgoing lines are connected. Bus-bars are of copper or aluminium. They are supported on epoxy-insulators block or resin bonded paper or resin bonded laminated-wood. The design, type depends on rated normal current and short-circuit capacity. The bus-bars are enclosed in bus-bar chamber. For single bus-bar arrangement, three conductors are provided for phases and one for neutral and earthing. The bus-sections of neighbouring units are connected by copper aluminium links.

The incoming and outgoing power cables are provided with cable-terminations. Power cables are brought in through cable trenches and terminated in the switchgear units. The rated voltage corresponds to busbar voltage. *

Current-transformer used in metal-enclosed switchgear are generally ring-type. They are fitted on insulated primary. The insulation is provided by cast epoxy-resin fittings.

Earthing facility is important. Each enclosure is earthed.

When circuit-breakers are incorporated in the switchgear, several inter-locks are necessary.

* High voltage : About 1000 V e.g. 3.6 kV, 12 kV, 36 kV, as per IEC.
Medium voltage : 1 to 36 kV as per CIRED.

15.4. DRAW-OUT TYPE METAL-ENCLOSED SWITCHGEAR

In this type of switchgear, the circuit-breaker and some other components are mounted on a withdrawable carriage. After opening the circuit-breaker the circuit-breaker is drawn-out mechanically by manual gear, resulting in isolation. The carriage is pulled out. In some earlier designs jacking arrangement was provided to raise the breaker-unit. Drawout switch-gear has mainly following components : (Refer Fig. 15.1 *a*).

1 = Busbars
2 = Circuit-breakers (SF_6)
3 = Current transformer
4 = Voltage transformer
5 = Cable termination
6 = Low-voltage compartment
7 = Cladding
8 = Shutters
9 = Isolators, etc.

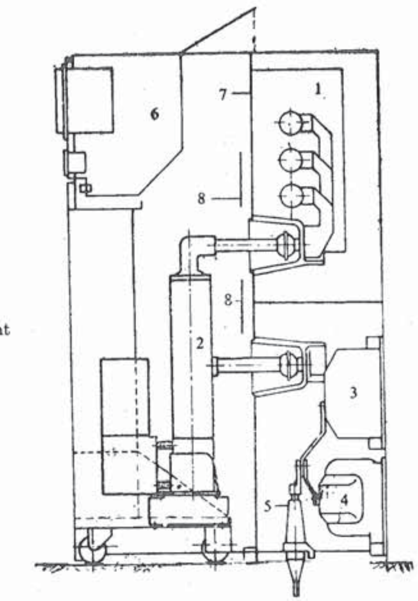


Fig. 15.1. (*a*) Metal-enclosed, 12 kV, Indoor Draw-out type Switchgear.

Normally the following interlockings are provided :

(1) The circuit-breaker must be in the open position before it can be lowered in its position/drawn out.

(2) The circuit-breaker cannot be closed before raising it to plug-in position/pushed in.

(3) Circuit-breaker can be closed only after raising to its final plug-in position.

(4) Interlockings between isolators, earthing switches and circuit-breaker.

Details of erection and arrangement in this type of switchgear are given in Sec. 13.4 Fig. 15.1 illustrates the arrangement. The circuit-breaker is installed on a movable truck. The circuit-breaker is tripped by a relay or by manual signal.

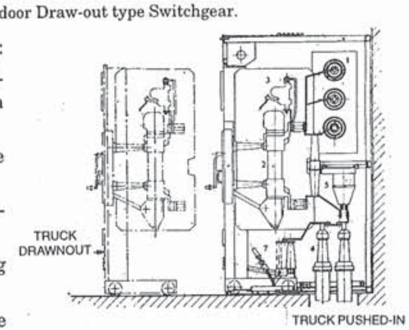
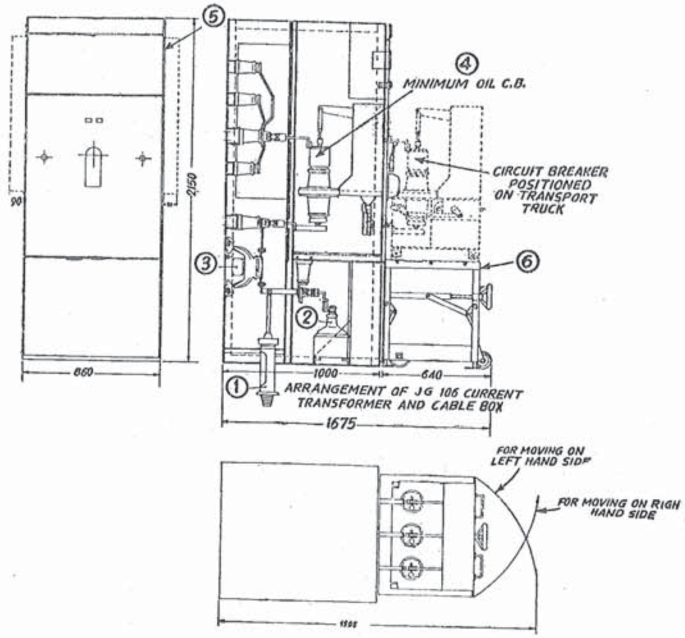


Fig. 15.1. (*b*) Indoor Metal enclosed Switchgear with

1. Busbars
2. Circuit-Breaker (SF_6)
3. Primary Relay
4. Cable-end seals
5. Current Transformer
6. Voltage Transformer
7. Earth.



1. Cable end
2. Voltage transformer
3. Current transformer
4. Minimum-oil circuit-breaker
5. Metal enclosure
6. Truck in withdrawn positions

Fig. 15.2. Draw-out type switchgear.

Table 15.3

Rated Voltage	*MVA Range*	*Rated Current Range*
12 kV*	250 MVA	
	350 MVA	400 A, 800 A, 1200 A, 1600 A
	500 MVA	2000 A, 3000 A, 3500 A
	750 MVA	
7.2 kV*	250 MVA	400 A, 600 A, 800 A, 1200 A
	350 MVA	1600 A, 2400 A, 3200 A.
	500 MVA	
3.6 kV*	150 MVA	400 A, 800 A, 1600 A, 2000 A
	250 MVA	1200 A
440 V**	15.6 MVA	400 A, 600 A, 800 A,,
	26 MVA	1200 A, 2400 A

* Circuit-breaker may be minimum oil, air break, vacuum of SF_6 type.
** Circuit-breaker or contactor generally air break type.
Contactor are used for control gear for repeated load switching.

15.5. SWITCHGEAR WITH VACUUM INTERRUPTERS

Vacuum interrupters have become popular in metal-clad switchgear. Several leading manufacturer in the world have introduced 7.2 kV, 12 kV and 36 kV vacuum switchgear during 1980's.

Mechanism is either 'solenoid closing/spring opening type' or 'spring-closing/spring opening type, Refer Fig. 15.3 illustrating operation of a triple-pole 12 kV metal-clad vacuum switchgear operated by a solenoid closing/spring tripping mechanism. *When solenoid (I) is energised, the breaker closes as follows :*

The magnetic field of the solenoid (17) lifts the plunger (2) through a distance of about 14 mm. the linkages, 5, 6, 7, 9, 12, 13 turn such that Insulating Rod (13) is driven vertically upwards so as to close the breaker. Simultaneously during the closing operations, the springs 14 and 8 get charged and contacts are held in closed position by spring pressure.

While opening, the contact spring '8' and return spring give the required force to open the contacts through about 8 to 12 mm travel. (Ref. Sec. 2.9.4 Solenoid mechanism.)

Vacuum switchgear used for motor switching incorporates *RC* surge suppressors having R =100 ohms and $C = 0.1\ \mu F$. (Ref. Fig 18.5). The RC surge suppressors absorb switching surges and are connected between phase and ground.

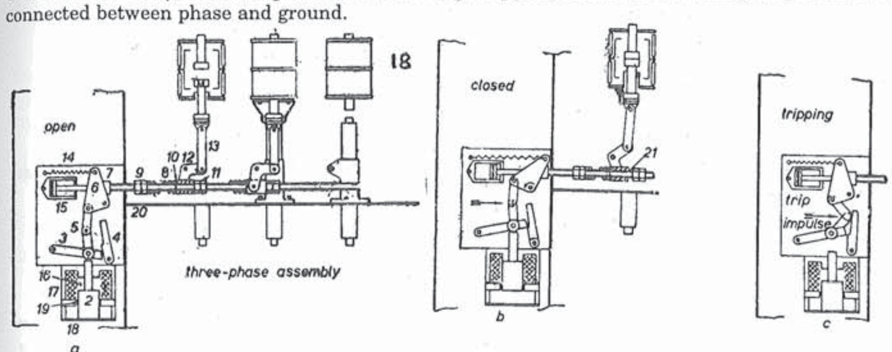


Fig. 15.3. Details of Drive Mechanism of a 3-phase Metal enclosed 12 kV, 25 kVA Vacuum Switchgear with Solenoid-closing Mechanism.
(*Courtesy* : Brush Switchgear Ltd. England)

(*a*) *3-phase* Assembly (*b*) Closed position (*c*) Tripping position

1. Solenoid 2. Plunger 3. Lever 4. Latch 5. Linkage
6. Lever 7. Drive rod 8. Contact Pressure Spring 9. Lock nuts
10. Sleeve 11. Lock nuts 12. Lever 13. Insulating rod 14. Return springs
15. Air buffer (Dash pot) 16. Air-gap 17. Magnetic circuit 18. Vacuum Interrupter.

PART B-LOW-Voltage Metalclad Switchgear and Low Voltage Circuit-breaker

15.6. UNIT TYPE METAL CLAD LOW VOLTAGE SWITCHGEAR AND MOTOR CONTROL CENTERS [REFER FIG. 15.4]

The design is of totally enclosed in superior quality gray iron castings. The rugged construction makes this type of switchgear ideal for industrial use on production floor, workshops, supply systems, electric plants, industrial plants etc.

The Switchgear and motor control centres are built of unit type bus-chambers of standard lengths having standard flange opening as the top and bottom, various units of bus-bar chambers securely bolted to each other forming and totally enclosed bus-bar chamber, with necessary number of flange openings for incoming and outgoing feeders. The bus-bar chamber is provided with detachable covers on both the ends.

Incoming and outgoing feeders are mounted on the top and bottom of bus-bar chambers, the feeder units are directly coupled to the bus-bar chamber through the flange openings.

The complete switch-boards assembly is mounted on a rigid channel is on framework suitable for wall mounting, or detachable pedestals for suitable floor mounting.

These switch-boards are front access type. All components are accessible from the front of the board for easy maintenance and replacement. The switch-board can, therefore, directly placed against the wall, resulting in minimum floor area coverage.

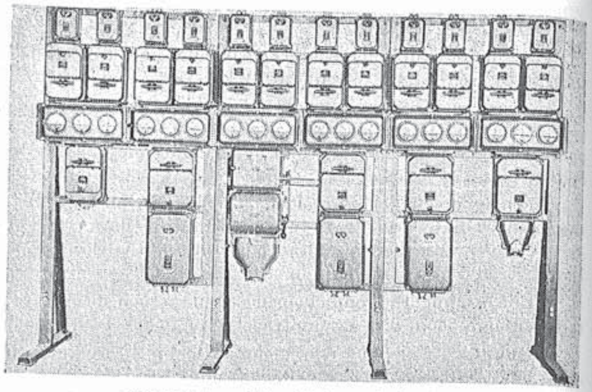


Fig. 15.4. Low voltage-Motor control centre : Metal-clad, indoor, low voltage switchgear. (*Courtesy* : Larsen and Toubro Ltd., India)

There are basically four types of designs :

(*a*) Switch-board with outgoing switch fuse units for main distribution boards.

(*b*) Fuse distribution boards with outgoing fuse units to serve sub-distribution boards.

(*c*) Motor-control centres consisting of outgoing motor starters backed by HRC fuses or switch fuses units.

(*d*) Switch-boards with incoming and outgoing circuit-breakers.

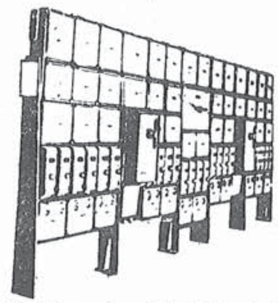


Fig. 15.5 Low voltage Metal-clad switchgear.

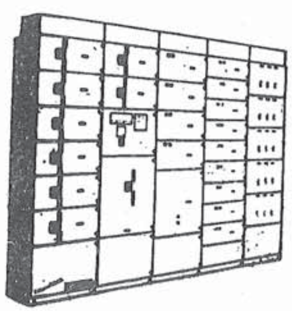


Fig. 15.6 (*a*) Low voltage sheet-metal enclosed load control centre.

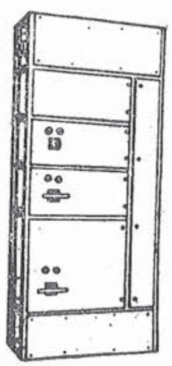


Fig. 15.6. (*b*) Low-voltage sheet-metal enclosed motor-control-centre. (Refer Fig. 15.7 for Details)

15.7. LOW VOLTAGE CIRCUIT BREAKERS

The circuit-breakers intended for circuits below rated voltage 1000 volts a.c. or 1200 volts d.c. are covered under the group low voltage switchgear. The construction, ratings, designs, specification for low voltage-breakers are generally different from those of high-voltage circuit-breakers (Ref, IEC - 15.7). However the theory discussed in Secs. 3.2 to 3.5 applies to voltage circuit-breakers also.

15.7.1. Classification.

The low voltage circuit-breakers are classified as follows :

(1) According to the method of control for closing operation, viz.,

- Dependent manual closing,
- Independent manual closing,
- Dependent power closing,
- Stored energy closing.

(2) According to the medium for interruption :

- Air-break circuit breaker (Ref., chapters 2 and 7)
- Oil immersed.

(3) According to the degree of protection provided by the enclosure (Ref. IEC - 144, Sec. 15.21).

15.7.2. Rated Quantities

The rated characteristics of low voltage circuit-breaker are slightly different from those for high-voltage circuit breakers.

Rated Voltages

- Rated operational voltage (U_o) is a value of voltage to which the making and breaking capacities and short-circuit performance categories refer.
- Rated insulation voltage (U_i) of a circuit-breaker refers to the voltage to which the test voltages, clearances and creepage distances refer. Rated insulation voltage is

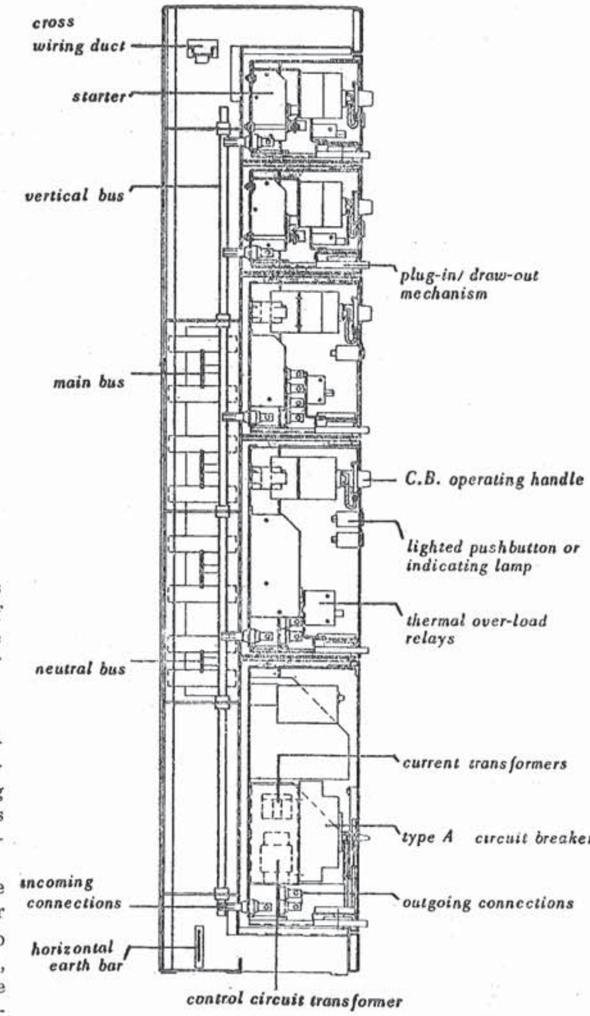


Fig. 15.7. (Cross-section of the load control centre in Fig. 15.6 (*b*).

generally the maximum operational voltage.

— For polyphase circuits, the rated voltage refers to voltage between phases.

Rated Currents

— **Rated thermal current (I_{th})** is the maximum current r.m.s. value of d.c. current or steady value a.c. current, which the circuit-breakers can carry in eight-hours duty.

— **Rated uninterrupted current (I_u)** is the value of which the circuit-breaker can carry in an uninterrupted duty.

Rated Duty

— Eight hour duty (Ref. Sec. 15.13)

— Uninterrupted duty

— **Rated short-circuit making capacity.** The rated short-circuit making capacity of a circuit-breaker at rated voltage, rated frequency and rated power-factor (or time-constant) is the value of prospective peak current that the circuit-breaker is capable of making and is expressed as prospective peak current. In a.c. circuit-breakers the rated making capacity should not be less than the rated breaking capacity multiplied by factor n. The factor n is of the order of 1.41 to 2.2 (Ref. Table) and depends upon the rated short-circuit breaking capacity. (Ref. Secs. 3.19.5 and 3.19.6).

— **Rated short-circuit breaking capacity.** Breaking current in a pole of a circuit-breaker refers to the current at the initiation of arc during the breaking operation. Rated breaking capacity (I_{cn}) refers to the r.m.s. value of a.c. component of current which the a.c. circuit-breaker can break under the specified conditions of voltage and power factor.

Relation between rated short-circuit making capacity, short-circuit breaking capacity and power factor

Rated short-circuit breaking capacity	*Standard p.f.*	*Minimum S.C. making capacity*
$Icn \le$ (amperes)		($n \times Icn$)
1500	0.95	$1.41 \times I_n$
1200 to 3000	0.9	$1.42 \times I_n$
3000 to 4500	0.8	$1.47 \times I_n$
4500 to 6000	0.7	$1.53 \times I_n$
6000 to 10000	0.5	$1.7 \times I_n$
10000 to 12000	0.3	$2.0 \times I_n$
20000 to 5000	0.25	$2.1 \times I_n$
20000 to 50000	0.2	$2.2 \times I_n$

Relation between power-factor and factors n is based on the ratio R/L of the circuit. (Ref. Eq. 3.17)

$$\cos \phi = \frac{R}{\sqrt{R^2 + \omega^2 L^2}}$$

By increasing R, $\cos \phi$ approaches unity. Refer Eq. 3.17, which gives the variation of d.c. component as

$$id_c = Ae^{(-R/L)t}$$

By increasing R, the value of i_{dc} decreases more rapidly. Hence the value of n reduces with improvement in power factor.

Rated short-time withstand current refers to r.m.s. value of current (for a.c. circuit-breakers) which the circuit-breakers can carry for a specified short-time (generally 1 sec), (Ref. Sec. 3.19.7).

Short-circuit Performance Categories

Category	*Operating sequence for short-circuit tests*
P-1	*O—t—CO*
P-2	*O—t—CO—t—CO*

O — represents a breaking operation.

CO — represents a making operation followed by breaking.

t — represents specified time-interval.

Type of releases for low voltage circuit-breakers. Release is a device, mechanically connected to a circuit-breaker, which release the holding means and permits openings or closing or circuit-breaker.

— **Overload release.** The over-current release is intended for protection against overloads.

— **Thermal overload release** responds to overloads by means of thermal action of the current flowing in the release.

— **Shunt release.** A release energized by the voltage source, *i.e.*, parallel to the load.

— **Under voltage release** is a shunt release which permits opening of a circuit-breaker when the voltage across the terminals of the release faults below a predetermined value.

15.7.3. Test on Low-voltage Circuit-breakers

— Type tests.

— Routine tests. (Ref. Secs. 10.2, 10.3)

Type tests

— verification of temperature rise limits. (Ref. Sec. 10.2.2)

— dielectric tests. (Ref. Ch. 12)

— short-circuit making and breaking tests. (Ref. Ch. 11)

— rated short-time withstand current. (Ref. Sec. 11.6)

— mechanical endurance test.

— electrical endurance test.

— verification of overload performance.

Routine tests

— mechanical operation tests.

— calibration of releases.

— dielectric tests. (Ref. I.E.C. 157)

15.8. 'EXPLOSION-PROOF' OR 'FLAME-PROOF' SWITCHGEAR

The term "Explosion-proof" is used in USA and 'Flame-proof' is used in UK and India, 'Pressure-proof type' in Germany. These three terms are synonymous.

Flame-proof enclosures of switchgear are specially designed and built for installation in hazardous locations. The hazardous locations include those which have

— Highly inflammable gases/vapour or liquids.

— Combustible dust.

— Combustible fibres floating in air.

— Highly inflammable liquids like petrol, naptha, benzene, ether, acetone, etc. These explosive mixtures of air and inflammable gas can explode in presence of electric arc or electric spark.

The primary consideration in the design or flame- proof enclosures is to prevent such explosion. The flame-proof switchgear should be built such that

The construction should be strong, enough to withstand the high pressure from within, caused by explosion of gas which enters the enclosure.

— The design should be such that the flame or spark within the enclosure should not be carried out of the enclosure.

— The enclosure should be gas-tight.

— The flame-proof switchgear should be installed, as far as possible away from hazardous location, in the rooms where explosive gas is absent. The switchgear should be 'flame-proof', or 'explosion-proof' and should satisfy the codes and standards specified for such switchgear.

When gas or mixture of air and gas explodes inside the enclosure, the flame of the burning mixture should be confined entirely within the enclosure and should not be communicate to outside atmosphere, so that the ignition of inflammable gas is prevented.

It is, therefor, necessary to make the enclosure strong enough to withstand high pressures generated within the enclosure due to internal explosions. The enclosures are built ruggedly. The sizes are also relatively ample.

SF_6 Gas insulated Switchgear (GIS) is metal enclosures filled with SF_6 gas. SF_6 gas is not flammable and is ideally suitable for 'Flame proof Switchgear'.

SF_6 switchgear is hermetically sealed. The internal gas pressure is 3 kgf/cm^2. Static seals and dynamic seals are provided with flanges, rotary shafts to ensure gas tight construction.

PART C
LOW-VOLTAGE CONTROL GEAR AND CONTACTORS

15.9. LOW VOLTAGE CONTROL GEAR

Control gear is a general term covering switching devices and their combination with associated control, measuring, protective equipment intended for control of power-consuming equipment.

Control gear comprises the following :

— some form of switching device capable of make and break the current in one or more electric circuits, such as contractors, circuit-breakers, switches, thyristors.

— measuring equipment comprising CTs, PTs, measuring instruments, measuring circuits, etc.

— regulating equipment such as voltage regulator, current regulator, speed regulator, temperature regulator.

— protective equipment such as fuses, relays.

— structural components such as enclosures, support structures, bus-bars, interconnections.

Control gear is primarily used for control of power consuming equipment such as motor, furnace, rolling mill, paper making machinery.

15.10. CONTACTORS

Contactor is a mechanical switching device capable of making, carrying and breaking electric current under normal circuit conditions including operating overload conditions.

The contactors are basically for operation under normal conditions and overload conditions. This condition distinguishes the 'contactors' from 'circuit-breaker'. Circuit-breakers must necessarily be capable of making, carrying and breaking short-circuit currents as per the assigned.

However contactors may be capable of making and breaking short-circuit currents, if they are designed for short-circuit duties also.

Contactors is usually intended to operate more frequently. During the mechanical endurance test contactors are operated 0.001 to 10 million times on no load to verify their resistance to mechanical wear.

Contactors have a main circuit and a control circuit. The contactors are designed according to the method of energising the control circuit, namely.

— electromagnetic — pneumatic — electro-pneumatic

15.11. SOME TERMS AND DEFINITIONS

1. **Electromagnetic Contactor.** A contactor in which the opening and closing of main contactors is achieved by means of a electro-magnet.

2. **Electro-pneumatic Contactor.** A contactor in which the force for closing and opening the main contacts is provided by an electrically operated pneumatic device. The electrically operated valve opens the passage of compressed air, thereby the air from auxiliary compressed air system enters the cylinder of the contactor and the contacts are operated.

3. **Main Circuit.** The conducting parts of a contactor designed to close or open. The current flows from the supply to the load through the main circuit of the contactor.

4. **Main Contact.** The contacts in the main circuit intended to carry the load current when the contactor is in closed position.

5. **Control Circuit.** The circuit which is energised or deenergised electrically for opening/closing operation of the contactor.

6. **Auxiliary Circuit.** The circuit other than the main and control circuit.

7. **(a) Contact (make contact).** A control contact which is closed when main contact is closed.

(b) Contact (break contact). A control contact which is open when the main contacts are closed.

15.12. CONTACTOR STARTERS FOR MOTORS [Ref. Sec. 31.4.1.]

Contactor starters are commonly used for starting squirrel cage induction motors. The starter has the following components enclosed in a sheet metal enclosure ;

1. One or more contactors.
2. Control circuit consisting of solenoid, auxiliary contacts etc.
3. Overload relays.
4. Start, stop, reverse push buttons.

Generally there are two distinct circuits namely, main circuit through which the current flows to the motor ; and an auxiliary or control circuit. The contactors are the switching units which can perform even 10 million operations under normal conditions. It consists of three main contacts (for 3-phase motor starter) and one or two auxiliary contacts. There is a control coil. When the coil is energized, the contactor closes by attracted armature action. When the coil is de-energized the contactor opens. Remote control of the starter can be obtained by making suitable connection in the starter. [Ref. Fig. 31.2 (*b*)]

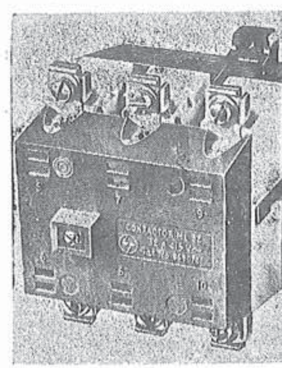


Fig. 15.8. Contactor.
(*Courtesy :* Larsen and Toubro Ltd., India)

In reversing contactor starter, there are two contactors, one for forward rotation and other for reverse. Only one is closed at a time. Phase reversal is obtained by the to contactors. Fuses provide back-up and short-circuit protection. Thermal relays provide over-load protection. (Ref. Sec. 31.4.2)

The following types of starters are common :

(1) Direct on line contactor starter. (2) Reversing contactor starter.
(3) Star-delta contactor starter.

15.13. RATED CHARACTERISTICS OF CONTACTORS

(1) **Type** — Electro magnetic — Electro-pneumatic — Pneumatic

(2) **Interrupting medium**

— air — oil — SF_6 gas — vacuum

(3) **Rated Values**

(*i*) **Rated Voltages**

— *Rated operational voltage (U_0) for three phase contactors. It is the rated voltage between phases.*

— *Rated insulation voltage (U_i).* It is the voltage to which the dielectric tests, creepage distance are referred.

(*ii*) **Rated Current**

— *Rated thermal current (I_{th})* is the maximum current the contactor can carry on eight-hour duty without the temperature rise exceeding the permissible limits.

— *Rated operational current (I_o)* of a contactor is stated by the manufacture by taking into account the rated frequency, operational voltage, rated duty and utilization category.

In case of contactors for motors, instead of/in addition to the rated operational current, maximum rated through put may be assigned.

(*iii*) **Rated Duty and Service Conditions**

(*a*) **Eight hours duty.** Contactors carry steady normal current for more than eight hours until the maximum temperature rise is attained. The rated thermal current (I_{th}) of the contactor is determined on the basis of eight hours duty.

(*b*) **Uninterrupted duty.** Contactor remains closed without interruption for a prolonged time (more than eight hours, weeks, months, years).

The dust, dirt, oxide coatings on contacts lead to progressive heating.

(*c*) **Intermittent duty.** Duty in which the contactors remains closed for periods having a definite relation with no load period, both no load and load periods are too short to allow thermal equilibrium. In intermittent duty, the contactor is made on and off in such duration that the thermal equilibrium is not reached.

For example :

In an intermittent duty, current of 200 A flows for four minutes in every fifteen minutes. This intermittent duty may be stated as : 'Intermittent Duty : 200 A, 4 min 1/15 min' or as 'Intermittent Duty : 200 A, 4 operating cycles per hour,

$$\frac{4}{15} \times 100 = 26.67\%$$

The standard values of on-load factor are :

15%, 25%, 40%, 60%.

The standard classes of intermittent duty as per IEC 158.1/1970 are as follows :

Class 0.03—upto 3 operating cycles per hour
Class 0.1—upto 12 " " " "
Class 0.3—upto 20 " " " "
Class 1—upto 120 " " " "
Class 3—upto 300 " " " "
Class 10—upto 1200 " " " "

Operating cycle comprises one closing operation followed by one opening operation.

For large number of cycle the following expression is recommended :

$$\int_0^T i_2 \, dt \, D \, I_{th_2} \times T$$

where i = current

T = total operating cycle time

I_{th} = rated thermal current.

(*d*) **Temporary Duty.** Duty in which the main contacts remain temporary closed for such a period that thermal equilibrium is not reached.

Example. 10 minutes, 30 minutes, 60 minutes and 90 minutes.

(*e*) **Making Capacity.** Rated making capacity of a contactor is the value of the current under steady condition which the contactor can make without welding or excessive erosion of contacts and without excessive display of flame.

The making capacity of a contactor is specified with reference to the following :

— voltage between poles before contact making.
— characteristic of the test circuit.
— utilization of category.

The rated making capacity of an a.c. contactor is expressed in terms of r.m.s. value of symmetrical component of current.

(*f*) **Breaking Capacity.** The rated breaking capacity of a contactor is the value of current which the contactor can break without excessive erosion of contacts or display of flame. For a.c. contactors, the rated breaking capacity is expressed by r.m.s. value of symmetrical component of current.

The condition of reference for breaking capacity are the following :

— characteristics of test circuit. — recovery voltage — utilization category.

Utilization Categories of Contactors

Category	*Applications*
AC-1	Non-inductive or slightly inductive loads, resistance furnaces
A.C. AC-2	Slip-ring induction motors : Starting, plugging*
AC-3	Squirrel-cage induction motors : Starting, switching, off
AC-4	Squirrel-cage motor : Starting, plugging, inching**
D.C. DC-1	Non-inductive and slightly inductive loads
DC-2	Shunt-motors : Starting, switching off
DC-3	Shunt-motors : Starting, plugging, inching
DC-4	Shunt-motors : Starting, switching off
DC-5	Shunt-motors : Starting, plugging, inching.

For details regarding conditions of making and breaking currents and power factors for various categories, please refer IEF 158.1 'Contractors'.

(*g*) **Utilization Category of Contactor.** Utilization of contactor is characterised by values of current and voltages expressed as multiple of rated operation current and rated operation voltage and power factor or time-constant and other test conditions.

* *Plugging :* stopping the motor rapidly by reversing the primary connection.

** *Inching (Jogging) :* energizing the motor once or repeat periods to obtain small movements for mechanisms.

15.14. TESTS ON CONTACTORS

The tests on contactors (Ref. IEC 158.1) are classified as

— Type tests — Routine test — Special tests

Type tests include the following :

— Temperature rise tests
— Dielectric tests
— Making capacity tests
— Breaking capacity tests
— Operating limit tests
— Mechanical endurance tests
— Short-circuit tests (if applicable)

Routine tests include :

— Operating tests — Dielectric tests.

Special test included electrical endurance tests.

PART D

15.15. CONTROL BOARDS OR CONTROL PANELS

In generating stations, receiving stations and sub-stations, the control and relaying equipment is installed in control-rooms. The arrangement of control and relay equipment needs careful attention to suit the layout and operational requirements of the installation. The requirements vary widely with the type and size of the station.

(*a*) **Large Installations.** When control of a large number of circuits is desired, as in the case of generating stations, the arrangement should be such that, the indicating apparatus should be clearly visible from the central place. To achieve this purpose, the equipment should be compact. The terminals should have good accessibility. The general trend is to provide separate panels for :

(*i*) Control and indication equipment and

(*ii*) Relay and indication equipment, voltage regular equipment.

The diagram of main connections are given on the front face of the panel, there diagrams indicate the positions of the circuit breakers and isolators. The control operator gets the idea as to which breaker open or closed. The controls of generator and main transformer circuits are generally brought on a separate control-desk, located centrally, in front of main control-board. Separate control desks are provided for prime-movers and boilers.

(*b*) **Medium Size Installation.** In medium size installations, panel width can be increased to accommodate relay and other equipment. In case of complex protective schemes, a separate relay panel is necessary.

Construction

The constructional features vary with the manufacturer and applications. However, a general pattern can be described. The control and relay boards are built of self-contained sheet steel cubicles. These cubicles are assembled on common channel-iron base plates according to the needs.

The cubicles are fabricated as follows : The angle-irons or channel-irons are cut according to drawings. The pieces are welded to form the frame. Sheets are cut on shearing machine to required sizes. They are placed on the frame at appropriate position and are welded.

The sheet of thickness 3 to 5 mm are used. The wiring is suitable for 250 V and are generally of grade 7/0.029 cable. The standard colour code (B.S. 158) is generally used. *Terminal Blocks* are used for connecting the wires.

Synchronising Arrangements

The panel for synchronising, can be conveniently arranged on the upper portion of the cubicle. The indicating instrument show "Incoming Volts", Bus-bar Volts" and "Slow or Fast".

Cubicle arrangements

The cubicles are arranged in a line, side by side. Sometimes, the relay cubicles are arranged back-to-back with their respective control cubicles, with a corridor in-between. The corridor is roofed and troughs are provided for wiring which run between the control and relay panels. The operator's control desk, personal-computer and Video-Display Screen, Event Recorder are usually located at the centre of the control room. Mimic-diagram board is at the front.

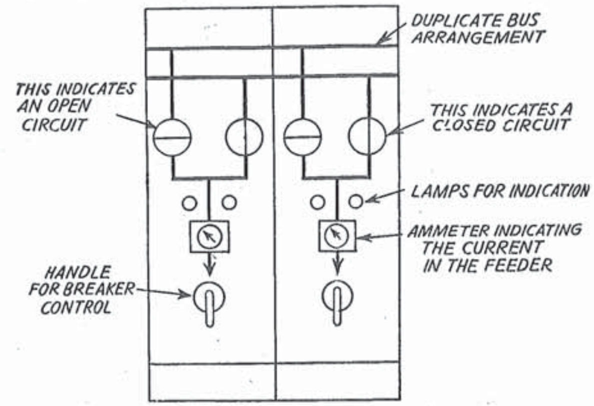


Fig. 15.9. Two units of a panel with Mimic-diagram. The diagram shows the circuit arrangement.

Panel Types*

These are illustrated in Figs. 15.4 and 15.9. There are a variety of patterns. The dimensions of cubicles are standardised.

(*a*) **Panel with Mimic Diagram**

(*b*) **Relay Panel.** As mentioned earlier, the relays are on a separate panel. Fig. 15.9 illustrates a typical panel. The type and number of relays depends on requirements.

(*c*) **Instrument Panel.** Indicating ammeters, voltmeters, energy meters, their selector switches, recording instruments, if any, fitted on instrument panel. Other types include

(*d*) Synchronizing panel.

(*e*) Automatic voltage regulator panel.

(*f*) Process control panels.

(*g*) *Event recorder.* Every operation in the main circuit/control circuit is recorded on print-out.

(*h*) *Fault Recorder.* The oscillographic record of variables is printed on graph sheet.

(*i*) *SCADA.* Supervisory control and Data Aquisition.

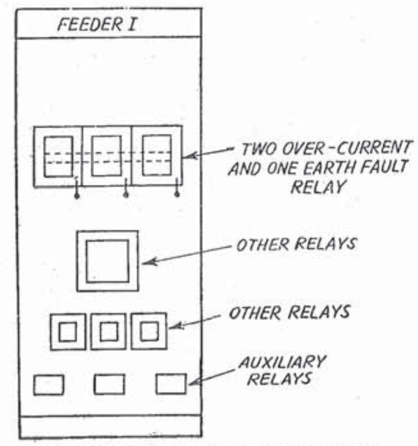


Fig. 15.10. Relay Panel, only one unit shown.

15.16. CONTROL ROOM-LAYOUTS

The layouts of control-room depend on the size and type of installation. Fig. 15.10 illustrates a typical layout. The types of panels installed in the room are indicated in the figure.

* Carrier communication panel is connected to the power line through coupling capacitor. Communication can be carried out between the stations by carrier channels. D.C. supply for protective relating is obtained from battery system.

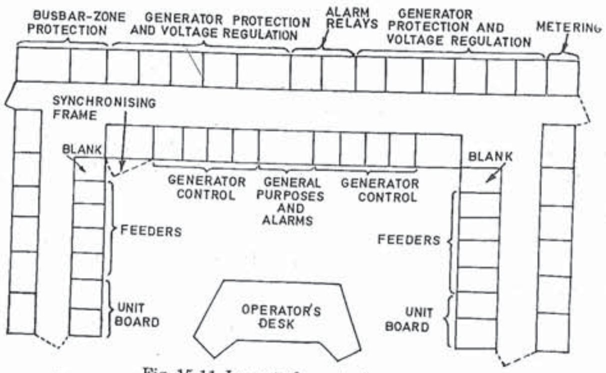


Fig. 15.11. Layout of a control-room.

QUESTIONS

1. Describe the construction of an indoor metal clad switchgear.
2. What are the various types of designs in medium voltage in door switchgear.
3. Which are the essential components in metal-clad switchgear ?
4. Describe the construction of a draw-out type or truck type switchgear ?
5. Describe the contactor starter with reference to its components and the function. (Ref. Fig. 31.2).
6. Describe the construction of SF_6 metal-clad switchgear. State its advantages.
7. Why the metallic non-current carrying metal parts of switchgear should necessarily be earthed ? Which safety precautions should be considered in the design of metal-clad switchgear ?
8. Draw an electrical single line diagram of a metal-clad switchgear.
9. State the design features of Flame-proof switchgear.
10. What are the merits of vacuum switchgear ?
11. Define the following terms with reference to contactors :
    — Breaking capacity — Category of duty — Rated thermal current.
12. Discuss in detail the major differences in the specifying the ratings of low voltage circuit-breaker and high voltages circuit-breaker. (a.c. only).

* Ref. Sec. 7-13 for SF_6 Insulated Metal-clad Switchgear used for voltages from 12 kV to 760 kV.
Ref. ch. 15-B for medium voltage switchgear with VCB and SF_6 CB.
Ref. ch. 15-C for Low Voltage Controlgear and Switchgear.

15-B

Medium Voltage Metal Enclosed Switchgear with SF6 CB and VCB

Part I : Introduction — Classification — Range — Application — Special requirements.
Part II : Constructional aspects — Variants — Cable terminations — Degree of protection — Design aspects cable termination systems.
Part III : Switching Phenomena — Motor Switching — Capacitor Switching — Repeated Switching — Associated problems SF_6 *B* and VCB.
Ch. 15-C : Low voltage controlgear and Switchgear.

PART I : APPLICATION AND RANGE

15.17. TYPE AND RANGE

The various types of Indoor Metalclad/Metal-enclosed switchgear described in Ch. 15A Part A have undergone significant improvements during 1980s.

Indoor Metalclad/Metal-enclosed Medium Voltage AC Switchgear are used in industrial and distribution substations, power plants etc. for voltage between 1 kV and 36 kV. Such switchgear are purchased by a very wide range of users. The earlier versions called cellular type and fixed type are no more preferred in India. Metalclad and Metal enclosed factory assembled drawout type switchgear are now very common.

The earlier designs had bulk-oil circuit-breakers and later minimum oil circuit-breakers. The SF_6 circuit-breakers and vacuum circuit-breakers have become very popular due to their non-explosive and maintenance free performance and better capabilities for repeated reliable switching under various switching conditions. With these circuit-breakers the switching phenomena like motor switching, capacitor switching, arc furnance switching, traction duty etc. has become easy.

The constructional of medium voltage switchgear can have several variants. The design is generally tailor-made to meet customers particular requirements.

15.18. IEC AND CIRED CLASSIFICATION

IEC defines voltage classes as follows :
Low Voltage. Upto and include 1000 V.
High Voltage. Above 1000 V.
IEC *does not* distinguish between Medium, High, EHV and UHV switchgear.
CIRED (The international conference of distribution systems) defines the following :
Low Voltage. Upto and include 1000 V.
Medium Voltage. Above 1000 V and upto and including 36 kV.
High Voltage. Above 36 kV.
The above are rms phase to phase voltages.

Chapter 3, Table 3.3 gives the various assigned ratings and the range of High Voltage AC circuit-breakers based on IEC 56 and IS 2516.

IEC 298. Revised Edition 1979 defines for the first time the various types of indoor metalclad switchgear as follows :

Metal-enclosed Switchgear is a general term for switchgear assemblies having earthed external metal enclosures upto but excluding the external connections. Metal-enclosed switchgear is divided into following three categories.

1. Metalclad Switchgear in which the main components are arranged in separate compartments with metal barriers. The shutters covering the fixed contacts (when carriage is drawn out) may be of insulating materials.

2. Compartmented Switchgear. It is a metalclad switchgear, but the barrier are of insulating material. Compared switchgear gives higher internal clearance between live parts and nearest earth parts because of insulating barriers.

3. Cubicle Switchgear has no internal compartments. It is more commonly known as metal-enclosed switchgear.

Table 15.1-B gives the range of above types.

In Metalclad Switchgear : separate metal compartment is provided for at least each of the following :

— Each main switching device

— Components connected to one side of switching device *e.g.* the feeder circuit.

— Components connected to the other side of switching device, *e.g.*, busbars.

The partitions between compartments are metallic and are earthed.

The **Cubicle switchgear** (Metal enclosed switchgear).

The number of compartments are less than those mentioned above. The degree of protection of partitions is less than that required for external enclosures. There are no partition and compartments.

Table 15.1-B Range of Metalclad Switchgear and Main Ratings

Rated Voltage kV, rms	*Preferred type*	*Busbar arrangement*	*Rated current A rms continuous*	*Rated S.C. current 1 sec kA rms*	*Rated Insulation Level*	
					1 in, 50 Hz kV rms	*Impulse kV peak*
7.2	ME	Single	630-3150	12.5-50	20	60
	C	Double				
12	ME	Single	630-3150	12.5-50	28	75
	C	Double				
17.5	ME	Single	630-3150	12.5-40	38	95
	C	Double				
24	ME	Single	630-3150	12.5-40	50	125
	C	Double				
36	ME	Single	630-3150	12.5-31.5	75	170
	C	Double				

ME = Metal-enclosed ; C = Compartment ; MC = Metalclad.

PART II. Constructional Aspects

15.19. CONFIGURATION AND VARIANTS

The functional requirements of a metal-enclosed switchgear include :

1. Control. Switching on/off during normal conditions for operation, automatically during abnormal conditions ; sequential switching etc.

2. Relays, Metering, instruments ; A, V, MW, MWh, cos ϕ, *f.*

3. **Earthing.** Facility to apply an earth connection readily to the circuit connection (and also to busbars).

4. **Testing.** Provision for making test connection to circuits (and also to busbars).

5. **Maintenance.** Provision of inspection, checking, servicing overhaul.

6. **Safety** to operators against explosion, fire, shocks, accidents. Interlocks to prevent wrong closing or opening.

7. **Degree of Protection.** This is designated by IP followed by two numerals. *e.g.* IP 3X, IP 5X.

A typical metal-enclosed switchgear has following components (Ref. Sec. 15.3) :

— Busbars, busbars connections

— Switching devices : Circuit-breakers, load break switches, isolators, earthing switches.

— CTs, VT

— Cable termination for incoming and outgoing power cables.

— Instrument and relay panel, metering panels.

— Electrical and mechanical interlocks.

The required components are arranged to form the factory assembled units and the total switchgear. In metalclad switchgear the components are housed in compartments. In metal-enclosed switchgear, there are no partitions and compartments.

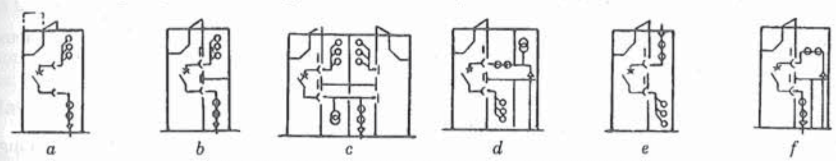


Fig. 15.12. Variants in Metal enclosed Switchgear Panels.

a = Standard metal-enclosed panel
b = Standard compartment panel
c = Duplex panel (Double bus-bar)
d = Busbar and cable entry reversed
e = Top cable entry
f = Panel with cable entry and cable exit.

In fixed type switchgear (no more preferred). The circuit-breaker unit is fixed and required isolators and earthing switches are provided with it.

In withdrawable switchgear (described below) the circuit-breaker unit is on withdrawable truck. After opening, the circuit-breaker truck can be withdrawn by pulling out the truck for isolation and inspection. While putting in service the circuit-breaker carriage is pushed in and the breaker is closed.

The variants in the configuration of cubicles of a drawout switchgear have been illustrated in Fig. 15.12. The layout of the total switchgear and the configuration of the individual cubicles is selected in accordance with the customers requirements.

Fig. 15.12 (a) illustrates one unit of a Metal-enclosed switchgear defined as cubicle switchgear in IEC.

This particular unit has following design features :

— Tubular single busbars mounted directly against the wall side of the cubicle.

— Front access for cabling therefore, the cubicle can be mounted directly against the wall.

Fig. 15.12. (b) shows a metal-enclosed type design with fully separated compartments for busbars, circuit-breakers, cable termination and with independently operated shutters.

Fig. 15.12 (c) illustrates Duplex Back-to-Back arrangement with complete duplication of busbars, and circuit breaker compartments. By equipping both the cubicles with the circuit-breakers, automatic bus transfer scheme and/or uninterrupted power supply scheme (UPS) is possible (Ref. Sec. 43.19). A front-to-front layout with appropriate arrangement of the cable connections provide 100% duplication with maximum security of supply. Principle of duplicate busbar system is described in Sec. 17.4.

Fig. 15.12 (d) and (e) show cable entries from below and from above at a suitable predetermined height above the floor level to suit the routing of cables with respect to civil works.

Fig. 15.12 (f) shows a single cubicle with cable connection from floor level and higher level. Such arrangement may be suitable for voltage control equipment, small generators, etc. where two feeders should be independently switched/isolated.

15.20. DRAWINGS AND DIAGRAMS

The design and construction of a metal enclosed switchgear is based on the following.

1. **Single Line Diagrams.** The diagram illustrates the main circuit and the main components viz. CB, isolator, busbars, incomers, outgoing lines CTs, VTs etc. (Fig. 17.26).

2. **Electrical Layout Diagrams.** This illustrates the arrangement of busbars and components in the switchgear and the cubicles.

3. **Civil Layout Diagram.** This illustrate physical arrangement of cubicles and switchgear with reference to the walls, floor, ceiling, cables trenches etc.

4. **Control Diagrams.** These illustrate control circuits, protection circuits, interlocking circuits, measurements, metering etc.

5. **General Arrangement and Overall Dimensional Drawings.** These give the various dimensions, foundation plan and general arrangement of the cubicles.

Metering Facilities

These include :

- Measurement of current, voltage, power, MVA, MVAr, on busbar side, cable side, incoming and outgoing circuits.
- Instruments are provided in the panel and are connected to CTs, VTs.
- Instruments for tariff purposes *e.g.* kWh meter.
- Relays for protection supervision etc.

Busbar VTs may be on withdrawable cubicle or as fixed cubicle.

The instruments and relays are flush mounted on the front side of the switchgear.

Enclosure Designs, Degree of Protection, Arc-Proof Test

The degree of protection against accidental contact with live parts and against the ingress of dust etc. is defined in detail in IEC Recommendations.

Standard degrees of protection by enclosures applicable to switchgear as regards :

1. Protection of persons against contact with live or moving parts inside the enclosure and protection against ingress of solid foreign bodies : dust

2. Standards specify the following :

Designations for these protective degrees are defined by IEC.

The degree of protection by enclosure is confirmed by tests. These tests are type tests for enclosure. They are carried out on standard products or prototype. Where this is not feasible the test should be carried out in accordance with an agreement between manufacturer and user.

15.21. DESIGNATION FOR THE DEGREE OF PROTECTION

The designation used for the degree of protection consists of the letters IP followed by two characteristic numerals :

It is recommended that the characteristic letter and numerals be marked on the name plate, or on the enclosure.

The standard cubicle design provides the degree of protection known as IP3X, being that normally specified for indoor switchgear. For cubicles used in particularly polluted environments this can be increased to IP5X. The switchgear is also available in a 'vermin-proof' design, additional precautions being taken to prevent the entry of insects, etc. In this case particular attention must be paid to ensure that all cable access openings are closed off when erections is completed.

Designations applicable to switchgear

First Numeral	*Description*
3	Protected against solid particles 2.5 mm dia
4	Protected against solid particles 1 mm dia
5	Dust protected
6	Dust tight
First Numeral	*Description*
O or X	Not protected against water since installed indoor.

IEC Recommendation No. 298 now includes standards for the performance of 'arc-proof' testing. The test requirements are for an internal fault arc of full short-circuit value to be continued for one second without danger to an operator standing in front of the cubicle. For some contracts, proof of this capability is agreed by the manufacturer and corresponding tests are performed, the cubicle being slightly modified by the addition of a separate door as for the vermin-proof cubicle designs. When 'arc-proof' switchgear is used the substation building has to be designed accordingly in order to achieve the correct degree of protection. The hot gas must be routed to a place where it can do no harm to operators.

The operating practices of some countries require special enclosure designs. The two most common requirements are for the circuit-breaker truck to remain within the enclosure when in the test/isolated position.

Maintenance Earthing

During operation and maintenance the first function performed on a switchgear is earthing of busbars and equipment. Operating practice as regards earthing is highly diverse so that alternative must be provided ; the following are the most frequently employed and are available in standard cubicles.

- Hand applied earths. Earthing cables manually applied by means of an insulated operating rod.
- Circuit-breaker earthed.

Truck mounted circuit-breaker with an appropriate set of connections short-circuited and earthed. The truck is provided with the necessary voltage testing and interlocking facilities. As a further variant, fittings are available which permit a normal feeder circuit-breaker to be used for earthing purposes.

- Earthing switch, either of the non-fault or fault-making type.

The isolator is permanently mounted in the cubicle and key-interlocked with the circuit-breaker. Live-line indication motorized operation of the isolator and electrical interlocking are possible when a voltage transformer is installed on the cable side.

Ancillary Devices and supplies

These include load break switches, fuses, voltage limiting devices such as surge suppressors, surge arrestors, neutral grounding resistors etc. These are housed in separate compartments of the metal enclosed switchgear. Auxiliary transformers required for substation lighting may also be incorporated in the cubicle. The Auxiliary DC supply 9110 VDC/220VDC) is obtained from Rectifier set and battery. Batteries are kept float-charged. Auxiliary AC supply is obtained from Auxiliary Transformer.

(*Ref. Sec. 17.3 for details about load break switches and sec. 17.13 for Factory substations*).

15.22. CABLE TERMINATIONS SYSTEMS

The incoming and outgoing cables require proper terminations system. Fig. 15.12 (*a*) to (*f*) illustrates the locations of cable terminations in the metal enclosed switchgear.

In earlier decades oil-impregnated paper insulated cables were used and these were terminated in metal boxes filled with liquid cable compound such as bitumen compound.

During 1970's epoxy cable sealing systems have been introduced.

The classification of cable boxes/cable joints/cable terminations can be made by various methods as follows :

1. **Classification based on voltage class.** Upto 1 kV, upto 6.6 kV, upto 11 kV, upto 33 kV.

2. **Classification based on application.** Jointing between straight lengths, trifercation, termination, type of cable.

Jointing is used for obtaining long length of cable line than available length of single cable. The number of joints/km length of cable line should not be more than six. The cable joints must be hermatically sealed, corrosion-resistant and should be mechanically and electrically strong.

3. **Classification based on material.** Cast iron jointing box, lead jointing box, epoxy junction box and type of cable.

4. **Classification based on design shape.** Straight, T-shaped, Y-shaped and X-shaped.

Epoxy Cable Sealing

Epoxy cable jointing systems are widely used for cable joints.

They have a number of advantages over cast-iron and lead cable boxes. They are compact and lighter in weight take shorter time and less labour for installation. Epoxy resins readily adheres to metals, provide reliable hermetic sealing, is not attacked by corrosion, and are sufficiently resistant to moisture.

Epoxy kits are manufactured at factories and delivered on site in the form of hollow epoxy or plastic shells. The shells are mounted on the cable joint and filled with epoxy resin plasticizer filler and hardener.

Plasticizers and fillers gives thermal stability, elasticity and mechanical strength of epoxy resin and reduce thermal expansion coefficient of the compound to a value approaching that of copper aluminium and lead, which are most frequently brought in contract with the compact with the compound when cables are joined together. The hardener accelerates polymerization of epoxy resin. Thereby reducing the hardening time of the compound.

Epoxy jointing systems are most often used for the low voltage, medium and high voltage connections of 1, 3.3, 6.6 and 11 kV cables.

The epoxy cable jointing system is composed up epoxy body, sheet steel screen, two cones with metal collars fitted with them. One of the cones is attached to the tabular portion of the cable in the factory. The other cone is fitted at site.

After making conductor jointing the epoxy compound is poured from a low height in the form of a continuous jet, 12 mm wide while doing this, tap the cable jointing system with a wooden hammer to help the escape of gas bubbles of the surface.

Check the compound for its hardness 15 hours after filling the cable jointing system by touching it with your hand ; at a temperature of 20°C the compound must harden in 12 hours after filling. A higher or lower ambient temperatures the hardening time is respectively, shorter or longer.

Epoxy compound is delivered on site already packed and with the filled introduced. The hardener is introduced at the time of installation of the cable jointing systems and terminations. The compound must be thoroughly mixed with the hardener and left to settle 10 to 15 minutes for the escape of air. The ready compound is effective for a period of :

0.5 to 1 hour at an ambient temperature of 0° to 10°C.
1.5 hour at an ambient temperature of 11° to 20°C.
2 hour an ambient temperature of 21°C to 35°C.

In mixing or filling the epoxy compound, care should be taken to prevent its contact with human skin and to protect human eyes because the compound (while not polymerized) contains toxic chemical agents that may cause local irritation and inflammation.

Locking and Interlocks

Metal-enclosed switchgear require several safety features including screens, locks and interlocks.

Padlocks are filled to ensure that unauthorised persons cannot operate the switchgear.

Key type interlocks ensure that one operation releases the key to perform the next sequential operation.

Electrical interlocks are essential in all metal-enclosed switchgear. With electrical interlocks, it is impossible to disconnect a switching device from the busbars. When it is in closed condition secondly, interlocks ensure that the switching device is in final correct position before it can be closed.

Some important features include :

— Unless circuit-breaker is open and in final correct position and isolators closed, it should be impossible to close the circuit-breaker.
— It should be impossible to close the circuit-breaker until earthing switch is opened.
— If a circuit-breaker carriage is used for earthing its tripping should be inoperative.

Load break Switches, Fuse-switch Units

By suitable choice of circuit-breakers, load break switches and fuse switch combination ; the metal clad switchgear can be made economical. (Ref. Figs. 17.26, 17.27).

Circuit-breakers are used for fault interruption and back up. Load-break switches for normal opening and closing operation. Further details in Sec. 17.13.

PART III. Switching Phenomena Associated with Medium Voltage Switchgear with SF_6 CB and VCB

15.23. GENERAL ASSESSMENT CRITERIA

Total Cost

This term denotes the cost arising from purchase, operation and servicing with respect to a specific required switching function. It is important to take the sum of all these costs into consideration. SF_6 and Vacuum circuit-breakers have very modest maintenance requirement. Hence they are economical during their long service life (about 20 years).

Mechanical Performance

Mechanical trouble accounts for the majority switchgear failures. Servicing requirements of a mechanical nature can be very costly.

Earlier switchgear with bulk-oil and minimum-oil circuit-breakers were designed for endurance of 1000 mechanical operations only. After that, overhaul was necessary. Modern VCB and SF_6 CB mechanisms for medium voltages are tested for the endurance of 5000 to 20,000 mechanical operation. The sliding parts are of PTFE requiring no oil lubrication. The maintenance requirements of mechanisms are modest.

Electrical Switching Phenomena

This concerns :

— The reliable breaking of currents ranging from full or partial short-circuit currents, through load currents down to magnetizing currents, motor switching, capacitor switching etc.
— Electrical side-effects likely to endanger other network elements *e.g.* switching over voltages produced when switching motors or transformers, restrike phenomena, voltage escalation phenomena etc. and precautions.

— Competent handling of various switching functions arising from special service conditions. Import switching functions associated with Medium Voltage switchgear include the following :

— Integrated Current Switching Capacity ($\Sigma I^2 n$)

Switching function	*Associated Phenomena*
1. Motor Switching, switching of low magnetising currents.	— Current chopping during opening.
	— Voltage escalation during closing of motors.
	— Overvoltages and failures of motor insulation.
2. Low arc current.	— Longer arcing time for self-generated pressure type CB like MOCB, OCB.
3. Capacitor switching cable switching.	— Restrike phenomenon, voltage surge, Breaker flashover, insulation failure.
	— High frequency inrush currents, pressure-rise.
4. Switching of Inductive loads.	— Current chopping.
5. Repeated switching.	— Breaker suitability with reference to maintenance schedule.

This term denotes the sum of all current values ranging from rated current to short-circuit which may be admissible switched before any attention need be paid to the switching chamber.

— Long-Term Rated Current Carrying Capacity.

It may be assumed that all switchgear is capable of handling the current it is rated for during entire service life.

MOCB, SF_6CB and VCB have different switching characteristics and need particular study before applications.

15.24. INTERRUPTION OF INDUCTIVE CURRENTS AND SMALL INDUCTIVE CURRENTS. (Ref. Sec. 3.12)

Following values of small/large inductive currents occur in practice

Transformers on no-load	: Upto 20 A
Neutral-grounding reactors	: Upto 2000 A
Neutral grounding transformers with reactor	: Upto 400 A
Load currents of motor	: Upto 1000 A
Starting current of motor	: Upto 5000 A
No-load current of motor	: Upto 20 A
Induction furnaces	: Upto 2500 A

Circuit-breakers which are capable of breaking short-circuit currents of several kA, find these inductive currents very small to interrupt.

The current may get chopped at current I_c before natural current zero giving rise to voltage (V_P)

$$V_P = I_c \sqrt{L/C}$$

$$f_n = \frac{1}{(2\pi \sqrt{LC})}$$

where V_P = Peak of switching overvoltage, Volts

f_n = Frequency of transient Hz

L = Inductance in load circuit, Henry

C = Shunt capacitance of load circuit, Farads

I_c = Chopped current, A, instantaneous Value

In circuit-breakers in which the dielectric strength across the contact gap gets rapidly re-established after current chopping (*e.g.* VCB, ABCB), there is no re-ignition of arc after current chopping and this can lead to inadmissible high switching overvoltage.

In case of OCB, MOCB the possibility of current chopping is less as the pressure generated in arc-quenching chamber is low for smaller currents. (Refer Sec. 6.3).

In case of ABCB and double pressure SF_6 blast circuit-breaker, the possibility of current chopping is more. (Ref. Sec. 6.3, External Extinguisher source).

In case of single pressure puffer type SF_6 CB. The gas is blown over the arc axially and the arc diameter is reduced to zero at current zero. Hence possibility of current chopping is less. (Ref. Sec. 7.5).

In case of VCB current chopping is likely for certain range of current. However in modern VCB, the chopping current is limited below 5 A by use of special chromium copper sintered contact tips with a small amount of material (1%) which vaporise easily. The vaporisation of this material helps in post arc conductivity and very low chopping levels.

15.25. SWITCHING-ON OF A MOTOR, VOLTAGE SURGE DUE TO MULTIPLE REIGNITION

So far, we discussed overvoltages occurring during opening of circuit-breakers. In motor closing, switching over-voltages can occur during closing of a circuit-breaker due to multiple re-ignition phenomena possible with VCB.

Consider closing of a VCB for starting a medium voltage motor.

In the first pole to close (or prestrike when contacts come closer), a surge wave is injected into the motor by the supply circuit (cable network, capacities) the surge is of at least peak to phase voltage if the source is rigid, *i.e.* having large capacitor or cables on supply side.

The voltage appearing on motor terminals U_m will be

$$U_m = U_s \left(\frac{2Z_i}{Z_c + Z_i} \right)$$

where U_m = Voltage appearing at motor terminal

U_x = Incident surge amplitude

Z_c = Surge impedance of supply cable

Z_i = Impedance of motor

Typical values of Z_c are 0.5 to 8, ohms and Z_i are 20 to 50 ohms. With these values

$$U_m = 2U_s$$

Due to damping and other effects actual value of U_m is between 1.5 to 1.8 U_s.

The three poles do not close simultaneously due to prestrike, difference in contact touch. The pole discrepance is of a few milliseconds (1 to 5). As the first pole close or prestrikes, the surge from the first pole to close will cause oscillations in the motor winding and the open terminals of other two windings, will show oscillatory overvoltage. Assuming first prestrike occurs a maximum voltage of the wave the peak voltages across second and third pole may approach a value of 2.0, 2.3 (= 0.5 + 1.5 to 1.8) times peak phase to neutral voltage. If any of those poles then close or prestrike, a surge wave of the same magnitude will be injected into motor circuit. Also the wave may be enhanced by reflection at motor terminals by factor 1.5 to 1.8 resulting in theoretical maximum swing of 3.0 to 4.1 per unit.

The above analysis for closing on a standstill motor. If the motor is running at full speed while the energising, and out of phase condition may occur, resulting higher than above values.

The large motor above 75 kW are supplied at medium voltages. The supply is given through power cables of some length between the switching device and the motor. Lumped capacitor are provided near the motor or switching for providing compensation for reactive power.

Following switching conditions are involved :

Closing — On no load

— On running motor which was switched off.

— re-switching of motor during starting.

Switching off : — One load

— During starting.

— On no load.

Severe conditions causing switching overvoltage include :

— Opening stalled motor

— Opening motor while starting.

— Closing the running motor.

Contact speed and contact material of vacuum circuit-breaker and vacuum contactors have influence on the prestrike behaviour.

The amplitude and rate of rise of overvoltage at closing is influenced by the surge characteristics of the motor, the surge characteristics of the connecting cable and supply network.

Type of circuit-breaker seems to have no influence on the normal prestrikes.

When the length of cable between the switch and the motor increases, the time to peak of switching overvoltages increases, rate of rise decreases.

High surge impedance of supply reduces the rate of rise and amplitude of surge-voltage.

Lumped capacitors (used for power factor correction) or a large number of cables connected to supply bus enhance the amplitude and rate of rise of surge-voltage.

While closing vacuum contactors or vacuum circuit-breakers, high frequency repetitive transients may occur due to multiple high frequency reignitions while closing. The pre-ignition (described above) causes high frequency transients with saw-tooth wave forms. Vacuum gap quenches the high frequency current zeros but rising voltage causes pre-strike again. This occurs repeatedly at high frequency 10 to 100 kHz for a few milliseconds (1 to 5). However such a phenomenon usually does not results in voltage escalation since the breakdown of vacuum gap causes limitation of amplitude of overvoltage. When interruption of starting-currents of motor and stalling currents is avoided by appropriate control actions ; the closing transients represent the next most severe switching condition will produce switching transient every time giving a statistical rise of excessive overvoltage and successive degradation of motor insulation eventually leading to motor insulation break-down.

15.26. MOTOR SWITCHING WITH PUFFER TYPE SF_6 CIRCUIT-BREAKERS

The puffer type SF_6 circuit-breaker have a very low current chopping level. This is due to the physical properties of the SF_6 gas, and low pressure axial blast in puffer principle. Because of the easy ionizability of sulphur, the plasma in SF_6 circuit-breaker remains conductive down to relatively low temperature, which counteracts instabilizing of the arc and there with interruption of the current before the natural current zero. The arc is blasted gently, which however due to the excellent arc extinguishing properties of SF_6 is adequate to assure interruption of the current. Because of this axial gentle blasting, the current chopping level of the puffer type SF_6 circuit-breaker is very low. Hence overvoltage occurring during motor switching due to current chopping are whithin permissible limits. The dielectric recovery of the contact gap of SF_6 circuit-breaker is very rapid. This is due to the electronegative behaviour of SF_6 and its dissociation products. In addition,

the contacts of the SF_6 puffer type circuit-breaker must travel a certain distance before circuit-breaker is able to interrupt (buildup of the required blasting pressure). For this reason the reignition probability of SF_6 self-extinguishing circuit-breaker is low. Reignition if any takes place through contact gap filled with ionised gas and does not allow the over voltage to reach high value. Current is interrupted at next zero.

The capability of interrupting high-frequency transient currents (di/dt at current zero upto a several (100 $A/\mu s$) is a unique characteristic of vacuum circuit-breakers. The associated phenomena such as virtual current chopping or multiple reignitions with voltage escalation occur with vacuum circuit-breakers. Such phenomena do not occur with puffer type SF_6 circuit-breaker because of the gentle blasting of the arc in the current range cannot interrupt high frequency currents. A reignition if any occurs, only once on the 50 cycle wave due to insufficient contact travel. Sequences of reignitions with sawtooth-like voltage characteristics as they occur from vacuum switching principles, do not occur with the SF_6 circuit-breaker. This property is useful for puffer type SF_6 in motor-switching applications. Hence puffer type SF_6 circuit-breaker are used without additional RC surge suppressors.

15.27. CAPACITOR SWITCHING

In medium voltage range capacitor switching applications include :

— Cables on no load, upto 100 A.

— Capacitor bank switching upto 2000 A.

The switching is of two types.

— Opening of single capacitor bank and associated restrike phenomenon (Sec. 3.14.1.).

— Closing of one capacitor-bank against another (Parallel bank-switching) and associated phenomenon of high frequency, high amplitude inrush currents during pre-ignition.

Opening of Capacitive Currents (Refer Sec. 3.14.1).

Where the current is interrupted the capacitor remains charged at + V_{ph}. After half a cycle the voltage of contacts. On supply side reaches – V_{ph}. Thus the contact gap is subjected to 2 V_{ph}. half cycle after current zero.

If contact gap does not withstand this voltage, the breaker restrikes causing release of energy from capacitor to supply side and another voltage rise after next current zero giving 4 V_{ph}. The result is that the stress on the insulation and the contact gap due to this voltage is much higher than before the first restrike. With increasing over voltage, the danger of further restrikes is very high.

So-called "Soft" circuit-breakers *e.g.* minimum oil and bulk-oil circuit-breakers which have no forced oil circulation, circuit-breakers with magnetic blowout and airbreak contactor have a tendency to restrike. They are not suitable for capacitor switching due to possibility of restrike.

SF_6 circuit-breakers have higher rate of dielectric recovery of contact gap and are, therefore restrike free for large capacitive currents. Vacuum breakers have best dielectric recovery and are ideally restrikes free.

Switching a Capacitor Bank into the Busbars

The making current I_m of a capacitor bank being switched into the power system can be calculated from the rated current I_c of the capacitor bank, the natural frequency f_c of the transient current between the power system and the capacitor bank and the frequency of the power system. The making current of an uncharged capacitor being switched on at the voltage maximum is given by

$$I_m = I_c \frac{f_c}{f} \qquad ...(1)$$

The natural frequency f_c can be calculated from the inductance L of the power system and the capacitance C of the capacitor.

$$f_c = I/2\pi\sqrt{LC} \quad ...(2)$$

The maximum rate of rise of current S_{max} is given by

$$S_{max} = I_m\, 2\pi f_c \quad ...(3)$$

Making currents up to approximately 15 kA and rates-of-rise or current upto approximately 20 $A/\mu s$ occur in practice.

Connecting Capacitors in parallel

The capacitor to be switched on is not charged and is switched on at the voltage maximum. This is assumed to be the most unfavourable case.

The equations (1), (2) and (3) are also valid in this case. However, the inductance of the power system L in equation (2) is to be replaced by the inductance L_2. L_2 is inductance of inductor connected between C_1 and C_2 for limiting in rush currents.

In practice, the inductane L_2 between the capacitors is very low as compared to the inductance L of the system and can be neglected. The transient currents are determined mainly by the inductance L_2 between the capacitance C_1 and C_2.

The natural frequency f_c is given by :

$$f_c = 1/2\pi\sqrt{L_2 C} \quad ...(2a)$$

The total capacitance C is given by

$$C = \frac{C_1 C_2}{C_1 + C_2} \quad ...(4)$$

and L_2 is inductance between C_1, C_2. As $f_c > f$, the making currents and rate-of-rise of current which occur when capacitors are connected in parallel are much higher than those which occur when capacitors are connected to the power system. Making currents upto 40 kA (or higher) and rates of rise of current upto 1000 $A/\mu s$ are possible in practice.

The making currents which occur when paralleling capacitors cause very high pressures and inadmissibly high-rate-of-rise of pressure in oil circuit-breakers. For this reason the inductance L_2 between the capacitance C_1 and C_2 must be provided.

In VCB, SF_6 CB there is no excess of pressure in the interrupter.

15-C

Low-Voltage Controlgear and Switchgear

15.28. APPLICATIONS AND BASIC REQUIREMENTS

The low voltage controlgear, contactor, low voltage switchgear etc. have been briefly described in Sec. 15.6 to 15.15. The classifications by IEC and CIRED define Low Voltage as voltage upto and including 1000 V. (Sec. 15.20). The definitions of metal-enclosed switchgear mentioned in Sec. 15.29 apply to the Low Voltage Switchgear covered in this chapter.

Low voltage switchgear and controlgear has a very wide range of applications. The switchgear is subjected to severe electrical and mechanical stresses associated with particular application. The low voltage switchgear has to perform the specified duty over a long span of operating life, with minimum maintenance requirements. The space available is generally less and the switchgear should be compact. The *design should be good-looking, compact, Safe and easy to install, operate and maintain.* The degree of protection and surface treatment are equally important.

The major differences between low voltage switchgear and High Voltage Switchgear include the following :

— Specifications and ratings are different.

— Characteristics of low voltage circuits with respect to stresses on switching device during opening and closing are different than those of HV circuits.

— Number of Switching operations demanded from low voltage switching devices (between periodic maintenance intervals) are very high (several tens of thousands to a million) as against a few thousand for a medium voltage switching device. The contact life of LV switching device is important.

— Medium voltage switching device has higher creapage distance, higher internal clearances than that of LV switchgear.

— LV switching device has generally a short contact travel. (a few mm) as against a long contact travel of MV switching device (a few cm). Due to small contact travel, the contact travel characteristics of an LV switching device is markedly different from that of MV switching device.

— Contact bounce assumes great significance in LV switching device.

— LV switches designed from very long mechanical life and contact life. The contacts are pressure type with minimum contact wiping and contact wear.

— In HV switchgear only four types of switching devices are used. These are circuit-breakers, Isolators, Earthing Switches and Load-break Switches (Sec. 17.3). In LV Switchgear several types of switching devices are used (Sec. 15.31).

15.29. COMPONENTS AND MODULAR STRUCTURAL CONFIGURATION

The LV Switchgear or controlgear has modular construction. The module of required rating are assembled to form the complete switchgear. Modular construction (called unit type construction in Sec. 15.6) enables the manufacturer to simplify the inventory and to produce required tailormade switchgear economically and in batch quantities. User gets his requirement at lower cost, with necessary variation and in shorter delivery periods.

In the modular construction of LV switchgear standard modules of specified dimensions and ratings are assembled together as per required circuit diagram. Modular system is used for cast-iron clad switchgear (Fig. 15.4), low voltage metal-enclosed load control centre (Fig. 15.6 *a*, *b*; Fig. 15.7).

The essential components in low voltage switchgear include components similar to high voltage metalclad switchgear described in Sec. 15.3, *i.e.*,

- — Switching devices. Circuit-breaker or contactor or some other device along with its operating mechanism.
- — Fuse Boxes or Fuse-switch combinations
- — Busbars
- — Incoming cables and cable terminations
- — Outgoing cables and cable terminations
- — Structure for supporting the modules, enclosure.
- — Earthing facility, earthing switches, earthing busbar.
- — Interlocking facility
- — CTs, VTs, over load relays as required
- — Measuring instrument chamber
- — Control cabling; etc.

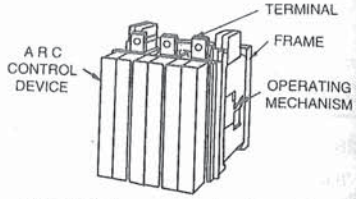


Fig. 15.13. Appearance of modern air-break contactor.

15.30. SWITCHING DEVICES

Several types of switching devices are used in LV switchgear. The switching devices are called circuit-breakers, Contactors, auxiliary switches, limit switches, motor starters, etc.

Table 15-C-1 gives the list and features of various switching devices.

Table 15-C-1. Switching Devices in LV Switchgear

Type of Switch	*Classification based on*	*Switching devices*
Circuit breakers (indoor, metal enclosed, with current limiting features) Ref. Chapter 5 -Miniature -Moulded-case	Breaking capacity for short-circuit current breaking. Circuit-breaker has assigned short-circuit breaking capacity and making capacity.	— Air break circuit breakers used exclusively in low voltage switchgear both for AC and DC duties (Ref. Chapter 5) — Miniature circuit-breaker molded case circuit-breakers (Sec. 5.11) — Oil-circuit breakers, SF_6 circuit breakers, Vacuum circuit-breakers are used for MV switchgear and HV switchgear. They are not used in LV switchgear
Switch-fuse combinations (Ref. Sec. 14.17)	Use of HRC fuse along with manual Switch	Fig. 14.14
Contactors (Ref. Sec. 15.10)	Switching load current and overload currents.	— Air-break are used in LV switchgear. — Suitable for large number of switching operations on load/overload
Load-break Switches.	Switching on load current and overload current.	— Rated opening and closing capacity upto 1.5 In. Lever switch with arcing chamber.

Type of Switch	*Classification based on*	*Switching devices*
Motor starters	Switching on and off the motor circuit; capability to make and breaker the starting currents.	Contactor starters, Oil immersed starters, star-delta starters, Direct-on line starters.
Isolating switches	Switching the circuit under no active load.	For safety, for isolation.
Manually operated switches.	Switches operated by hand or by foot.	
Remote controlled switches	Power operated	Compressed air, motor mechanism or solenoid operated switches.
Limit switches	For switching when particular limit of physical quantity is reached.	Mechanical switch is arranged to operate by physically moving part on the machine. Limit switch contacts can be connected in motor starter circuit.
Stop switch	No restoring force	Lever switch, pressure switch, cam switch
Lock switch	With mechanical lock and trip-free release	Motor protection circuit-breaker.
Key or push button	With restoring force	With contactors
Selector switches	For selection of circuit between two or more alternative current paths	Change over switches Multiple switches.
Auxiliary switch	For switching on/off auxiliary circuits several pairs of contacts which include NO-Normally open NC-Normally closed NO-NC Short-time contacting NO	Auxiliary circuits are for switching, operating, locking signalling etc.

15.31. MECHANICAL RATED LIFE OF A SWITCHING DEVICE

Rated Contact Life. These terms are complementary. The LV switching device is designed and rated to perform a large number of mechanical operations per hour and several thousand mechanical operations during its operating life.

Rated Mechanical Life of a switching device is expressed in terms of the number of switching operations can be performed without loading the current path. Nominal value of rated mechanical life is assigned at 90% of the limiting value.

Rated Contact Life is assigned with reference to the capability contacts to perform number of switching operations on full load.

Majority of switching devices are capable of performing more than assigned number of switching operations during the life. Table 15-C-3 gives data about typical values of rated mechanical life for various types of LV switching devices.

Table 15-C-2. Reference Values of Rated Mechanical Life of LV Switchgear Devices

Type of switching device	*Class as per VDE 0660*	*Rated Switching frequency per hour on no load*	*Rated Mechanical life in Number of switching operations on no load*
Isolators, large switches, lever switches, high speed switches, large circuit breakers etc. large motor starters.	AI	10	1000 (10^3)
Medium and small circuit breakers, Medium and small motor switches for railway vehicle, high speed switches	BI	20	10,000 (10^4)
Large contactors, pressure switches manual motor switches.	CI	50	100,000 (10^5)
Smaller contactors, Control switches for intermittent operations switching devices for small haulage equipment.	DI	500	10,00,000 (10^6)
Contactors for intermittent operation in auxiliary drives, in rolling mills, for special machine etc.	EI	3000	100,00,000 (10^7)

15.32. DESIGN ASPECTS FOR LONG MECHANICAL LIFE

Long mechanical life is an essential requirement of a LV switching device for the economic use—Long mechanical life cannot be expected from switching devices having higher contact load (Table 15-C-3, A1). However, devices such as contactors having lower contact load are designed for very lage switching frequencies and mechanical operating life (D_1, E_1).

For achieving long mechanical life, the design of contactors has been perfected over the years through continuous design and development efforts. Following principles are used :

— **Small, low weight components.**

Components are made of optimum size with reduced weights and removal of unnecessary extra material. This ensures reduced dynamic stresses. Earlier designs had oversize components.

— **Form Locking of components.**

Use of form-locking design, *i.e.* the structural forms of neighbouring components are such that the assembly is easily made by mutual supporting and guiding position with minimum screws, springs, clips, pins etc. The components should remain in desired position during 'open' and 'Close' switch position by their mutual shape.

Pressure contacts. Long mechanical life and long contact life requires reduced mechanical contact wear. **Pressure contacts** are preferred in which contact wear due to wiping action is avoided.

Maintenance-free bearings

Bearings get worn out quickly during mechanical operations due to heat developed with mechanical loading and wear of sliding components during operations. Bearings are 'weak spots' in the switching device. Bearings are not accessible for maintenance during service life. They cannot be easily replaced.

Wear of bearing components depends on (1) temperature during continuous mechanical operation due to mechanical loading (2) Coefficient of friction of sliding surfaces and effect of lubrication (3) Characteristics of materials (4) Commulative travel of sliding surface (km) and material lost by abrasion (rubbing actions) mg/km.

Abrasion between steel shaft and brass housing is reported to be 150 times that between corresponding steel shaft and plastic housing.

In LV switches, for small sliding components sliding surfaces are preferred with

— plastic sliding against steel
— Plastic sliding against plastic

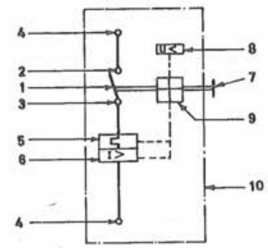
Porous plastics are preferred as they act like sintered metals. Permanently lubricated bearing surfaces are preferred. Special coatings such as PTFE (Teflon) are used on plastic and metal contact surfaces to reduce coefficient of friction.

15.33. MAIN ELECTRICAL CIRCUIT AND COMPONENTS IN A SWITCHING DEVICE

Fig. 15.13 (*a*) represents a single phase schematic diagram showing essential components associated with the Low Voltage Switchgear (contactor or circuit-breaker).

The main components shown in Fig. 15.13 (*a*) include the following :

— Switching device
— Moving contact terminal
— Tripping unit
— Latching system for switch 1
— Undervoltage trip
— Fixed contact terminal
— Terminals for connection to busbars
— Overcurrent trip (usually electromagnetic)
— Operating handle or drive
— Enclosure



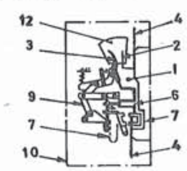
1. Main switching device
2. Fixed contact
3. Moving contact
4. Connection (terminal)
5. Tripping unit (electromagnetic)
6. Tripping unit (thermal)
7. Handle or operating mechanism
8. Undervoltage trip
9. Latching system
10. Enclosure

Fig. 15.13. (*a*) Schematic diagram of LV Switching Device. (Single phase representation)

Fig. 15.13 (*b*) shows the configuration of a simple air-break circuit-breaker incorporating the above components and also the following :

— Fixed contact
— Arc extinction device
— Moving contact
— Support frame.

The principle of air-break circuit breaker and arc extension by elongation of arc has been described in Chapter 5.1.



1. Main switching device
2. Fixed contact
3. Moving contact
4. Connection (terminal)
5. Tripping unit (electromagnetic)
6. Tripping unit (thermal)
7. Handle or operating mechanism
8. Under voltage trip
9. Latching system
10. Enclosure
11. Support frame
12. Arc Quenching device.

Fig. 15.13. (*b*) Configuration of LV Air-break Switch.

15.34. MAIN CIRCUIT COMPONENTS ASSOCIATED WITH CONTACTOR STARTERS OF LV

Direct-on-line started Induction Motors. The components include :

— HRC fuse — Contactor — Thermal relay

Fig. 31.2 (*a*), (*b*) and 31.4 in Chapter 31 protection of Induction Motor gives the details.

15.35. PROTECTION ASPECTS

The protection of LV loads is provided by

— Thermal relays and overload tripping devices
— Under-voltage tripping devices
— HRC Fuses for short-circuit protection
— Circuit breakers with current limiting feature for short circuit protection, stalling protection.

Chapter 31 gives details about motor-protection.

15.36. CONTACT TRAVEL CHARACTERISTICS OF LV SWITCHING DEVICE DURING OPERATING AND CLOSING OPERATIONS, SWITCHING TIME DEFINITIONS.

The switching device performs opening and closing operations. The contact travel characteristic is plotted with Time on X axis (in milli-seconds) and contact travel on Y axis in mm.

The important time-steps in the contact travel characteristics for LV switching devices as defined in VDE 0660 are as follows :

Definitions of remote controlled LV Switching Devices in main current path.

(A) For the Closing Action (making operation) the following definitions are applicable (Fig. 15.14 (a)).

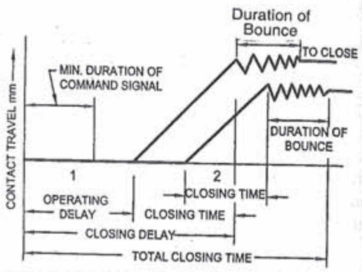


Fig. 15.14. (a) Time travel characteristic during closing of LV switch contacts. (Definitions as per VDE 0660)

1. **Delay before movement.** It is the time from the commencement of the communel pulse to the commencement of the movement of the contacts.
2. **Closing time.** It is the time from the commencement of the command until the contacts of the first pole to close first make contact.
3. **Delay before closure.** It is the time from the commencement of the command pulse until the contacts of the first pole to close first make contact. It is equal to the sum of the delay before movement and the closing time.
4. **Duration of bounce.** It is the time from the first make until the final contact in a switching operation (Fig. 15.14 (b)).
5. **Total closing time.** It is the time from the commencement of the command pulse until all contact members have finally closed.

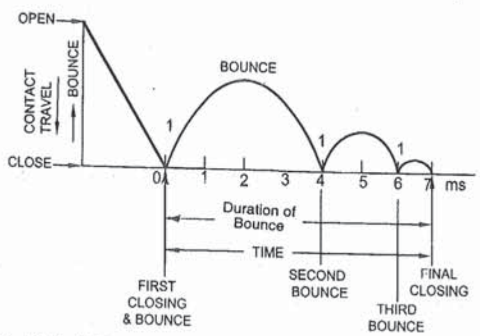


Fig. 15.14. (b) Time-travel characteristic of contact bounce during closing of LV switch/contactor.

(B) For the Opening Action (Breaking operation). The following definitions are applicable (Fig. 15.15).

1. **Tripping time.** It is the time from the occurrence of the condition which cause tripping until the holding system is removed or the restoring force of the switch is released. The times of additional relay devices, whether dependent on or independent of the current, are included in the tripping time.
2. **Inherent operating time.** It is the time from when its holding device is released until the commencement of opening of the contacts of the last current path to open.
3. **Opening delay.** It is the time from the occurrance of the condition which causes tripping until the commencement of opening of the contacts of the last current path to open. It is the sum of the tripping time and the inherent operating time.
4. **Arc Development time.** It is the time from the commencement of opening until the maximum of the restricted short-circuit current.
5. **Arc Duration.** It is the time from the commencement of the contacts in the first pole to open until the end of the current flow in all poles.

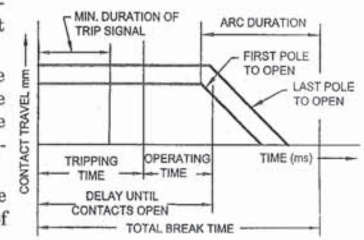


Fig. 15.15. Time-travel characteristic during opening of LV switch contacts. (Definitions as per VDE 0660)

6. **Total breaking time.** It is the time from the occurrance of the condition which causes tripping until the end of the current flow in all poles.

(C) The Minimum Duration of the command pulse

It is the shortest time for a closing or opening pulse which is necessary for the complete or opening of the switch. The minimum duration of the command pulse may include any intentional time delays.

(D) The transfer time of a change over switch which operates with "break before make".

It is the time from the opening of the one contact position until contact is first made at the other.

(E) The overlap time of a change over switch, which works with "Make before break".

It is the time from the find closure (closure after completion of bouncing) of the one contact position until the opening of the other.

15.37. CONNECTION AND CROSS SECTIONAL AREA OF CABLES

The external circuit is connected to the switching device by means of leads (cables/conductors). The part which provides the connection is called the "Connection". The connections carry the circuit current. The type of connection and size of connection used depends upon nominal value current.

Types of Connections

The current carrying paths include the connections. The get heated due to I^2Rt losses. Connection resistance should be low. They should not become loose due to mechanical vibrations. Types of connections include

Screw connections are used with curved spring washers, flat plate and nut etc. Spring washers ensure constant high pressure connection and securing the position of screw.

Flat connections are used for higher current ratings.

Plug connections are without screw. The male part is inserted into female part. The grip is provided by the spring action of the female part.

Soldered connections are used for smaller wires upto 2.5 mm^2 cross section. Table 15-C-3 gives data about applications.

Table 15-C-3. Application of types of Connections

Type of connections	*Application wire size*
Screw with spring washer	1×2.5 mm^2
Screw with Frame Terminal	2×5 mm^2
Flat connection	Flats of high current
Plug connection	
Soldered connection	Upto 2.5 mm^2

15.38. CONTACT CONFIGURATION AND DESIGN ASPECTS

The requirement of Contacts depends upon

- — required frequency of operation, *i.e.* number of switching operations per hour and rated contact life.
- — required normal current rating
- — required rated electrical performance characteristics
- — rated utilization category

The contacts are in pairs, with are fixed contact and other moving contact.

Main contacts are designed for achieving low contact resistance, long contact life.

Contact pressure is important. Contacts for LV switches are generally designed without contact grip.

Fig. 15.16. (*a* to *f*) illustrates various configuration of contacts for LV air break switches, and LV air/break contactors.

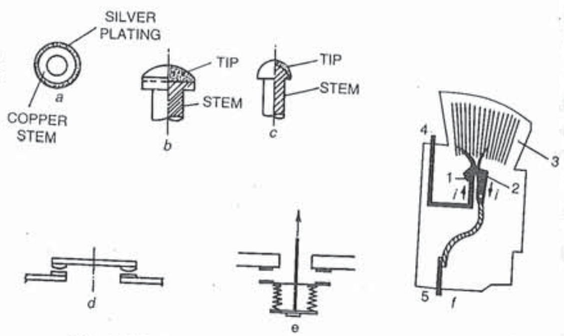


Fig. 15.16. (*a* to *f*) Contact configurations in LV switches.

Requirements of Contact in LV Switching Devices

For LV circuit-breakers, the same principles mentioned above are applicable. Distinction is essential between.

- — Main contacts having low contact resistance, high electrical conductivity.
- — Arcing contacts having high arcing resistance, high temperature withstand and low burning.

The low contact resistance material does not have the high arc-resistance properties. Hence separate sets of main contacts and arcing contacts in case of LV circuit-breakers. Alternatively the main contacts are provided with arcing tips.

15.39. CONTACT MATERIALS

Table 15 gives a list of contact materials used for main contacts and arcing contacts in LV Switching devices.

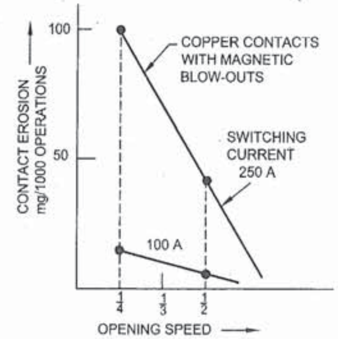
Table 15-C-4 List of Contact Materials

	Material	*Main Properties*	*Remarks*
1.	Main Contacts Silver Silver Copper	High electrical conductivity.	Silver plated.
	Palladium alloy Palladium Gold alloy	Corrosion resistance	Sintered
2.	Arcing contacts Tungsten-copper Tungsten Tungsten-silver	High arc resistance	Sintered

15.40. CONTACT SPEED DURING OPENING OPERATION

The speed of contact for opening stroke determines the time of arcing and contact erossion. For higher breaking current, higher contact speed is used. In LV switches the contact speed is in the range of 0.25 m/s and 0.5 m/s. Contact travel is a few mm. In MV switches contact speed is in the range of 1 m/s and 4 m/s. In HV switches the contact speed is 2 m/s to 6 m/s and contact travel is between 100 cm and 175 cm.

Fig. 15.17 (*a*) and (*b*) indicate the effect of opening speed and closing speed on contact erosion.



Switch with magnetic blow-out. Copper contacts, switching voltage 110 V d.c.
Fig. 15.17. (*a*) Effects of Opening speed on contact erosion for air-break.

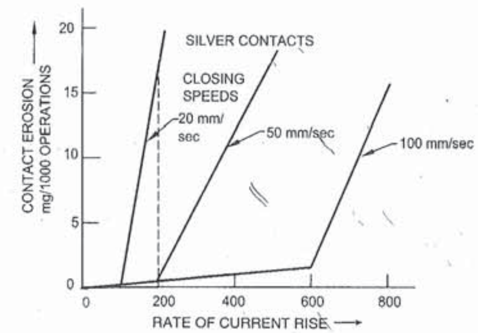


Fig. 15.17. (*b*) Effect of closing speeds on contact erosion for silver contacts.

15.41. AUXILIARY SWITCHES

Fig. 15.18 (*a*) shows schematic diagram of an auxiliary switch, connected with isolator mechanism. Fig. 15.18 (*b*) indicates the sequence of switching operations. An auxiliary switch has several pairs of contacts. The types of contacts include the following.

- — Normally-closed contacts
- — Normally open contacts
- — Changeover contacts
- — Fleeting contacts

Normally-closed contacts. These are closed when the main switch is open and open when the main switch closes.

Normally open contacts. These are open when the main switch is open and close when the main switch closes.

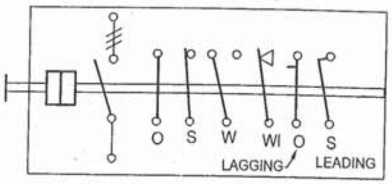


Fig. 15.18. (*a*) Schematic diagram of an Auxiliary Switch for an Isolator.

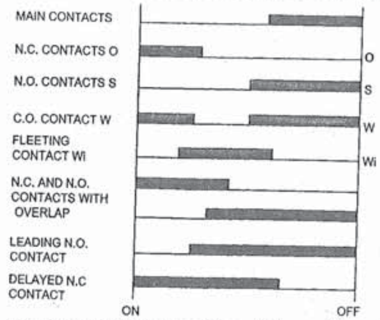


Fig. 15.18. (*b*) Contact positions of the auxiliary switch during operation.

Changeover Contacts. These have two separate fixed contacts for each position. They have one moving contact which closes with either fixed contact depending on the main switch position.

Fleeting contacts. These are closed briefly during the transition of the switching device from one position to the other.

Auxiliary switch operates with operating device, with the help of auxiliary switch, auxiliary circuits such as command, actuation, alarm and measurement circuits, are closed and opened in conjunction with the main circuit switchgear.

Auxiliary switches are of great importance, especially in extensive control and interlock systems and must therefore function reliably. Special attention must be given to the reliable making of contacts because auxiliary circuits often operate at low voltages and high currents.

15.42. TRIPPING DEVICE AND RELAYS

Tripping devices are components of switches which release them mechanically. Relays are control devices which electrically control other devices. Tripping devices are relays are operated by changing physical, predominantly electrical quantities.

These are measuring and non-measuring tripping devices. Table 15-C-8 gives list of tripping devices and relays.

Table 15-C-5. Tripping Devices and Relays

Function	*Abnormal condition causing operation*
Overload release	Over current above set value
Under current release	Under current below set value
Reverse current release	Current direction reversed
Under voltage release, no-volt release	Voltage value below set value
Fault current release	Fault current above set value
Fault voltage release	Fault voltage above set value
Over current in common conductor	Current in the common conductor above set value.

Fig. 15.13 (*b*) shows single line diagram of LV switch with (1) Electromagnetic over-current trip with auxiliary switch (2) Electrical of Electronic timed (3) Undervoltage or shunt trip (4) Switch latching mechanism.

Fig. 15 shows schematic circuit diagram of a three phase LV Motor Control Switch in Corporating (1) Open-Circuit trip (2) Undervoltage trip (3) Auxiliary switch unit (4) Connector block (5)

three-pole over current release. During abnormal conditions, the corresponding release is actuated and the switch mechanism is unlatched thereby causing opening of the main switching device.

Ref. Fig. 31.2, 31.4.

In case of MV switchgear, various protective relays are connected to the secondary of CT and VT. These relays operate in response to respective abnormal conditions and close trip circuit. Ref. Fig. 27.3. Overcurrent release, undervoltage release etc. are not provided in main circuit as in LV switchgear. Fig. 15.13 (*a*) and Fig. 15.13 (*b*) show components, with a typical LV switch.

15.43. DEGREE OF PROTECTION, IP CODE

LV and MV switchgear are installed indoor and need protection against ingress of dust, water, external bodies. The operators should be protected from accidential contact with line parts or moving parts. These aspects must be considered while designing the LV switchgear and MV switchgear. The enclosures should have adequate provisions of 'Protection'. The following protection are covered in the IEC 144, DIN 40050 etc. Specify various grades of Degree of Protection by IP code numbers. (P = Protection).

Standard degrees of protection by enclosures are applicable to respective electrical machines (IEC 34.5), LV switchgear and controlgear (IEC 144) etc. They specify design and testing requirements with respect to :

1. Protection against accidential contact of persons with live parts or moving parts inside enclosures and protections of internal parts against ingress of external solid parts such as dust, solid wires, objects. These two functional requirements are usually combined in a common numeral of the IP code.
2. Protection of internal parts covered by the enclosure against ingress of external water and liquids falling on the enclosure at various pressures.

The IP code is usually defined in the standard in four digits *e.g.*

Code letters IP are common. They indicates reference to the degree of protection.

First characteristic numeral disigrates degrees of protection provided by enclosure against contact by persons as well as against ingress of foreign bodies.

Second characteristic numeral designates degree of protection provided by enclosure against harmful ingress of water of liquids.

The LV switchgear enclosures are designed for achieving specific degree of protection and are tested in special laboratories as per test procedures for particularly specified degree of protection. The tests are simple and consist of showering talcum powder dust or water at spay of specified intensity for specified time. After the test the amount of ingress of dust/water into the enclosure is measured. It should be within specified limits.

Ref. Sec. 15.21 for standard numerals as per IEC 144.

15.44. MEDIUM VOLTAGE VACUUM CONTACTORS FOR 3.6 TO 12 kV

Courtesy : Siemens, West Germany.

Application

The vacuum contactors are particularly suitable for controlling AC loads with a high switching rate and unlimited on time.

They are used for the following functions :

— Switching of three-phase motors in AC 3 duty
— Inching in AC4 duty switching off of three-phase motors during run-up
— Switching of transformers
— Switching of capacitors

— Switching or resistive loads (*e.g.* electric furnace)

High voltage vacuum contactors are designed to meet IEC - 470, DE 066, BS 775-2, AS 1864 etc.

Construction and function (Ref. Fig. 15.19)

The vacuum contactor consists of a low-voltage section, a high-voltage section and an integral rocker as a dynamic link between the solenoid operating mechanism and the vacuum interrupters.

The LV section contains the solenoid mechanism, auxiliary switch blocks, centrally arranged terminal blocks, mechanical closing latch, and a mechanical lock-out.

The main HV parts are the moulded plastic housing with the three vacuum interrupters and the power terminals. The contactors are fitted with **vacuum interrupters** for the required particular voltage (3.6/7.2/12 kV). When the contactor closes the operating stroke of the solenoid is transmitted by the integral rocker to the moving contact of the vacuum interrupter. The contact gap is closed by the atmospheric pressure and an additional spring. When the solenoid circuit is interrupted the two restoring springs establish the contact gap by acting on the integral rocker. The contactor has a life expectancy of upto 2×10^6 operation cycle.

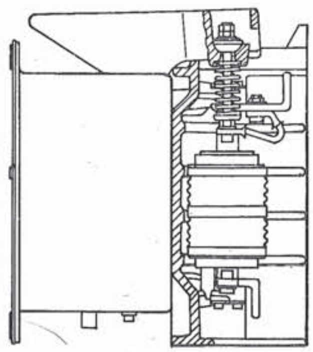


Fig. 15.19. Cross Section of Vacuum Contactor. Side View
Courtesy : Siemens, West Germany.

16

HVDC Circuit-Breaker and Metallic Return Transfer Breaker (MRTB)

Introduction to HVDC Systems — Why no need of HVDC Circuit Breaker in main power poles ? — Bipolar 2-Terminal HVDC System — Three Terminal Parallel Tapping — Multi-terminal (MTDC) — Back to Back HVDC Coupling Station (BBCS) — Metallic Return Transfer Breaker (MRTB) in Earth Return Path.
HVDC Arc Interruption by Artificial Current Zero-Energy Considerations in Breaking of Direct Current in HVDC Circuit Breakers — HVDC Circuit Breaker Principle — Commutation Principle — Control of dv/dt — Triggerred Vacuum Gap — HVDC Switching Devices in use — Metallic Return Transfer Breaker in 2TDC — Switching Arrangement in 3T Parallel tapping HVDC — Type of Breakers in Main DC Circuit : Type A, Type B1, Type B2 — Time considerations. HVDC Circuit Breaker for Parallel Tap-Conclusions.

16.1. INTRODUCTION TO HVDC SWITCHING SYSTEM

— HVDC Transmission Systems have become commercially successful in India and many other nations after around 1980. High Voltage Direct Current Transmission (HVDC) is an alternative to 3 Phase, 50 Hz, AC transmission in following applications :

— Bipolar Long Distance High Power Transmission from Super Thermal Power Plants/Super Hydro Plants to Mega-load centers. Typical Ratings of such HVDC Links ; single circuit 2 Pole ± 500 kV DC or ± 600 kV DC, 1500 MW, 2000 MW, 6000 MW, 750 km to 2000 km long, without any compensating substation in between. For example : Rihand Delhi HVDC Link : 820 km, ± 500 kV DC, 1500 MW. Chandrapur Padghe HVDC Link of same rating.

— System Interconnections (100 MW, 500 MW, 1000 MW, 2000 MW).

— Frequency conversion (50 Hz/60 Hz)

— Back to Back HVDC Coupling Station between two neighbouring AC Grids. National Grids with several such interconnections.

— Submarine Cable Transmission through oceans and lakes for feeding power to islands or for interconnection between two Grids separated by long ocean/channel.

— Multi-terminal interconnections between several AC Networks by Long High Power HVDC Transmission Bus.

Table 16.1. Particular Applications of HVDC Transmission Systems

Type	*Principal Criteria of Choice*
1. Long 2-Terminal Bipolar High Power HVDC Systems *e.g.* Rihand Delhi, India 1991 ; Chandrapur-Padghe (1997)	— Economy in capital cost, — Better power control, accurate, fast control of power flow (30 MW/min) through particular line, this is not possible with AC Line in a Network. — Lower transmission losses as no reactive power flow. — Energy Conservation — Higher Stability Limit