University of Global Village (UGV), Barishal

POWER SYSTEM II (PROTECTION)

CONTENT OF THEORY COURSE

Prepared by:

Md. Mutassim Fuad
Lecturer, Dept. of EEE
University of Global Village (UGV), Barishal

Basic Course Information

Course Title	Power System II (Protection)
Course Code	EEE 0031-4203
Credits	03
CIE Marks	90
SEE Marks	60
Exam Hours	2 hours (Mid Exam) 3 hours (Semester Final Exam)
Level	8th Semester
Academic Session	Winter 2025

Continuous Assessment Plan

Quizzes

Altogether 4 quizzes may be taken during the semester, 2 quizzes will be taken for midterm and 2 quizzes will be taken for final term.

Assignments

Altogether 4 assignments may be taken during the semester, 2 assignments will be taken for midterm and 2 assignments will be taken for final term.

Presentation

The students will have to form a group of maximum 3 members. The topic of the presentation will be given to each group and students will have to do the group presentation on the given topic.

Assessment Pattern

CIE – Continuous Internal Evaluation (90 Marks)

Bloom's Category Marks (out of 90)	Mid Exam (45)	Assignment (15)	Quiz (15)	Attendance & External Participation in Curricular/Co-Curricular Activities (15)
Remember	05		05	
Understand	05	05	05	
Apply	10		05	15
Analyze	10			
Evaluate	10			
Create	05	05		

Assessment Pattern

SEE – Semester End Examination (60 Marks)

Bloom's Category	Final Examination
Remember	15
Understand	10
Apply	10
Analyze	10
Evaluate	10
Create	05

Course Learning Outcomes (CLOs)

01
CLO 1

Demonstrate proficiency in analyzing switchgear systems and protective relay operation.

02
CLO 2

Design effective protective schemes for power system applications.

03
CLO 3

Evaluate fault detection and clearance strategies for optimal system performance.

04
CLO 4

Apply theoretical principles to solve practical problems in switchgear protection.

Synopsis / Rationale

This Course is very essential for the students to work in the fields of power systems. From this course students will learn about switchgear equipment and their uses as well as protection schemes for power systems.

COURSE OBJECTIVES

This course has been designed for the students. To provide an overview of different types of switchgear equipment and their uses. To develop students' understanding of the protection system of different parts of the power system. To make them aware of different types of faults and their remedies happens in the power system. To enhance the ability of students to cope with the practical challenges in the field of protection.

COURSE SUMMARY

Serial No.	Course Content	Hours
1.	**Introduction to switchgear and protection:** Circuit breakers, the principle of arc extinction in DC and AC circuit breakers. Recovery voltage, rate of rise of recovery voltage, and other transient phenomena. Switching surges. Disconnection of unloaded transformer and transmission line. Speed of circuit breaker.	**10**
2.	Construction, operation, rating, and testing of bulk oil and minimum oil breaker, SF6 circuit breaker, ABCB, ACB, and VCB. Selection of circuit breaker. Traveling wave in the transmission line. Surge absorber, lightning arrester, horn gap, its rating, and testing.	**6**
3.	**Protective relaying:** Relay voltage rating, high, medium, and low. Basic protective zone. Relaying Scheme. Electromechanical Relays: Principal, general equation. Overcurrent, balanced current, overvoltage, distance, directional, positive sequence, negative sequence, and differential relays and their applications.	**8**

COURSE SUMMARY

Serial No.	Course Content	Hours
4.	**Static relays:** Introduction to solid state device in the construction of static relays. Different types of static relays.	10
5.	Generator protection. Transformer protection, Bucholz's relay. Protection of bus bars, transmission line, feeder, etc. Relay testing. Sub-Stations.	6

COURSE PLAN MAPPED WITH CLO

Week No.	Topics	Teaching-Learning Strategy	Assessment Strategy	Alignment to CLO
1.	Switchgear, Normal and Abnormal Condition, Fault, Minimization of fault, Protective Zone, Primary and Back up Protection	Lecture, Multimedia, Group Discussion	Feedback, Q&A	CLO 1
2.	Protective Relays , Types of relay,Desirable qualities for protective relays,Reliability of Protective System,	Lecture, Multimedia, Practical Example	Feedback, Q&A	CLO 1, CLO 2
3.	Attracted armature type relay ,Characteristics of Attracted armature type relay , Solenoid type relay,Balanced beam type relay	Lecture, Multimedia, Practical Example	Feedback, Q&A Assignment	CLO 1, CLO 2, CLO 3

COURSE PLAN MAPPED WITH CLO

Week No.	Topics	Teaching-Learning Strategy	Assessment Strategy	Alignment to CLO
4.	Induction relay,Types of induction relay, Shaded-pole structure relay ,Watt-hour meter structure relay , Induction cup structure	Lecture, Multimedia, Group Discussion	Feedback, Q&A	CLO 1
5.	Pick-up current , Current setting ,Plug-setting multiplier, Time-setting multiplier, Time/P.S.M. Curve	Lecture, Multimedia, Practical Example	Feedback, Q&A	CLO 1, CLO 2
6.	Bus Bar Arrangement	Lecture, Multimedia, Practical Example	Feedback, Q&A Assignment	CLO 1, CLO 2, CLO 3

COURSE PLAN MAPPED WITH CLO

Week No.	Topics	Teaching-Learning Strategy	Assessment Strategy	Alignment to CLO
7.	Substation, Classification of substation, Comparison between indoor and outdoor substation, Transformer substation	Lecture, Multimedia, Group Discussion	Feedback, Q&A	CLO 1
8.	Pole mounted Substation, Underground substation, Equipments of substation	Lecture, Multimedia, Practical Example	Feedback, Q&A	CLO 1, CLO 2
9.	Bus Bar arrangements in a substation: advantages, dis advantages and reliability issue	Lecture, Multimedia, Practical Example	Feedback, Q&A Assignment	CLO 1, CLO 2, CLO 3

COURSE PLAN MAPPED WITH CLO

Week No.	Topics	Teaching-Learning Strategy	Assessment Strategy	Alignment to CLO
10.	Key Diagram of 66/11 KV Sub-station, Key Diagram of 11KV/400 V indoor sub station	Lecture, Multimedia, Group Discussion	Feedback, Q&A	CLO 1
11.	Principles of Arc Extinction, Methods of Arc Extinction,	Lecture, Multimedia, Practical Example	Feedback, Q&A	CLO 1, CLO 2
12.	Classification of Circuit breakers, Oil Circuit Breakers, Types of Oil Circuit Breaker , Plain brake oil Circuit Breaker	Lecture, Multimedia, Practical Example	Feedback, Q&A Assignment	CLO 1, CLO 2, CLO 3

COURSE PLAN MAPPED WITH CLO

Week No.	Topics	Teaching-Learning Strategy	Assessment Strategy	Alignment to CLO
13.	Arc Extinction oil Circuit breakers and their operation	Lecture, Multimedia, Group Discussion	Feedback, Q&A	CLO 1
14.	Low oil Circuit Breaker and their Operation, Maintenance of oil circuit breaker.	Lecture, Multimedia, Practical Example	Feedback, Q&A	CLO 1, CLO 2
15.	Airblast Circuit Breaker Principle, types, construction and operation	Lecture, Multimedia, Practical Example	Feedback, Q&A Assignment	CLO 1, CLO 2, CLO 3

COURSE PLAN MAPPED WITH CLO

Week No.	Topics	Teaching-Learning Strategy	Assessment Strategy	Alignment to CLO
16.	Gas Circuit Breaker Principle, types, construction and operation, Vaccum Circuit Breaker Principle, types, construction and operation	Lecture, Multimedia, Group Discussion	Feedback, Q&A	CLO 1
17.	Review Class	Lecture, Multimedia, Practical Example	Feedback, Q&A	CLO 1, CLO 2

Week 01
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Switchgear

The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as **switchgear**.

The scheme which sense the abnormal conditions in a part of the power system and gives an alarm or isolates that part from the healthy system is known as protective relaying.

The functions of protective relaying include the following:

1. To sound an alarm on to close the trip circuit of CB so as to disconnect a component during an abnormal condition in the component which includes over-voltage, under-voltage, temperature rise, unbalanced load, reverse power, under frequency, short circuit etc.

Normal condition: *Predetermined condition to run the system properly*

Abnormal condition: *Anything which is not normal*

2. To disconnect the abnormally operating part as to prevent the subsequent faults, over load protection of a machine to protect the machine and prevent the insulation failure.
3. To disconnect the faulty part quickly so as to minimize the damage to the faulty part: If a machine disconnect immediately after a winding fault, only a few coils may need replacement, otherwise the entire winding will be damaged.
4. To localize the effect of fault by disconnecting the faulty part from the healthy part causing least disturbance to the healthy system.
5. To disconnect the faulty part quickly so as to improve the system stability service continuously and system performance.

Fault cannot be avoided completely but they can be minimized. Protective relaying pays an important role in minimizing the fault and also in minimizing the damage in the equipment.

How to minimize the fault?

Fault can be minimized to some extent by taking the following precautions:

1. Improvement in the quality of machines, equipment, installation etc. by improving in design, manufacturing techniques, material quality, control, testing, research & development.
2. Improvement in system design, connect layout choice of equipment.
3. Adequate and reliable protective system.
4. Regular and detailed maintenance by trained personnel.
5. Trained personnel for operation and management of electrical plant.

Fault

Fault *is a defect in its electrical circuit due to which the flow of current is diverted from the intended path.*

Causes of Fault

1) **Overhead Line:** Lightening-stroke, storms, earthquakes, icing, birds, trees, kites, airplanes, internal overvoltage etc.
2) **Underground Cables:** Damage due to digging, insulation failure due to temperature rise, failure of joints etc.
3) **Alternators:** Stator faults, rotor faults, abnormal conditions, associated equipment, protective system etc.
4) **Transformer:** Insulation, tap-change fault, fault in bushing, fault in protection circuit, overhead lines, overvoltage etc.
5) **CT & PT:** Overvoltage, insulation fault, breaking of conductors, wrong connection etc.
6) **Switchgear:** Insulation, mechanical defect, leakage of air/gas/oil, lack of maintenance etc.

Table 1-1: Fault statistics (Ref: Ojha)

Element	Error Percentage (%)
Overhead transmission line	45-55
Underground cable	8-12
Switchgear	13-17
Power transformer	10-14
CT & PT	1-3
Control circuit equipment	2-4
miscellaneous	7-9

Protective Zone

In order to provide selectivity to the system, it is a usual practice to divide the entire system into several protection zones. When a fault occurs in a given zone, then only the circuit breakers within that zone will be opened. This will isolate only the faulty circuit or apparatus, leaving the healthy circuits intact. The system can be divided into the following protection zones:

(a) Generators,   (b) Low-tension switchgear,   (c) Transformers,
(d) High-tension switchgear, (e) transmission lines.

A *part of the system protected by a certain protective scheme is called a* **protective zone**.
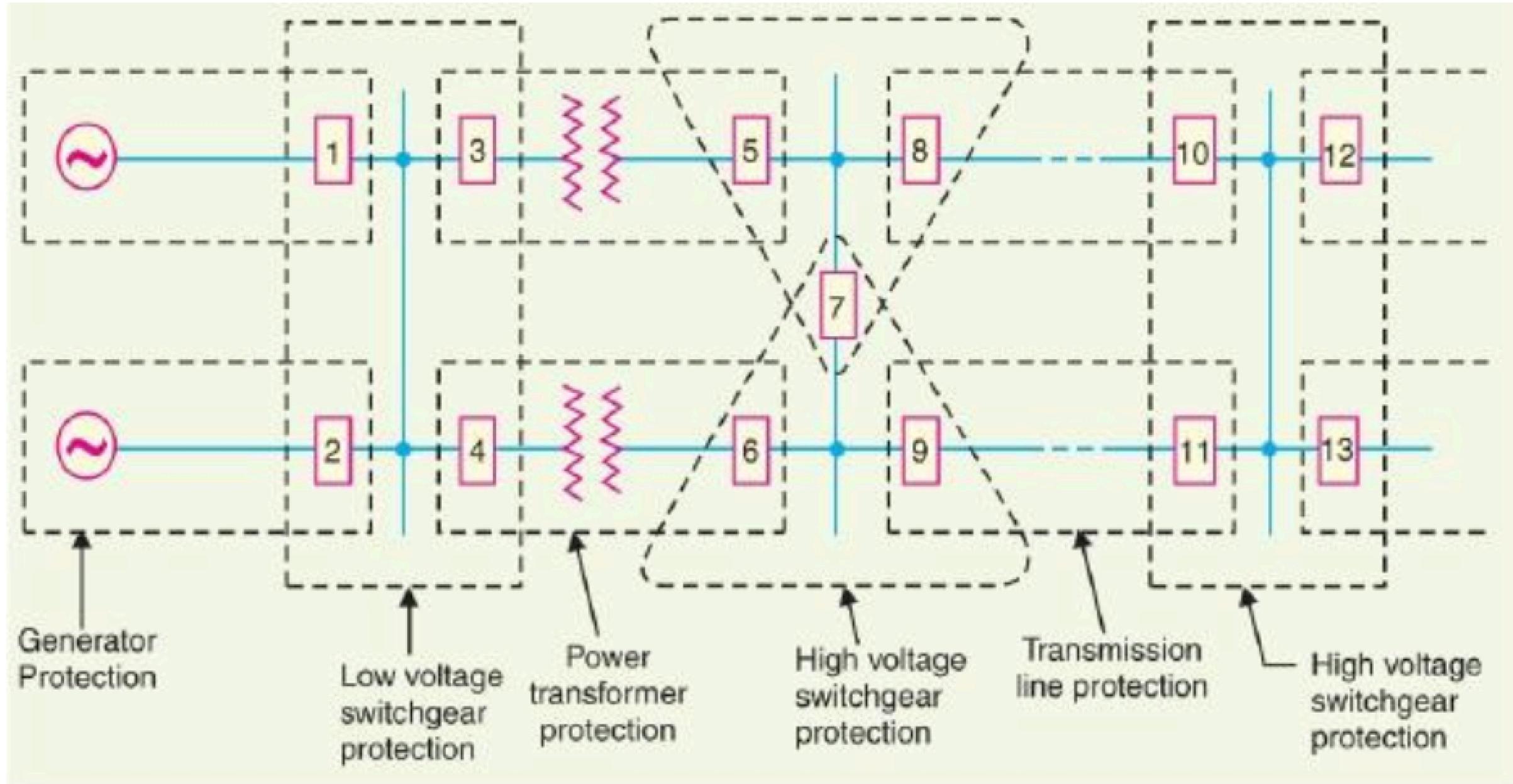
Figure: Different protective zone with Circuit Breakers (CB).

Primary Protection

It is the protection scheme which is designed to protect the component parts of the power system. If a fault occurs on any line, it will be cleared by its relay and circuit breaker. This forms the primary or main protection and serves as the first line of defense. The service record of primary relaying is very high with well over ninety percent of all operations being correct.
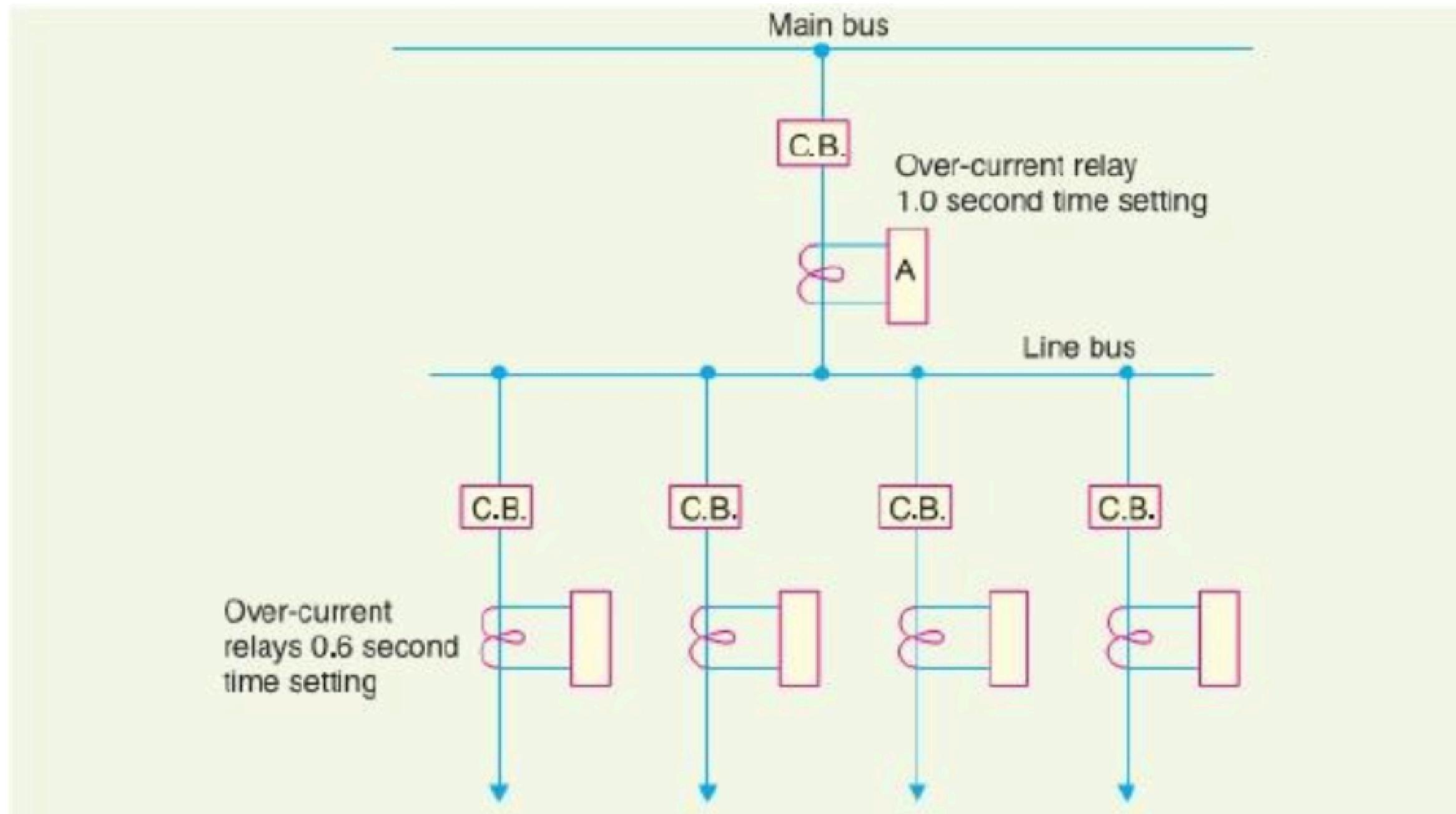
Backup Protection

It is the second line of defense in case of failure of the primary protection. It is designed to operate with sufficient time delay so that primary relaying will be given enough time to function if it is able to.

1) **Relay Backup:** Same breaker is used by both main and backup protection but the protective systems are different. Separate coils may be provided for the same breaker.
2) **Breaker Backup:** Different breaker is provided for main and backup protection, both breakers being in the same station.
3) **Remote Backup:** The main backup protection is provided of different stations and are completely independent.
4) **Centrally Co-ordinated Backup:** The main backup protection is provided and controlled centrally.

Backup protection by time grading
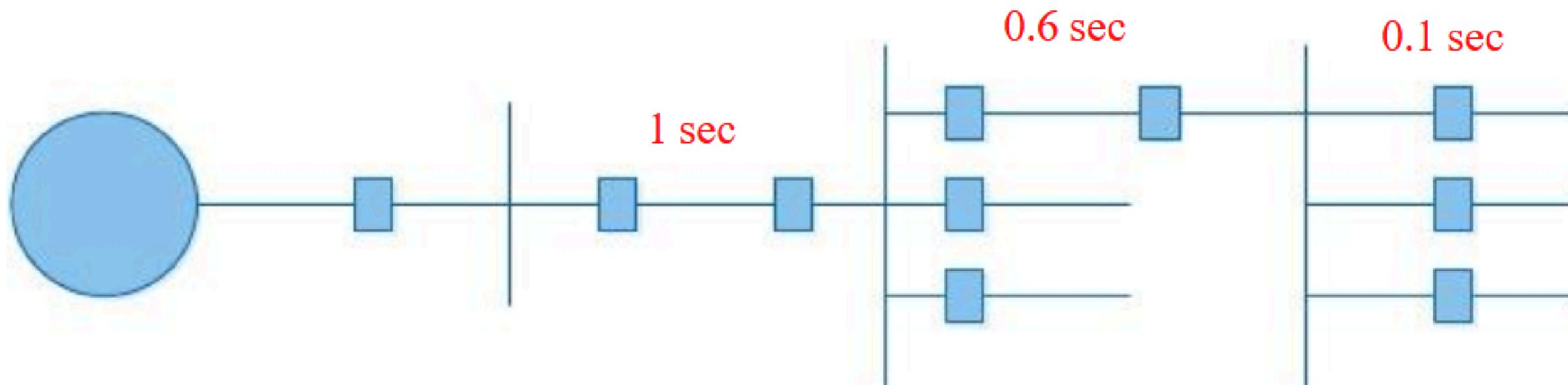
Why backup Protection is necessary?

Answer:

This protection is necessary when the primary protection fails to operate the failure of which may be to any of the following reasons:

1. The DC supply of the tripping circuit.
2. The tripping mechanism of CB fails.
3. The current on voltage supply to the relay.
4. The CB fails to operate.
5. The primary protective relay fails.

Week 02
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Protective Relays
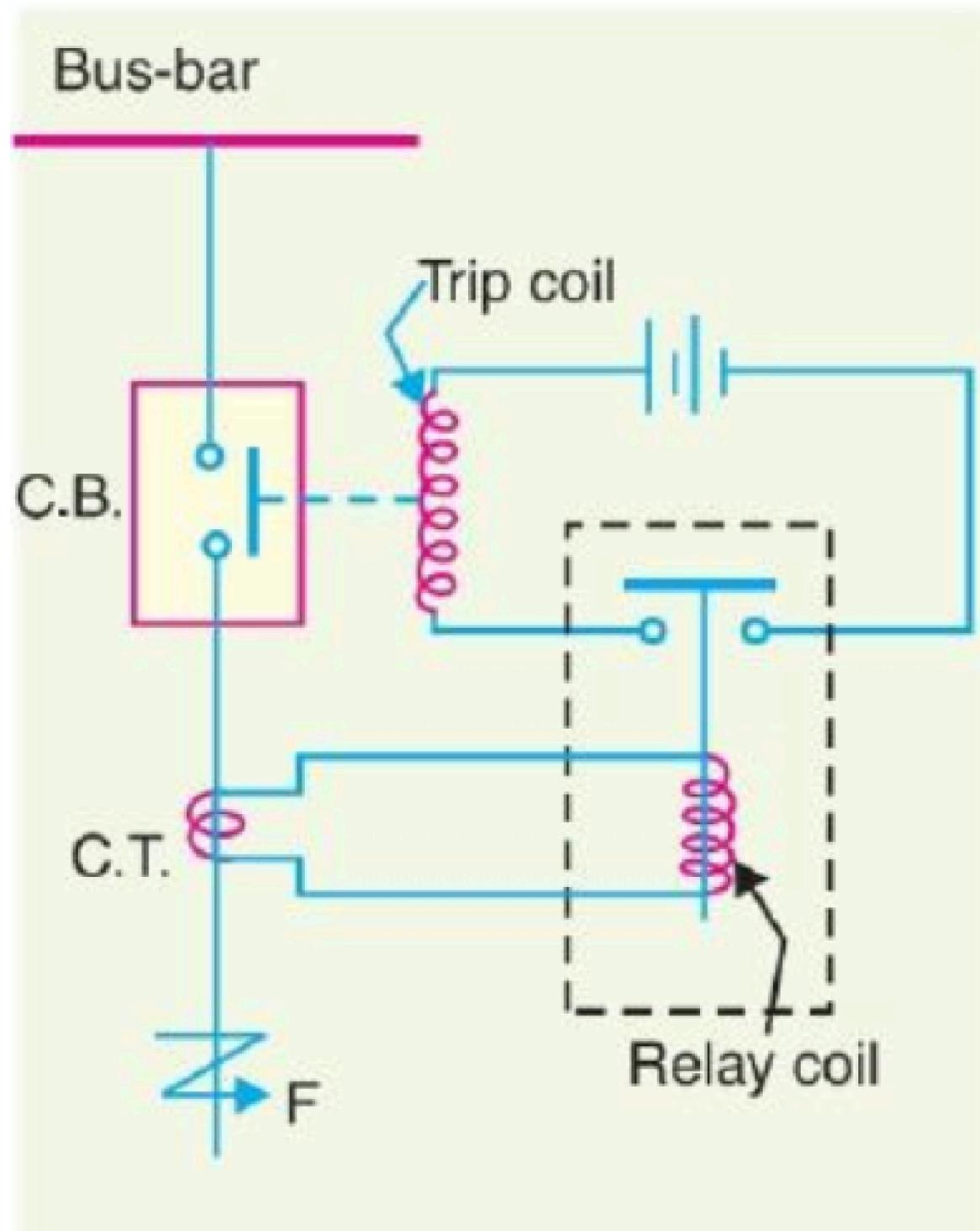
A **protective relay** *is a device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system.*

A typical relay circuit is shown in Figure. This diagram shows one phase of 3-phase system for simplicity. The relay circuit connections can be divided into three parts:

i)   First part is the primary winding of a current transformer (C.T.) which is connected in series with the line to be protected.

ii)   Second part consists of secondary winding of C.T. and the relay operating coil.

iii)   Third part is the tripping circuit which may be either AC or DC. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts.

When a short circuit occurs at point F on the transmission line, the current flowing in the line increases to an enormous value.

This results in a heavy current flow through the relay coil, causing the relay to operate by closing its contacts. This in turn closes the trip circuit of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system. In this way, the relay ensures the safety of the circuit equipment from damage and normal working of the healthy portion of the system.

Types of relay

According to construction and principle of operation

1) *Electromagnetic attraction type relays*
   (a) Attracted armature type relay,
   (b) Solenoid type relay,
   (c) Balanced beam type relay.

2) *Electromagnetic induction type relays*
   (a) Shaded-pole structure relay,
   (b) Watt-hour meter or double winding structure relay,
   (c) Induction cup structure relay.

3) *Electrodynamics type*
   (a) Moving coil type,
   (b) Moving iron type,
   (c) Thermal type.

According to application

i)   Overvoltage on overcurrent on overpower relay,

ii)   Under voltage on under current on under power relay,

iii)   Directional on reuse current relay,

iv)   Directional on reuse power relay,

v)   Differential relay (Current & Voltage),

vi)   Distance relay (Impedance, reactance & Mho),

vii)   Gas protected relay,

viii)   Rectifier relay,

ix)   Static relay.

According to time characteristics

i)   Instantaneous relay,

ii)   Definite time lag relay,

iii)   Inverse time relay,

iv)   Inverse definite minimum time relay.

Desirable qualities for protective relays

In order that protective relay system may perform its function satisfactorily, it should have the following qualities:

1) Selectivity
2) Discrimination
3) Speed
4) Time
5) Sensitivity
6) Power consumption
7) Stability
8) Reliability
9) Simplicity
10) Economy
11) Adequateness.

1) **Selectivity:** It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.

2) **Discrimination:** It is the act discriminating or distinguishing the difference between "normal condition" and "abnormal condition" within the protective zone or elsewhere.

3) **Speed:** The relay system should disconnect the faulty section as fast as possible for the following reasons :

   (*a*) Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.

   (*b*) A failure on the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumers' motors and the generators on the system may become unstable.

   (*c*) The high speed relay system decreases the possibility of development of one type of fault into the other more severe type.

4) **Time:** Fault clearing time is the time between the instant of fault and instant of final arc interruption.

$$Fault\ clearing\ time\ =\ Relay\ time\ +\ Circuit\ breaker\ time.$$

5) **Sensitivity:** It is the ability of the relay system to operate with low value of actuating quantity.

$$K_S = \frac{I_S}{I_0}$$

Here,

    Ks = Sensitivity factor,

    Is = Minimum short circuit current in the zone,

    Io = Minimum operating current of protection.

The sensitivity should be increased to such a level that the system stability is not hampered.

6) **Power consumption:** The relay should be operated at least power as possible.

7) **Stability:** It is defined as the quality of protective system by the virtue of which the protective system remains in operating and stable under certain specified condition such as system disturbance, through faults, transient etc.

8) **Reliability:** It is the ability of the relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

10) **Economy:** The most important factor in the choice of a particular protection scheme is the economic aspect. Sometimes it is economically unjustified to use an ideal scheme of protection and a compromise method has to be adopted. As a rule, the protective gear should not cost more than 5% of total cost. However, when the apparatus to be protected is of utmost importance (*e.g.* generator, main transmission line etc.), economic considerations are often subordinated to reliability.

11) **Adequateness:** There can be many abnormal conditions & providing protection against every absence condition is economically impossible.

However the protection provided for any machine should be adequate:
  (a) Rating of the protected machine,
  (b) Location of the protected machine,
  (c) Probability of abnormal condition due to internal & external causes
  (d) Cost of the machine,
  (e) Continuity of supply as affected by failure of machine.

Reliability of Protective System
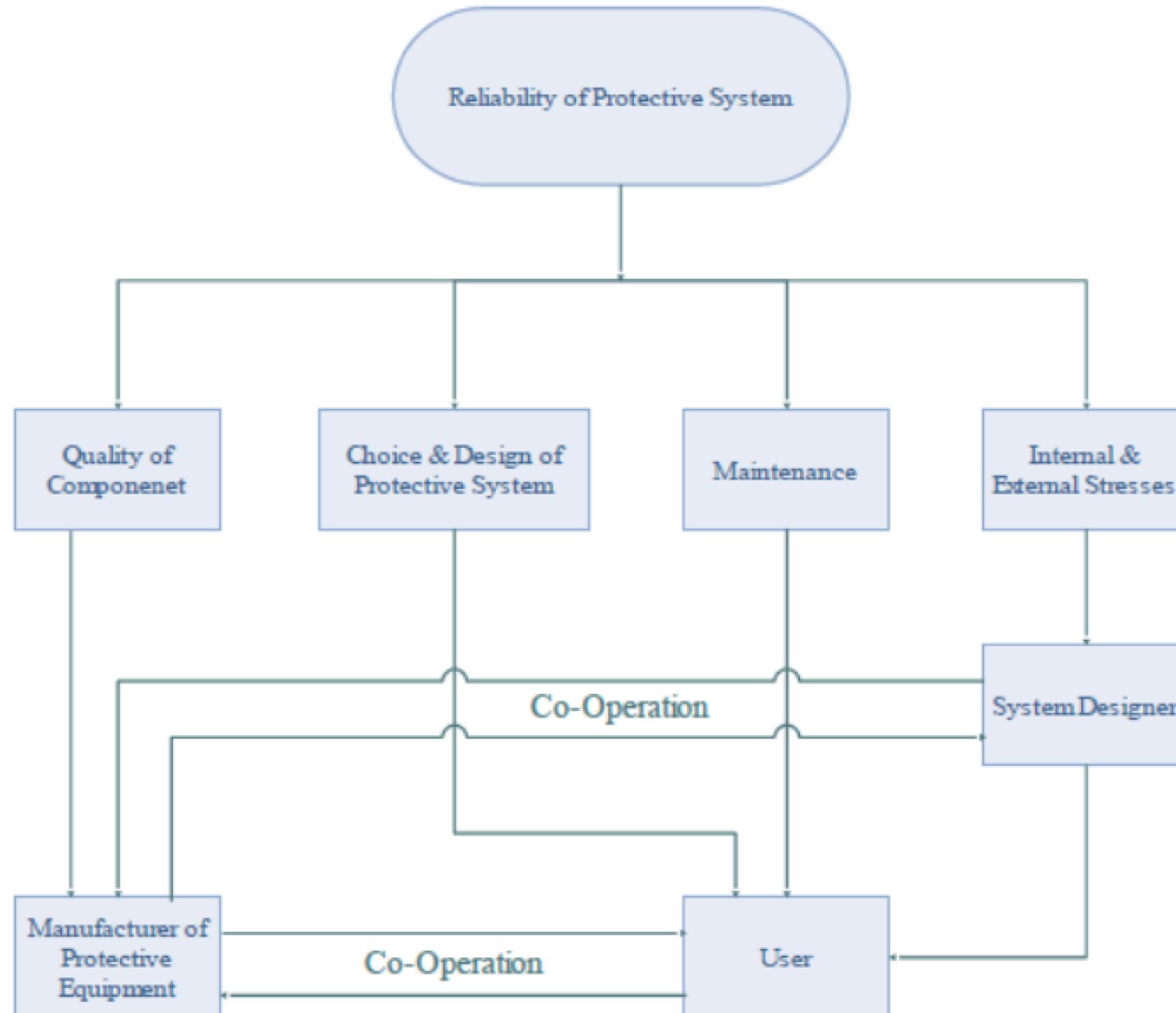
Week 03
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Attracted armature type relay

It consists of a laminated electromagnet M carrying a coil C and a pivoted laminated armature. The armature is balanced by a counterweight and carries a pair of spring contact fingers at its free end.
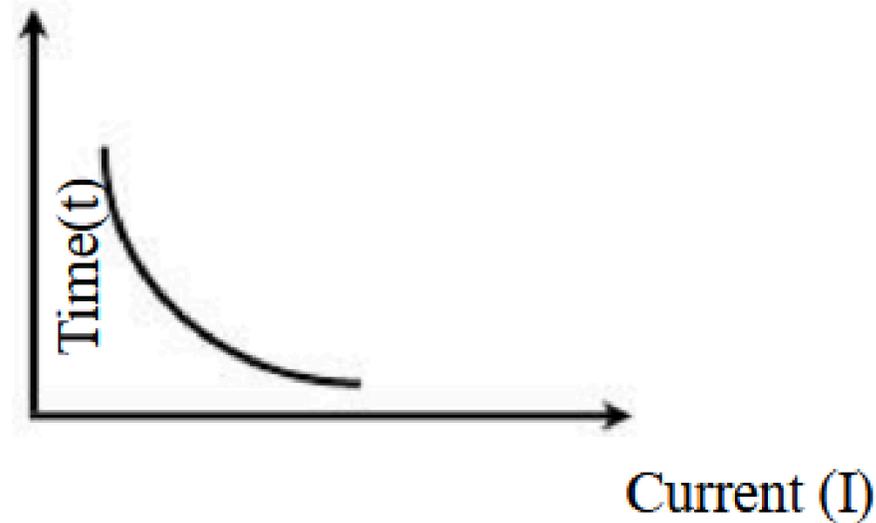

Under normal operating conditions, the current through the relay coil C is such that counterweight holds the armature in the position shown.

However, when a short-circuit occurs the current through the relay coil increases sufficiently and the relay armature is attracted upwards. The contacts on the relay armature bridge a pair of stationary contacts attached to the relay frame. This completes the trip circuit which results in the opening of the circuit breaker and, therefore, in the disconnection of the faulty circuit.
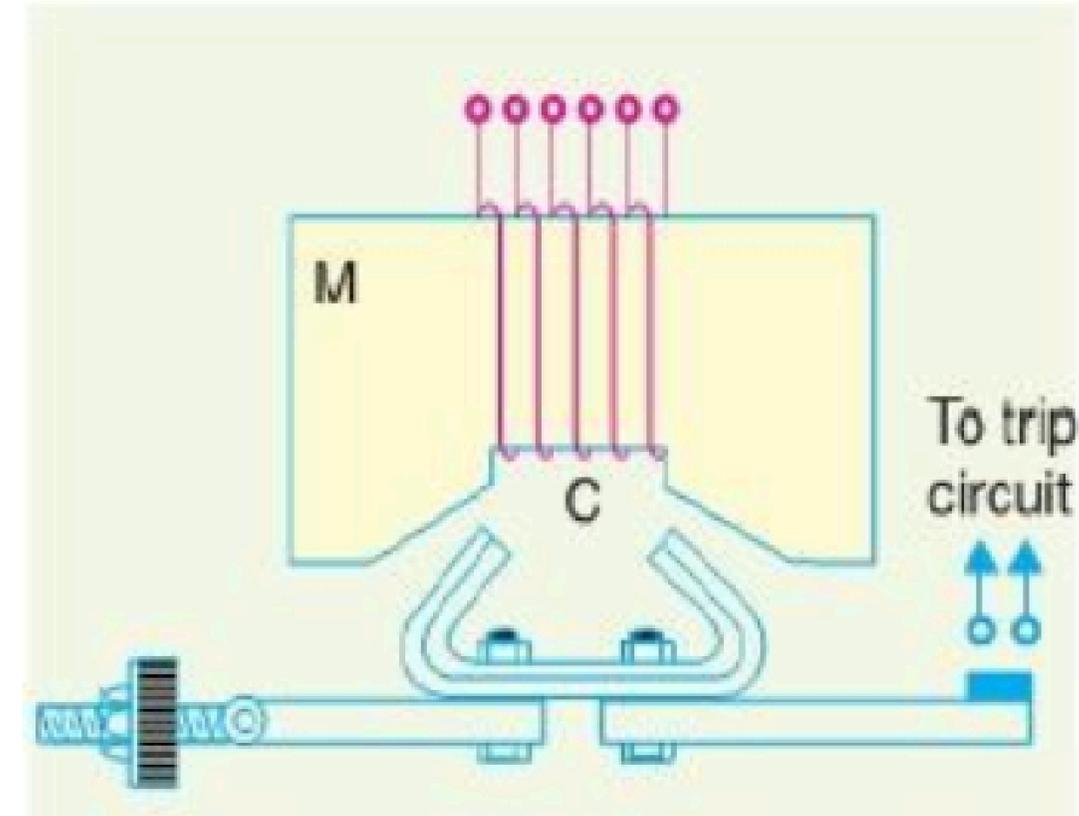
Characteristics of Attracted armature type relay

1. Responses both DC & AC because torque is proportional to I^2.
2. These relays are fast relays, because small length of travel and.......
3. May be instantaneous, does operating (0.1s) and resetting time (0.5s).
4. Also very high speed operating are possible modern 0.5.
5. The time vs current characteristic is---

6. Do not have directional figure.
7. Transient effected.
8. VA burden depends on construction setting. For a typical relay it is of the order of 0.2VA to 0.6VA for current 0.1A to 0.4A.

Applications of Attracted armature type relay

Used as over current relay, definite time lag relay, differential relay, auxiliary relay etc.

Solenoid type relay

It consists of a solenoid and movable iron plunger arranged as shown.

Under normal operating conditions, the current through the relay coil C is such that it holds the plunger by gravity or spring in the position shown.

However, on the occurrence of a fault, the current through the relay coil becomes more than the pickup value, causing the plunger to be attracted to the solenoid. The upward movement of the plunger closes the trip circuit, thus opening the circuit breaker and disconnecting the faulty circuit.

C

To trip
Circuit
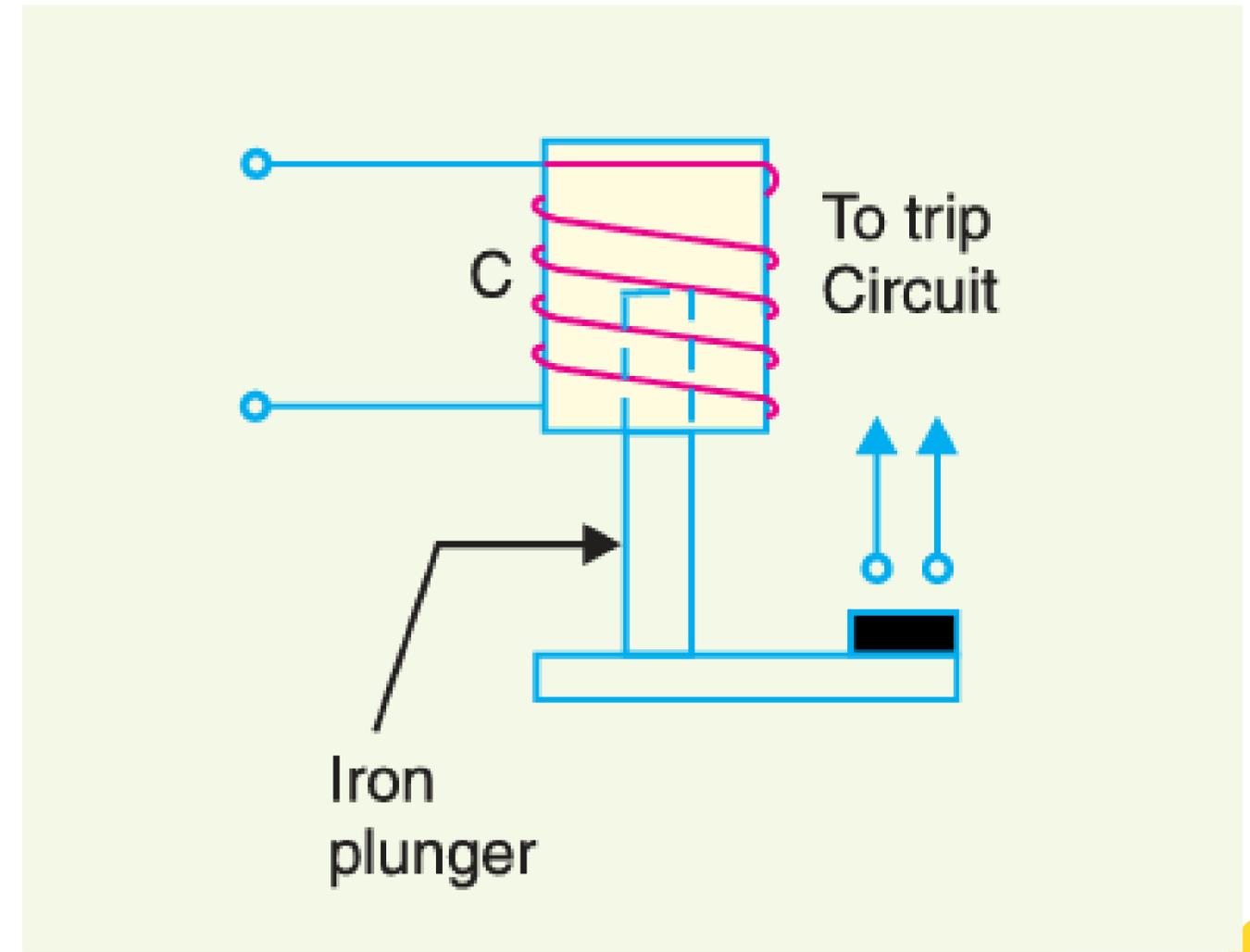
Iron
plunger

Balanced beam type relay

It consists of an iron armature fastened to a balance beam.

Under normal operating conditions, the current through the relay coil is such that the beam is held in the horizontal position by the spring.

However, when a fault occurs, the current through the relay coil becomes greater than the pickup value and the beam is attracted to close the trip circuit. This causes the opening of the circuit breaker to isolate the faulty circuit.

The beam remains in horizontal position till operating force become more than restoring force.

When operating torque increases, the beam shakes & the contact closes.
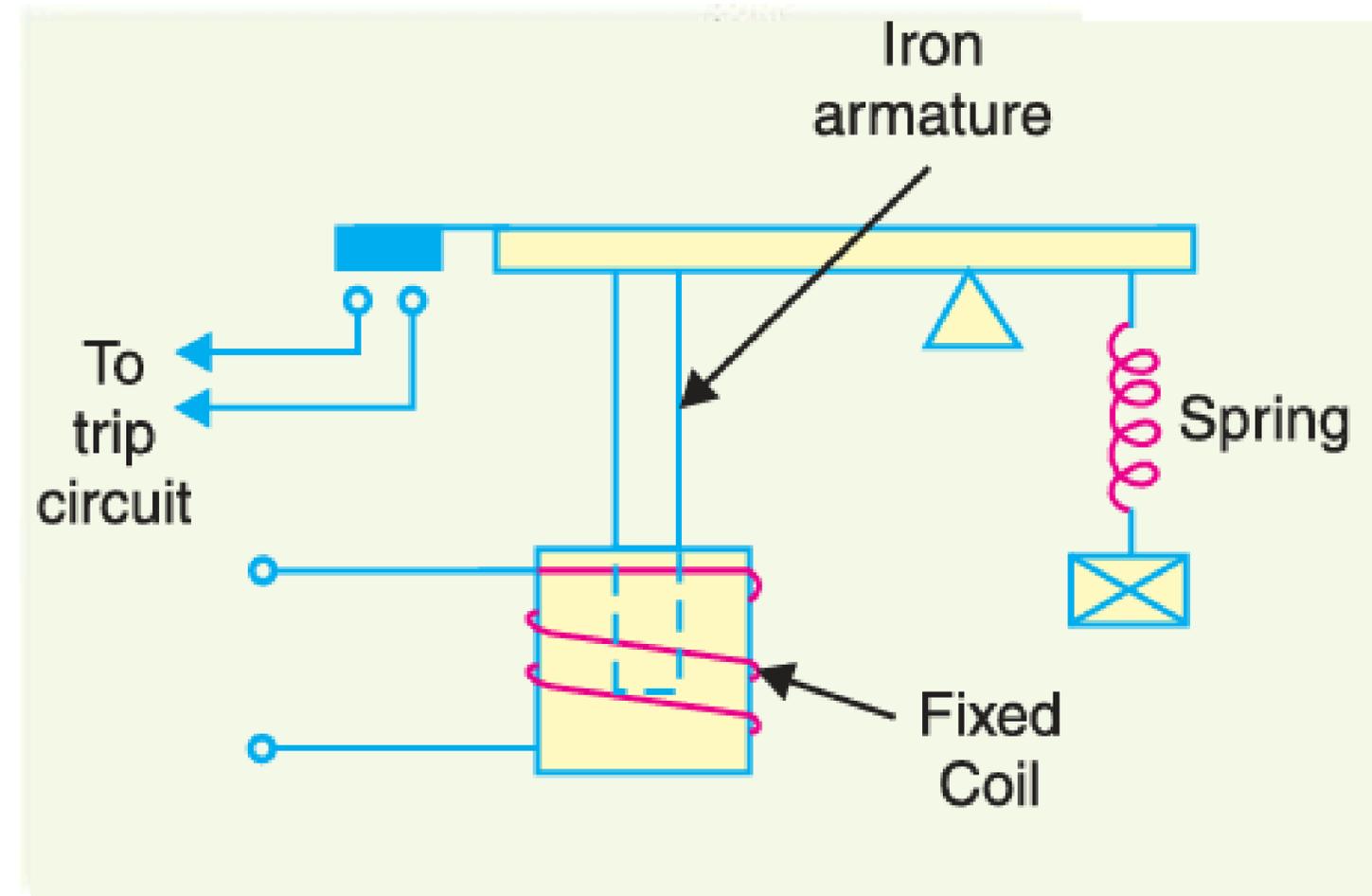
Week 04
Page 43-50

Induction relay

Electromagnetic induction relays operate on the principle of induction motor and are widely used for protective relaying purposes involving only AC quantities.

Referring to Fig. 21.6 (*ii*) where the two a.c. fluxes and induced currents are shown separately for clarity, let

$$\phi_1 = \phi_{1max} \sin \omega t$$

$$\phi_2 = \phi_{2max} \sin (\omega t + \alpha)$$

where ϕ_1 and ϕ_2 are the instantaneous values of fluxes and ϕ_2 leads ϕ_1 by an angle α.

Assuming that the paths in which the rotor currents flow have negligible self-inductance, the rotor currents will be in phase with their voltages.

$$\therefore \quad i_1 \propto \frac{d\phi_1}{dt} \propto \frac{d}{dt} (\phi_{1max} \sin \omega t)$$

and

$$i_2 \propto \frac{d\phi_2}{dt} \propto \phi_{2max} \cos (\omega t + \alpha)$$

Now,

$$F_1 \propto \phi_1 \, i_2 \quad \text{and} \quad F_2 \propto \phi_2 \, i_1$$

(i)

(ii)
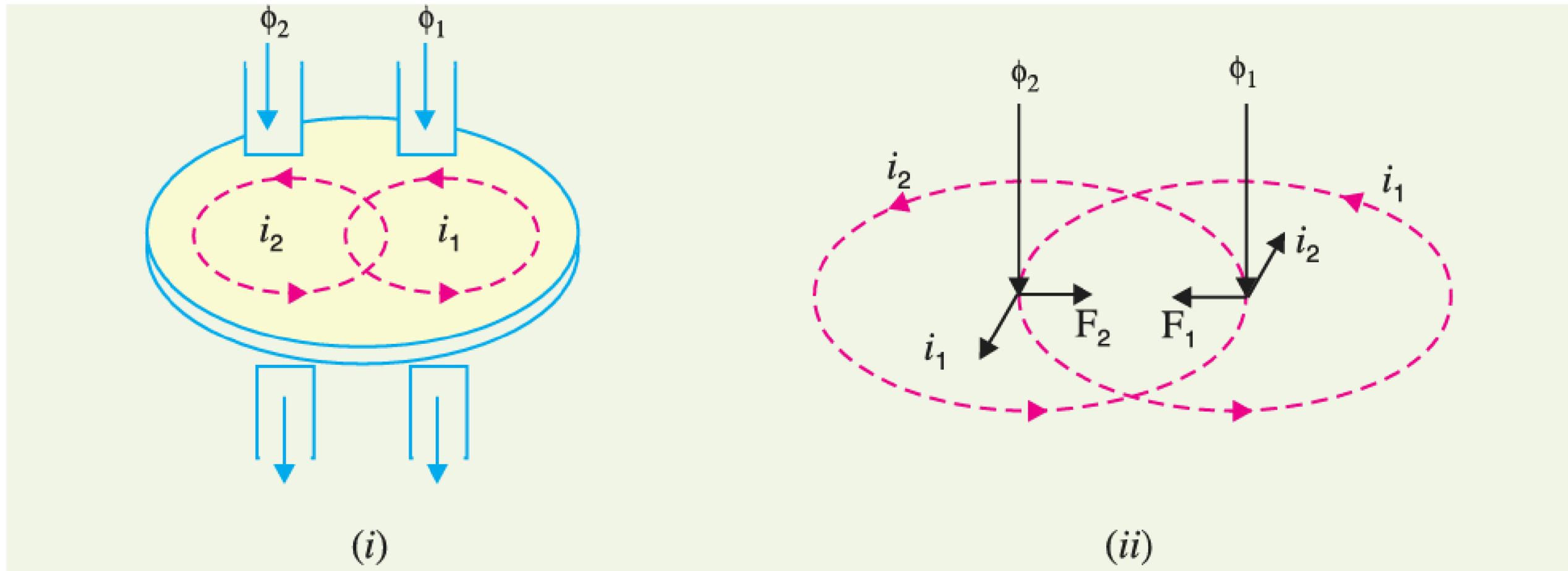
∴   Net force F at the instant considered is

$$F \propto F_2 - F_1$$

$$\propto \phi_2\, i_1 - \phi_1\, i_2$$

$$\propto \phi_{2max} \sin(\omega t + \alpha)\, \phi_{1max} \cos \omega t - \phi_{1max} \sin \omega t\, \phi_{2max} \cos(\omega t + \alpha)$$

$$\propto \phi_{1max}\, \phi_{2max} \left[\sin(\omega t + \alpha) \cos \omega t - \sin \omega t \cos(\omega t + \alpha)\right]$$

$$\propto \phi_{1max}\, \phi_{2max} \sin \alpha$$

$$\propto \phi_1\, \phi_2 \sin \alpha \qquad \ldots(i)$$

The following points may be noted from exp. (*i*) :

(*a*) The greater the phase angle α between the fluxes, the greater is the net force applied to the disc. Obviously, the maximum force will be produced when the two fluxes are 90° out of phase.

(*b*) The net force is the same at every instant. This fact does not depend upon the assumptions made in arriving at exp. (*i*).

(*c*) The direction of net force and hence the direction of motion of the disc depends upon which flux is leading.

The following three types of structures are commonly used for obtaining the phase difference in the fluxes and hence the operating torque in induction relays :

(*i*) shaded-pole structure

(*ii*) watthour-meter or double winding structure

(*iii*) induction cup structure

(*i*) **Shaded-pole structure.** The general arrangement of shaded-pole structure is shown in Fig. 21.7. It consists of a pivoted aluminium disc free to rotate in the air-gap of an electromagnet. One-half of each pole of the magnet is surrounded by a copper band known as *shading ring.* The alternating flux ϕ_s in the shaded protion of the poles will, owing to the reaction of the current induced in the ring, lag behind the flux ϕ_u in the unshaded portion by an angle α. These two a.c. fluxes differing in phase will produce the necessary torque to rotate the disc. As proved earlier, the driving torque T is

$$T \propto \phi_s \, \phi_u \sin \alpha$$

Assuming the fluxes ϕ_s and ϕ_u to be proportional to the current I in the relay coil,

$$T \propto I^2 \sin \alpha$$
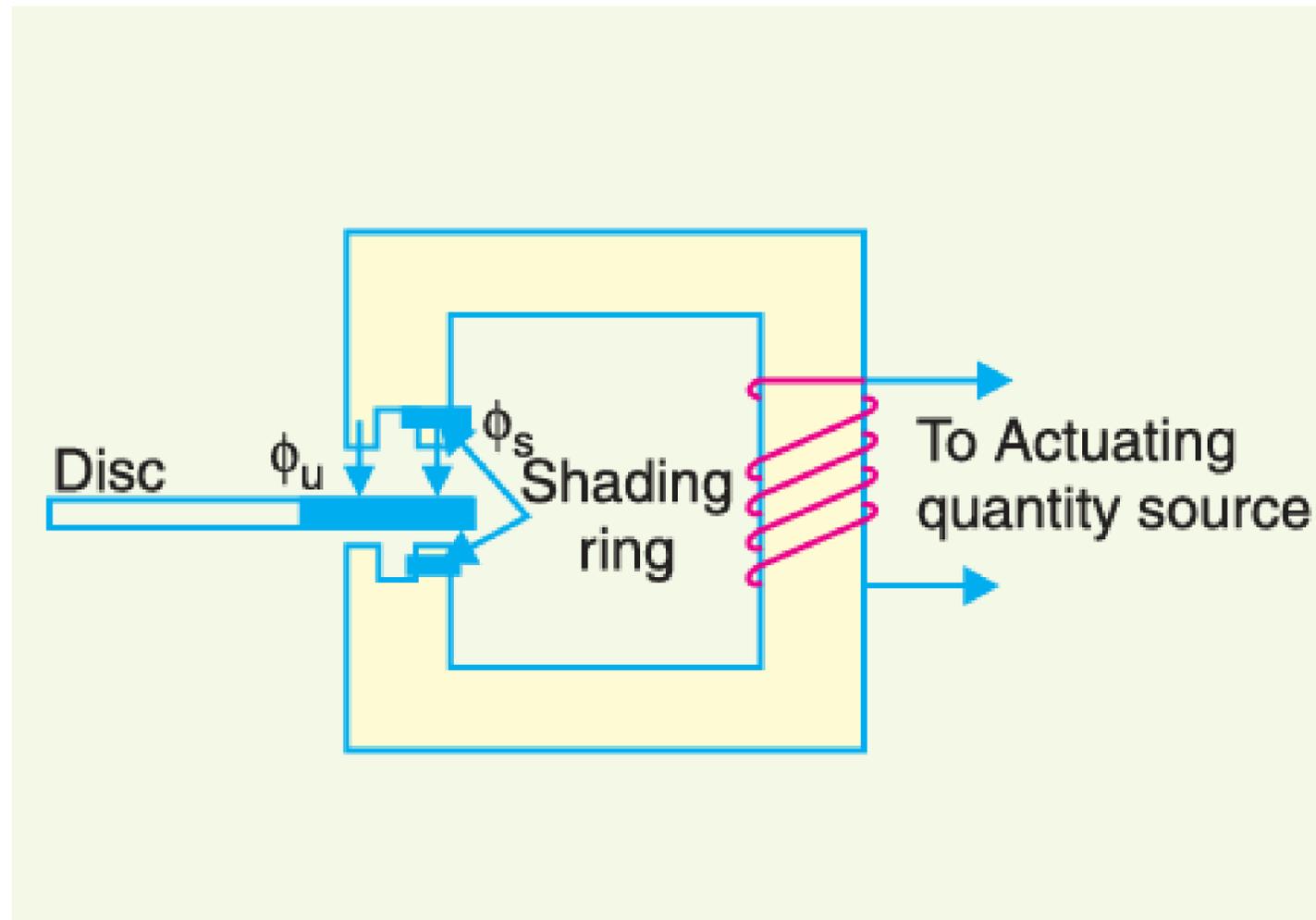
(*ii*) **Watthour-meter structure.** This structure gets its name from the fact that it is used in watt-hour meters. The general arrangement of this type of relay is shown in Fig. 21.8. It consists of a pivoted aluminium disc arranged to rotate freely between the poles of two electromagnets. The upper electromagnet carries two windings ; the pirmary and the secondary. The primary winding carries the relay current I_1 while the secondary winding is connected to the winding of the lower magnet. The primary current induces e.m.f. in the secondary and so circulates a current I_2 in it. The flux ϕ_2 induced in the lower magnet by the current in the secondary winding of the upper magnet will lag behind ϕ_1 by an angle α. The two fluxes ϕ_1 and ϕ_2 differing in phase by α will produce a driving torque on the disc proportional to $\phi_1 \phi_2 \sin \alpha$.

An important feature of this type of relay is that its operation can be controlled by opening or closing the secondary winding circuit. If this circuit is opened, no flux can be set by the lower magnet however great the vaule of current in the pirmary winding may be and consequently no torque will be produced. Therefore, the relay can be made inoperative by opening its secondary winding circuit.
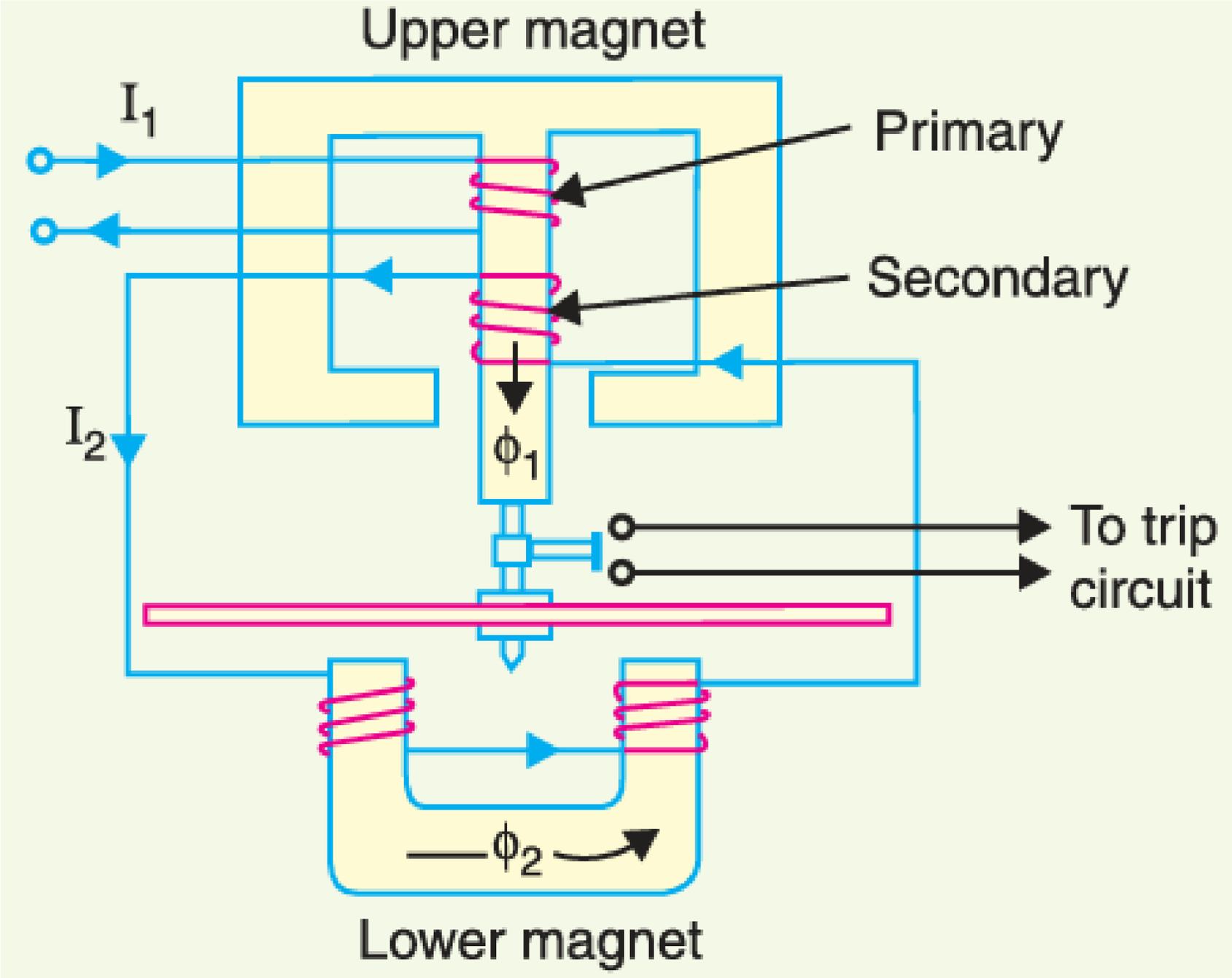
Induction cup structure

It most closely resembles an induction motor, except that the rotor iron is stationary, only the rotor conductor portion being free to rotate.

The moving element is a hollow cylindrical rotor which turns on its axis. The rotating field is produced by two pairs of coils wound on four poles as shown.

The rotating field induces currents in the cup to provide the necessary driving torque. If ϕ_1 and ϕ_2 represent the fluxes produced by the respective pairs of poles, then torque produced is proportional to $I^2 \sin \alpha$ where, α is the phase difference between the two fluxes. A control spring and the back stop for closing of the contacts carried on an arm are attached to the spindle of the cup to prevent the continuous rotation.
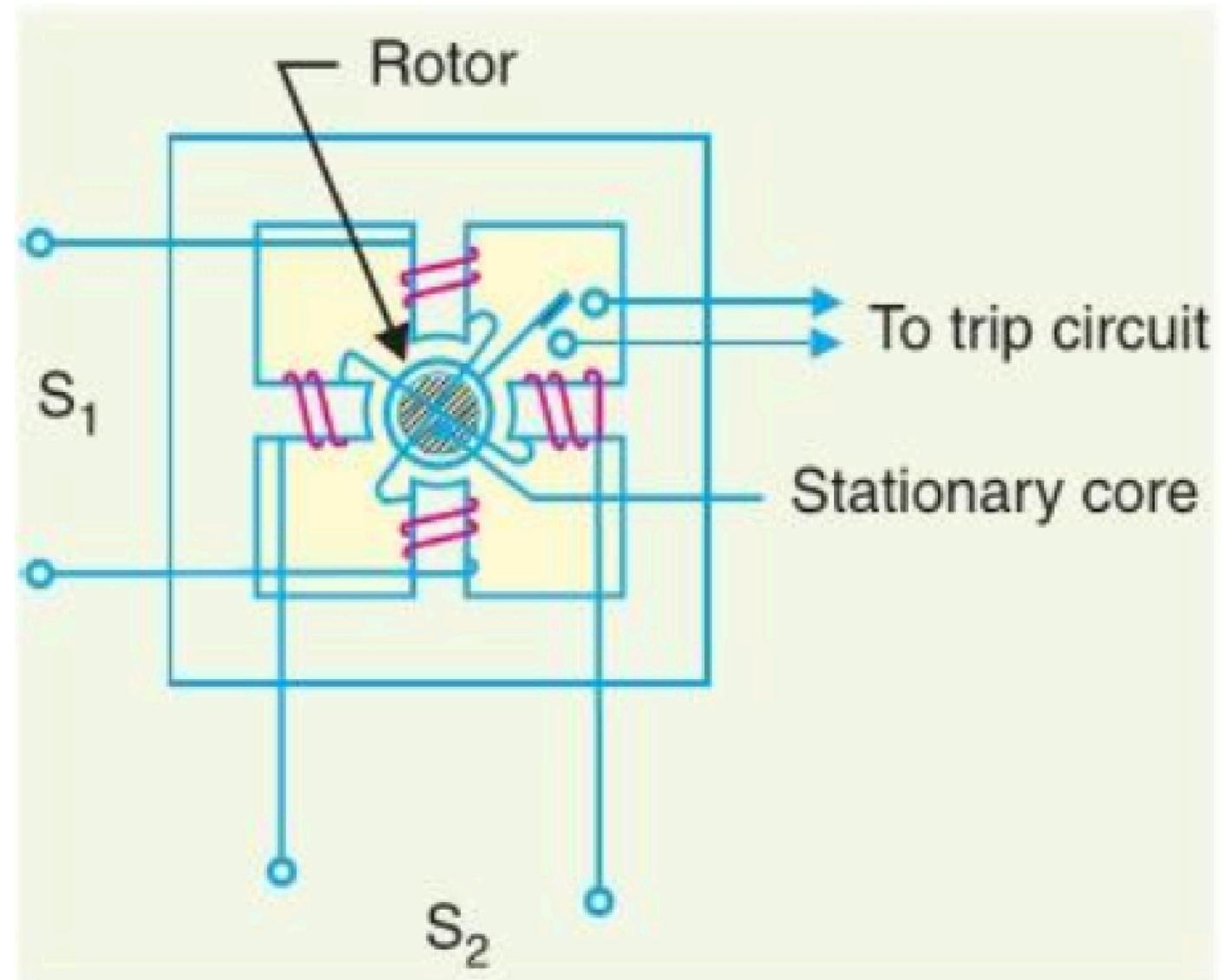
Characteristics of induction relay

1. The operation of induction relay can be controlled by opening secondary coil as opening of this coil makes relay inoperative.
2. The time vs current characteristics is---
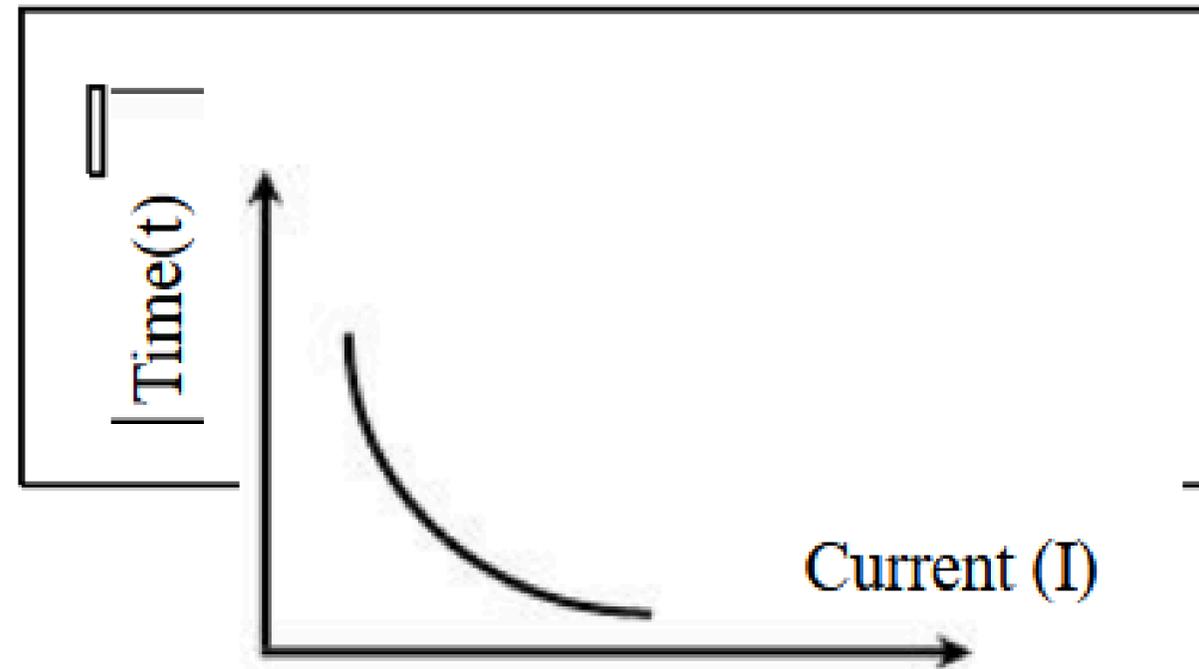
3. The current setting can be changed by taking suitable number of turns. The time setting can be obtained by changing the relative position of the contact.

Week 05
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(*i*) **Pick-up current.** It is the minimum current in the relay coil at which the relay starts to operate. So long as the current in the relay is less than the pick-up value, the relay does not operate and the breaker controlled by it remains in the closed position. However, when the relay coil current is equal to or greater than the pickup value, the relay operates to energise the trip coil which opens the circuit breaker.

(*ii*) **Current setting.** It is often desirable to adjust the pick-up current to any required value. This is known as current setting and is usually achieved by the use of tappings on the relay operating coil. The taps are brought out to a plug bridge as shown in Fig. 21.14. The plug bridge permits to alter the number of turns on the relay coil. This changes the torque on the disc and hence the time of operation of the relay. The values

Fig. 21.14

assigned to each tap are expressed in terms of percentage full-load rating of C.T. with which the relay is associated and represents the value *above* which the disc commences to rotate and finally closes the trip circuit.
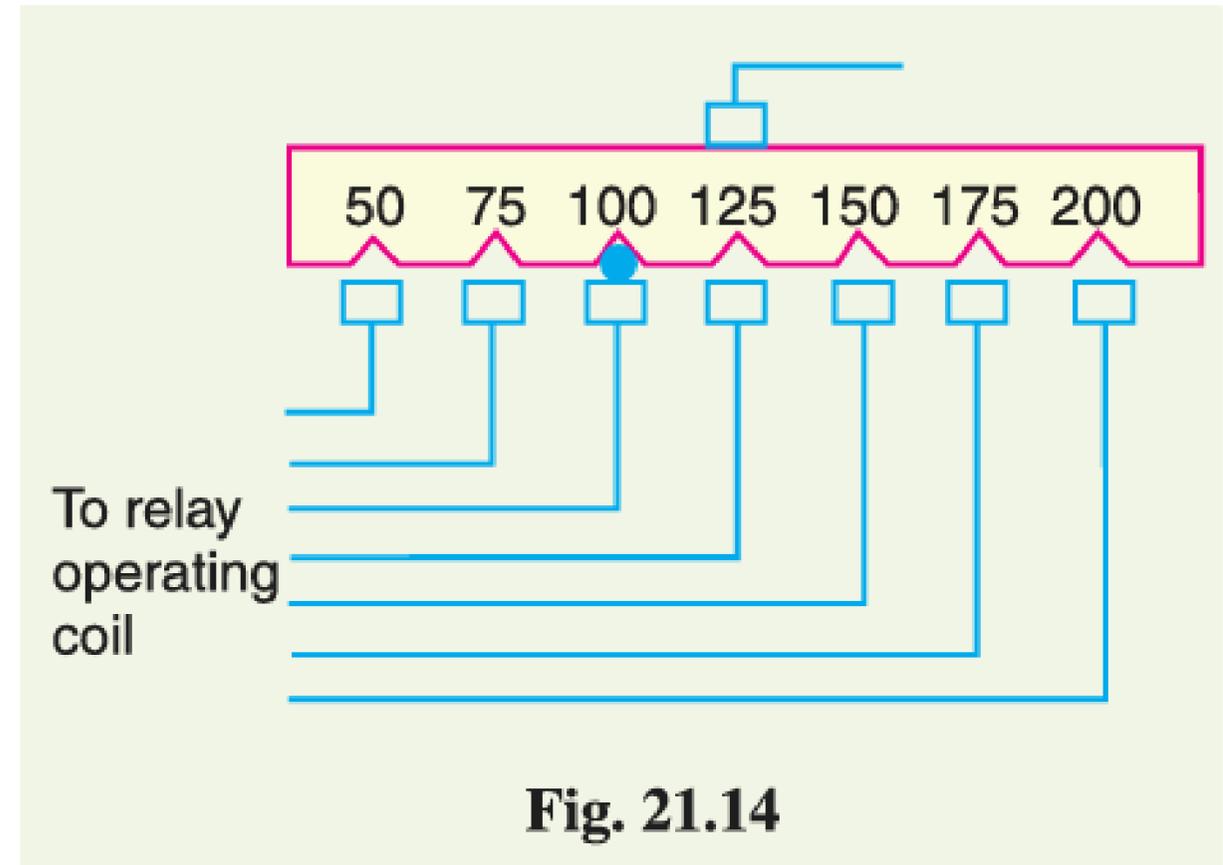
$$\therefore \qquad \text{Pick-up current} \; = \; \text{Rated secondary current of C.T.} \times \text{Current setting}$$

For example, suppose that an overcurrent relay having current setting of 125% is connected to a supply circuit through a current transformer of 400/5. The rated secondary current of C.T. is 5 amperes. Therefore, the pick-up value will be 25% more than 5 A *i.e.* $5 \times 1 \cdot 25 = 6 \cdot 25$ A. It means that with above current setting, the relay will actually operate for a relay coil current equal to or greater than 6·25 A.

The current plug settings usually range from 50% to 200% in steps of 25% for overcurrent relays and 10% to 70% in steps of 10% for earth leakage relays. The desired current setting is obtained by inserting a plug between the jaws of a bridge type socket at the tap value required.

(*iii*) **Plug-setting multiplier (P.S.M.).** It is the ratio of fault current in relay coil to the pick-up current *i.e.*

$$\text{P.S.M.} \; = \; \frac{\text{Fault current in relay coil}}{\text{Pick - up current}}$$

$$= \frac{\text{Fault current in relay coil}}{\text{Rated secondary current of } CT \times \text{Current setting}}$$
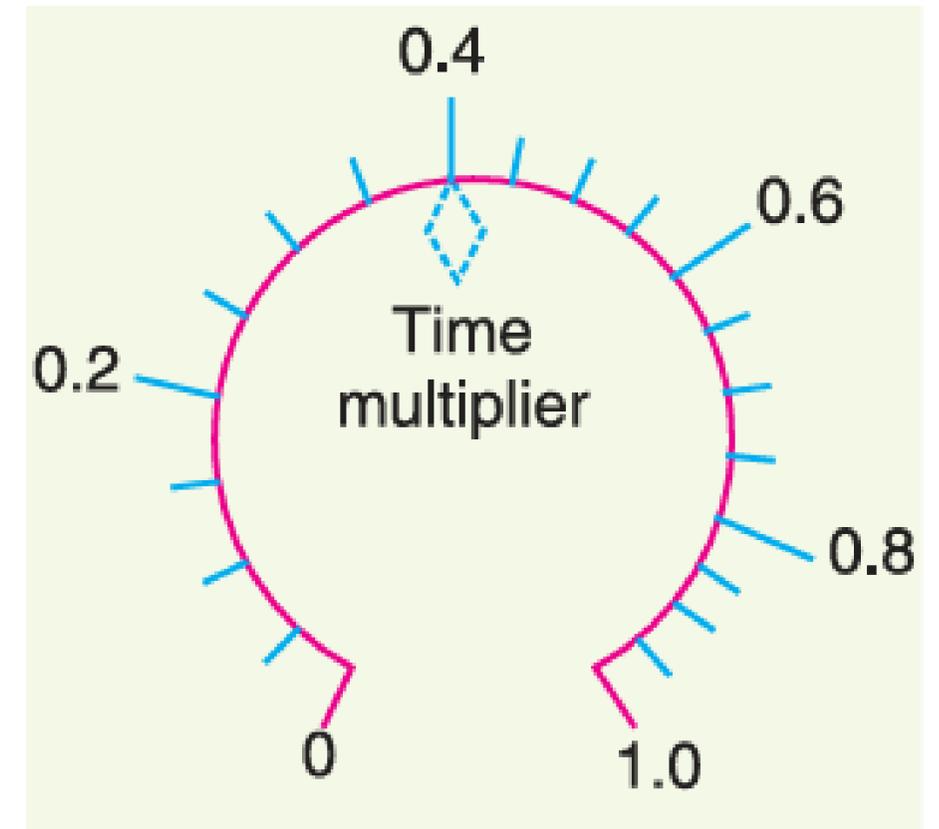
For example, suppose that a relay is connected to a 400/5 current transformer and set at 150%. With a primary fault current of 2400 A, the plug-setting multiplier can be calculated as under :

Pick-up value $=$ Rated secondary current of $CT \times$ Current setting

$= 5 \times 1 \cdot 5 = 7 \cdot 5$ A

Fault current in relay coil $= 2400 \times \dfrac{5}{400} = 30$ A

$\therefore$ P.S.M. $= 30/7 \cdot 5 = 4$

(iv) Time-setting multiplier. A relay is generally provided with control to adjust the time of operation. This adjustment is known as time-setting multiplier. The time-setting dial is calibrated from 0 to 1 in steps of 0.05 sec (see Fig. 21.15). These figures are multipliers to be used to convert the time derived from time/P.S.M. curve into the actual operating time. Thus if the time setting is 0·1 and the time obtained from the time/P.S.M. curve is 3 seconds, then actual relay operating time = $3 \times 0·1 = 0·3$ second. For instance, in an induction relay, the time of operation is controlled by adjusting the amount of travel of the disc from its reset position to its pickup position. This is achieved by the adjustment of the position of a movable backstop which controls the travel of the disc and thereby varies the time in which the relay will close its contacts for given values of fault current. A so-called "time dial" with an evenly divided scale provides this adjustment. The acutal time of operation is calculated by multiplying the time setting multiplier with the time obtained from time/P.S.M. curve of the relay.

Time/P.S.M. Curve

The horizontal scale is marked in terms of plug-setting multiplier and represents the number of times the relay current is in excess of the current setting. The vertical scale is marked in terms of the time required for relay operation. If the P.S.M. is 10, then the time of operation (from the curve) is 3 seconds.

The actual time of operation is obtained by multiplying this time by the time-setting multiplier.

It is evident from the figure that for lower values of overcurrent, time of operation varies inversely with the current but as the current approaches 20 times full-load value, the operating time of relay tends to become constant. This feature is necessary in order to ensure discrimination on very heavy fault currents flowing through sound feeders.
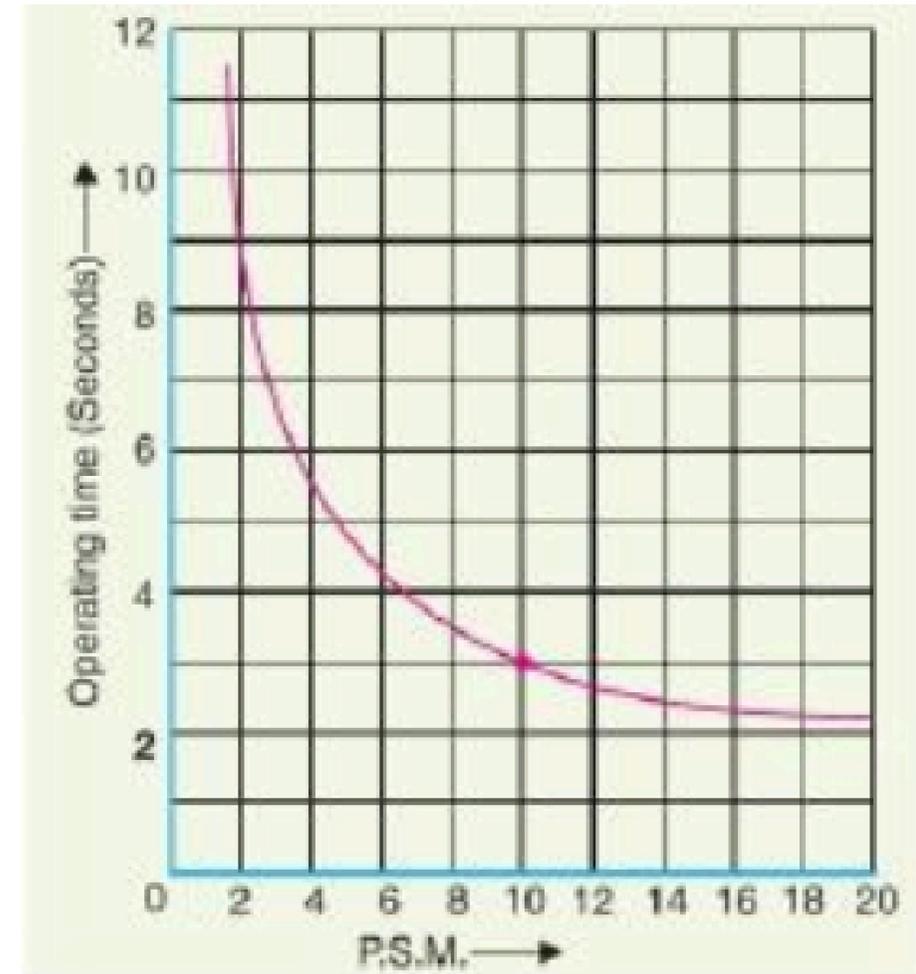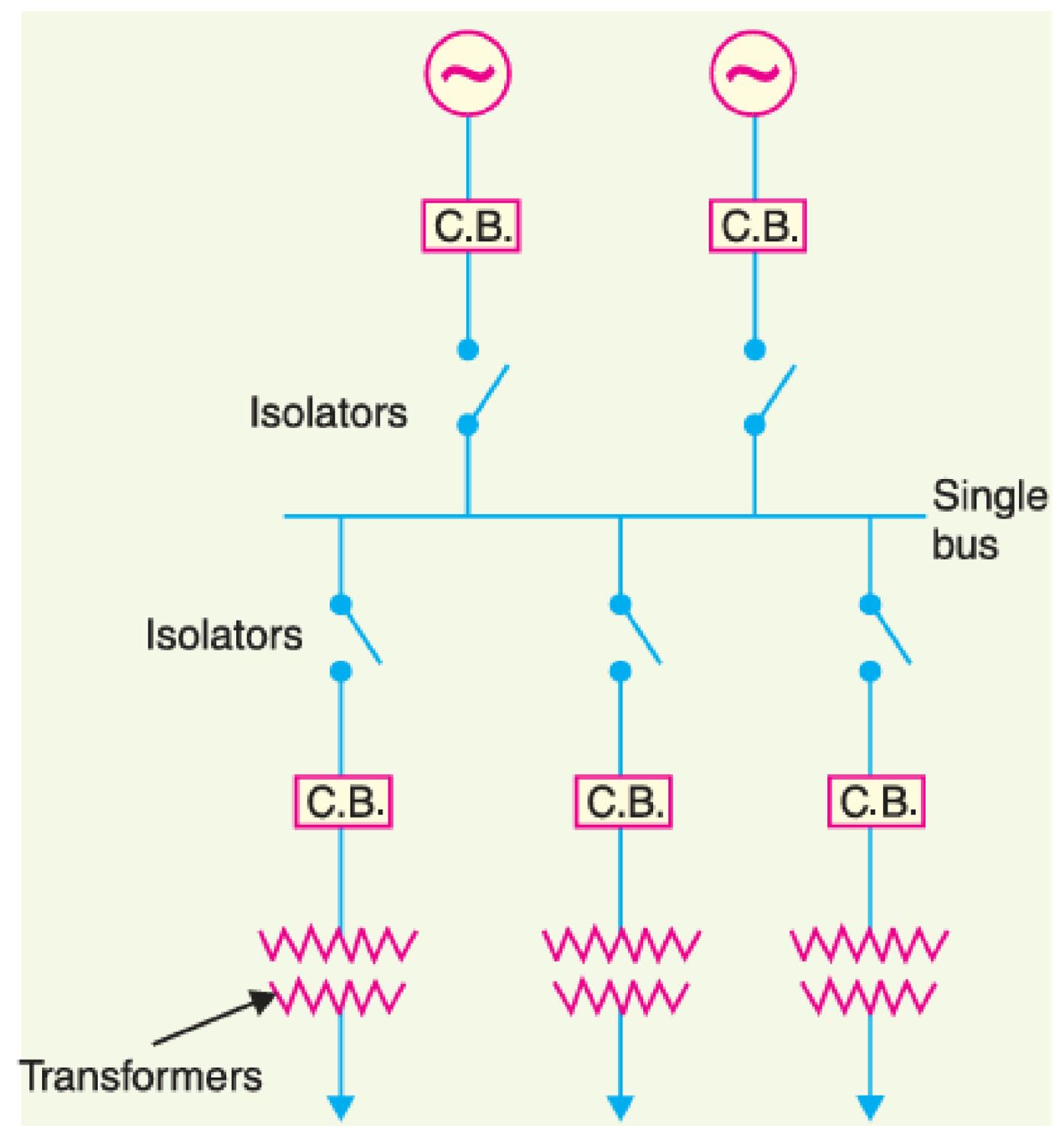
Week 06
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Bus-Bar Arrangements

(1) Single Bus-bar System. The single bus-bar system has the simplest design and is used for power stations. It is also used in small outdoor stations having relatively few outgoing or incoming feeders and lines. Fig. 16.2 shows the single bus-bar system for a typical power station. The generators, outgoing lines and transformers are connected to the bus-bar. Each generator and feeder is controlled by a circuit breaker. The isolators permit to isolate generators, feeders and circuit breakers from the bus-bar for maintenance. The chief advantages of this type of arrangement are low initial cost, less maintenance and simple operation.

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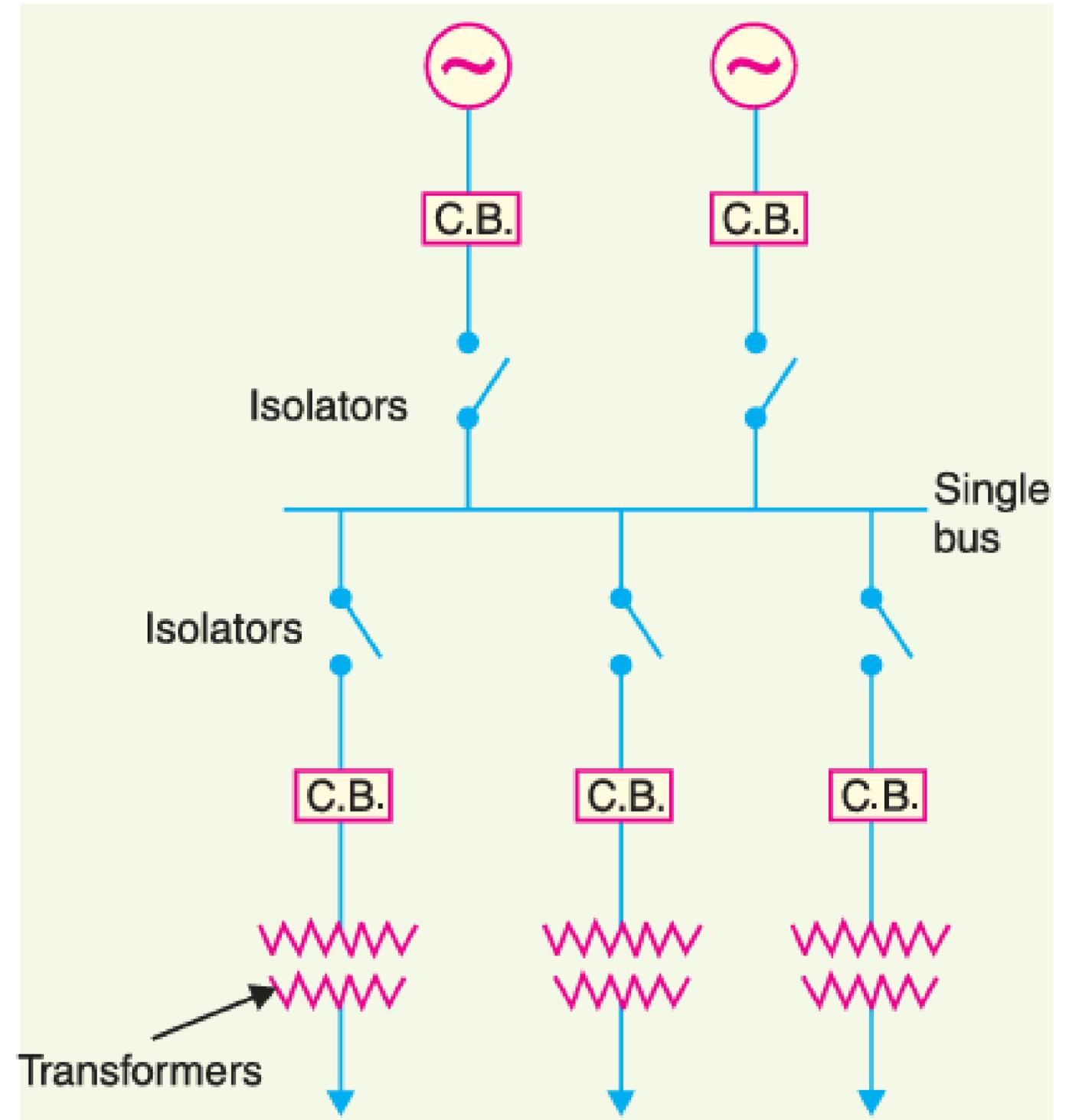
Disadvantages. Single bus-bar system has the following three principal disadvantages :

(*i*) The bus-bar cannot be cleaned, repaired or tested without de-energising the whole system.

(*ii*) If a fault occurs on the bus-bar itself, there is complete interruption of supply.

(*iii*) Any fault on the system is fed by all the generating capacity, resulting in very large fault currents.

(2) **Single bus-bar system with Sectionalisation.** In large generating stations where several units are installed, it is a common practice to sectionalise the bus so that fault on any section of the bus-bar will not cause complete shut down. This is illustrated in Fig. 16.3 which shows the bus-bar divided into two sections connected by a circuit breaker and isolators. Three principal advantages are claimed for this arrangement. Firstly, if a fault occurs on any section of the bus-bar, that section can be isolated without affecting the supply to other sections. Secondly, if a fault occurs on any feeder, the fault current is much **lower than with unsectionalised bus-bar. This permits the use of circuit breakers of lower capacity in the feeders. Thirdly, repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of complete shut-down.
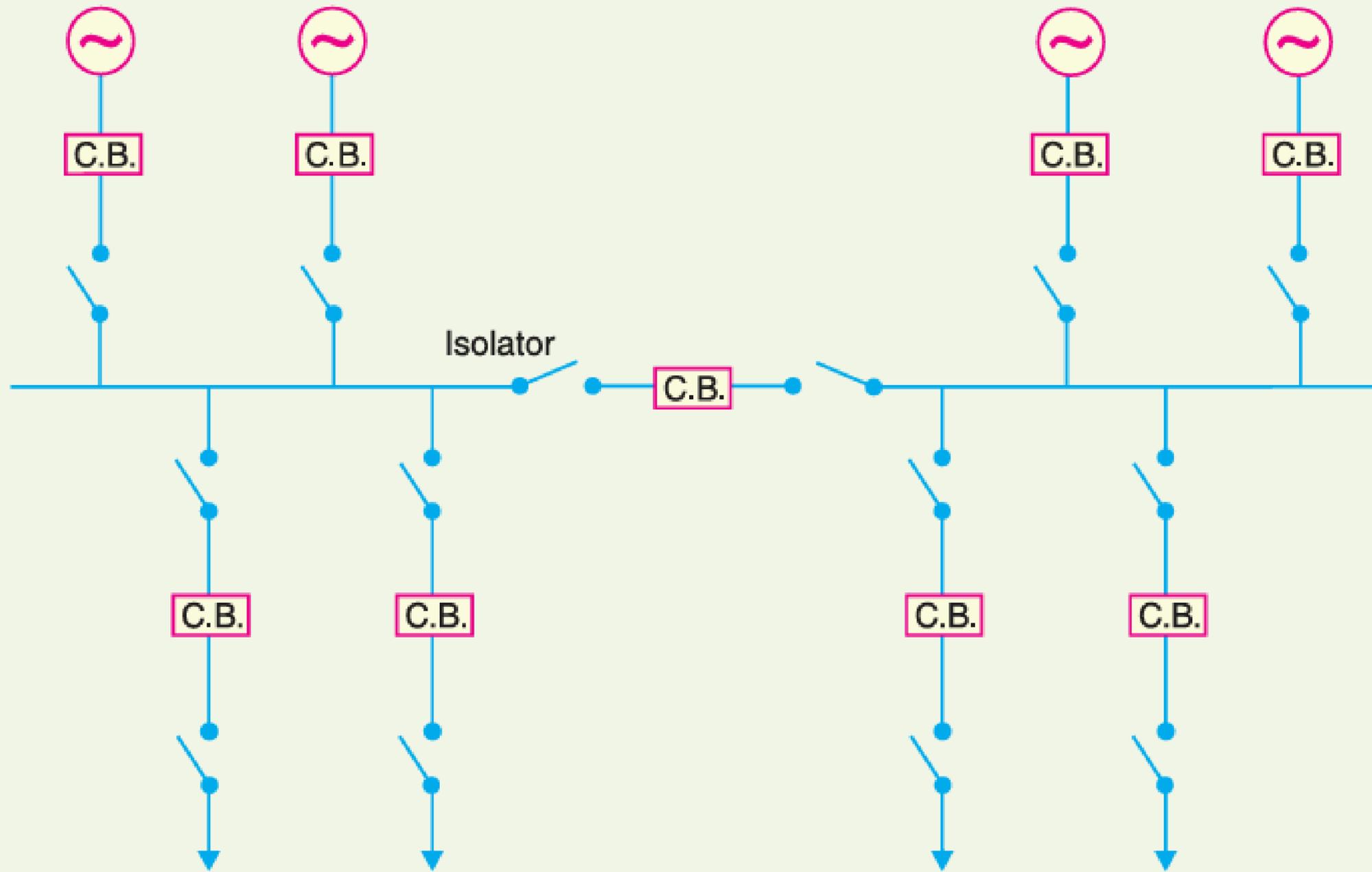
(3) Duplicate bus-bar system. In large stations, it is important that breakdowns and mainte-nance should interfere as little as possible with continuity of supply. In order to achieve this objec-tive, duplicate bus-bar system is used in important stations. Such a system consists of two bus-bars, a "main bus-bar'' and a "spare" bus-bar (see Fig. 16.4). Each generator and feeder may be connected to either bus-bar with the help of bus coupler which consists of a circuit breaker and isolators.

In the scheme shown in Fig. 16.4, service is in-terrupted during switch over from one bus to an-other. However, if it were desired to switch a circuit from one to another with-out interruption of service, there would have to be two circuit breakers per circuit.
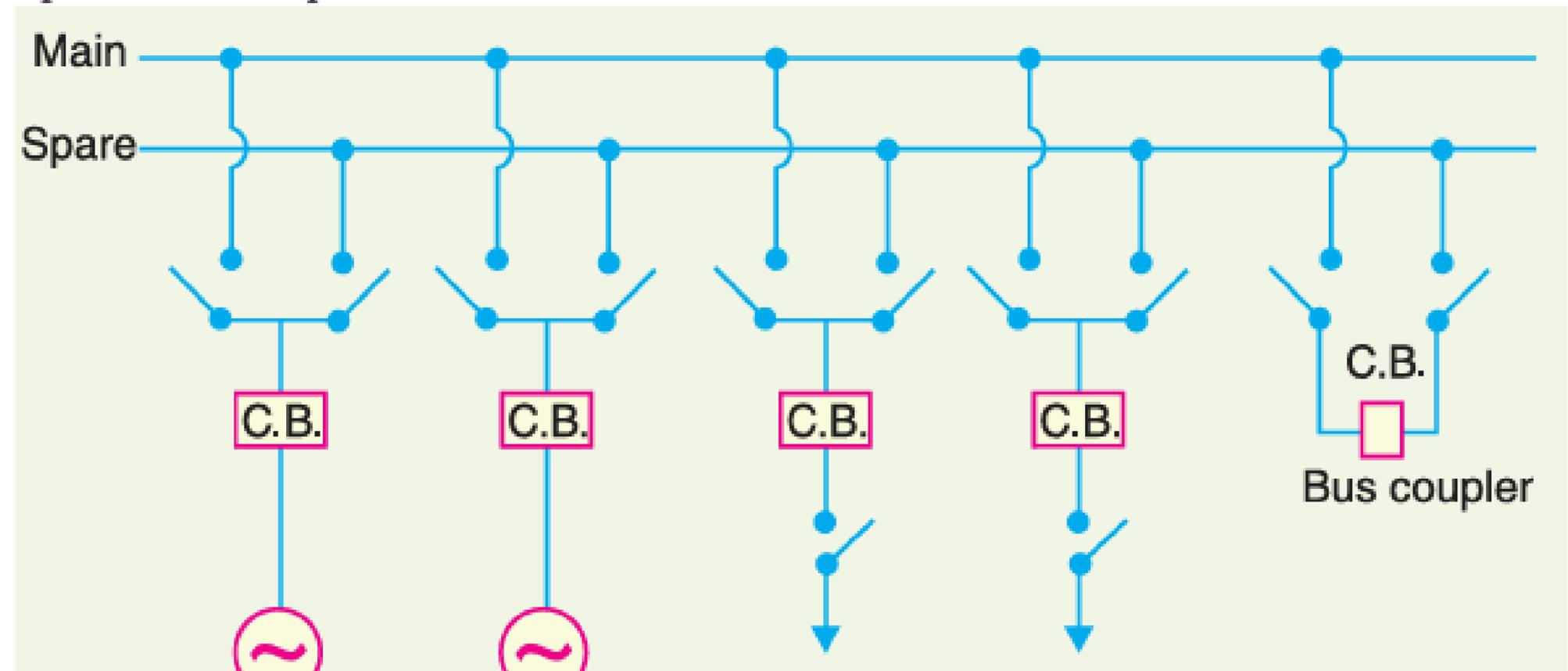
Advantages

(i) If repair and maintenance it to be carried on the main bus, the supply need not be interrupted as the entire load can be transferred to the spare bus.

(ii) The testing of feeder circuit breakers can be done by putting them on spare bus-bar, thus keeping the main bus-bar undisturbed.

iii) If a fault occurs on the bus-bar, the continuity of supply to the circuit can be maintained by transferring it to the other bus-bar.

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Sub-Station

The assembly of apparatus used to change some characteristic (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a **sub-station.**

Sub-stations are important part of power system. The continuity of supply depends to a considerable extent upon the successful operation of sub-stations. It is, therefore, essential to exercise utmost care while designing and building a sub-station. The following are the important points which must be kept in view while laying out a sub-station :

(*i*) It should be located at a proper site. As far as possible, it should be located at the centre of gravity of load.

(*ii*) It should provide safe and reliable arrangement. For safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear *etc.*

(*iii*) It should be easily operated and maintained.

(*iv*) It should involve minimum capital cost.

Classification of Sub-Stations

There are several ways of classifying sub-stations. However, the two most important ways of classifying them are according to (1) service requirement and (2) constructional features.

    1.   According to service requirement. A sub-station may be called upon to change voltage level or improve power factor or convert a.c. power into d.c. power etc. According to the service requirement, sub-stations may be classified into :

    (*i*)   Transformer sub-stations. Those sub-stations which change the voltage level of electric supply are called transformer sub-stations. These sub-stations receive power at some voltage and deliver it at some other voltage. Obviously, transformer will be the main component in such sub-stations. Most of the sub-stations in the power system are of this type.

    (*ii*)   Switching sub-stations. These sub-stations do not change the voltage level *i.e.* incoming and outgoing lines have the same voltage. However, they simply perform the switching operations of power lines.

    (*iii*)   Power factor correction sub-stations. Those sub-stations which improve the power factor of the system are called power factor correction sub-stations. Such sub-stations are generally located at the receiving end of transmission lines. These sub-stations generally use synchronous condensers as the power factor improvement equipment.

    (*iv*)   Frequency changer sub-stations. Those sub-stations which change the supply frequency are known as frequency changer sub-stations. Such a frequency change may be required for industrial utilisation.

    (*v*)   Converting sub-stations. Those sub-stations which change a.c. power into d.c. power are called converting sub-stations. These sub-stations receive a.c. power and convert it into d.c. power

Classification of Sub-Stations

with suitable apparatus (*e.g.* ignitron) to supply for such purposes as traction, electroplating, electric welding etc.

(*vi*) **Industrial sub-stations.** Those sub-stations which supply power to individual industrial concerns are known as industrial sub-stations.

2. **According to constructional features.** A sub-station has many components (*e.g.* circuit breakers, switches, fuses, instruments etc.) which must be housed properly to ensure continuous and reliable service. According to constructional features, the sub-stations are classified as :

(*i*)   Indoor sub-station   (*ii*)   Outdoor sub-station

(*iii*)   Underground sub-station   (*iv*)   Pole-mounted sub-station

(*i*) **Indoor sub-stations.** For voltages upto 11 kV, the equipment of the sub-station is installed indoor because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

Classification of Sub-Stations

(*i*) **Indoor sub-stations.** For voltages upto 11 kV, the equipment of the sub-station is installed indoor because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

(*ii*) **Outdoor sub-stations.** For voltages beyond 66 kV, equipment is invariably installed outdoor. It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers and other equipment becomes so great that it is not economical to install the equipment indoor.

(*iii*) **Underground sub-stations.** In thickly populated areas, the space available for equipment and building is limited and the cost of land is high. Under such situations, the sub-station is created underground. The reader may find further discussion on underground sub-stations in Art. 25.6.

(*iv*) **Pole-mounted sub-stations.** This is an outdoor sub-station with equipment installed overhead on *H*-pole or 4-pole structure. It is the cheapest form of sub-station for voltages not exceeding 11kV (or 33 kV in some cases). Electric power is almost distributed in localities through such sub-

Comparison between Outdoor and Indoor Sub-Stations

S.No.	Particular	Outdoor Sub-station	Indoor Sub-station
1	Space required	More	Less
2	Time required for erection	Less	More
3	Future extension	Easy	Difficult
4	Fault location	Easier beacuse the equipment is in full view	Difficult because the equipment is enclosed
5	Capital cost	Low	High
6	Operation	Difficult	Easier
7	Possibility of fault escalation	Less because greater clearances can be provided	More

From the above comparison, it is clear that each type has its own advantages and disadvantages. However, comparative economics (*i.e.* annual cost of operation) is the most powerful factor influencing the choice between indoor and outdoor sub-stations. The greater cost of indoor sub-station prohibits its use. But sometimes non-economic factors (*e.g.* public safety) exert considerable influence in choosing indoor sub-station. In general, most of the sub-stations are of outdoor type and the indoor sub-stations are erected only where outdoor construction is impracticable or prohibited by the local laws.

Transformer Sub-Stations

component employed to change the voltage level. Depending upon the purpose served, transformer sub-stations may be classified into :

(*i*) Step-up sub-station   (*ii*) Primary grid sub-station

(*iii*) Secondary sub-station   (*iv*) Distribution sub-station

(*i*) **Step-up sub-station.**   The generation voltage (11 kV in this case) is stepped up to high voltage (220 kV) to affect economy in transmission of electric power. The sub-stations which accomplish this job are called step-up sub-stations. These are generally located in the power houses and are of outdoor type.

(*ii*) **Primary grid sub-station.** From the step-up sub-station, electric power at 220 kV is transmitted by 3-phase, 3-wire overhead system to the outskirts of the city. Here, electric power is received by the primary grid sub-station which reduces the voltage level to 66 kV for secondary transmission. The primary grid sub-station is generally of outdoor type.

(*iii*) **Secondary sub-station.** From the primary grid sub-station, electric power is transmitted at 66 kV by 3-phase, 3-wire system to various secondary sub-stations located at the strategic points in the city. At a secondary sub-station, the voltage is further stepped down to 11 kV. The 11 kV lines run along the important road sides of the city. It may be noted that big consumers (having demand more than 50 kW) are generally supplied power at 11 kV for further handling with their own sub-

Transformer Sub-Stations

stations. The secondary sub-stations are also generally of outdoor type.

(iv) **Distribution sub-station.** The electric power from 11 kV lines is delivered to distribution sub-stations. These sub-stations are located near the consumers localities and step down the voltage to 400 V, 3-phase, 4-wire for supplying to the consumers. The voltage between any two phases is 400V and between any phase and neutral it is 230 V.   The single phase residential lighting load is connected between any one phase and neutral whereas 3-phase, 400V motor load is connected across 3-phase lines directly. It may be worthwhile to mention here that majority of the distribution sub-stations are of pole-mounted type.
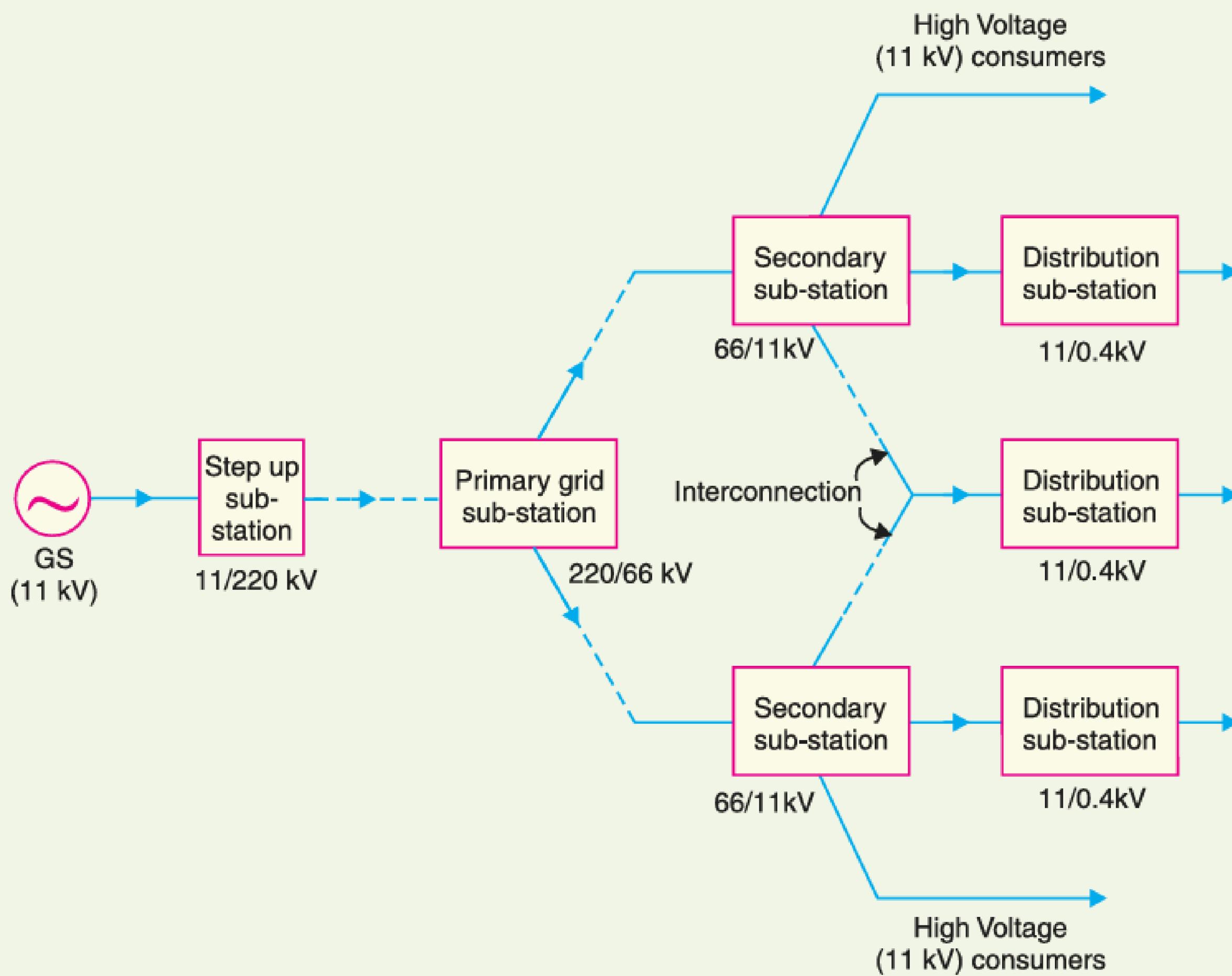
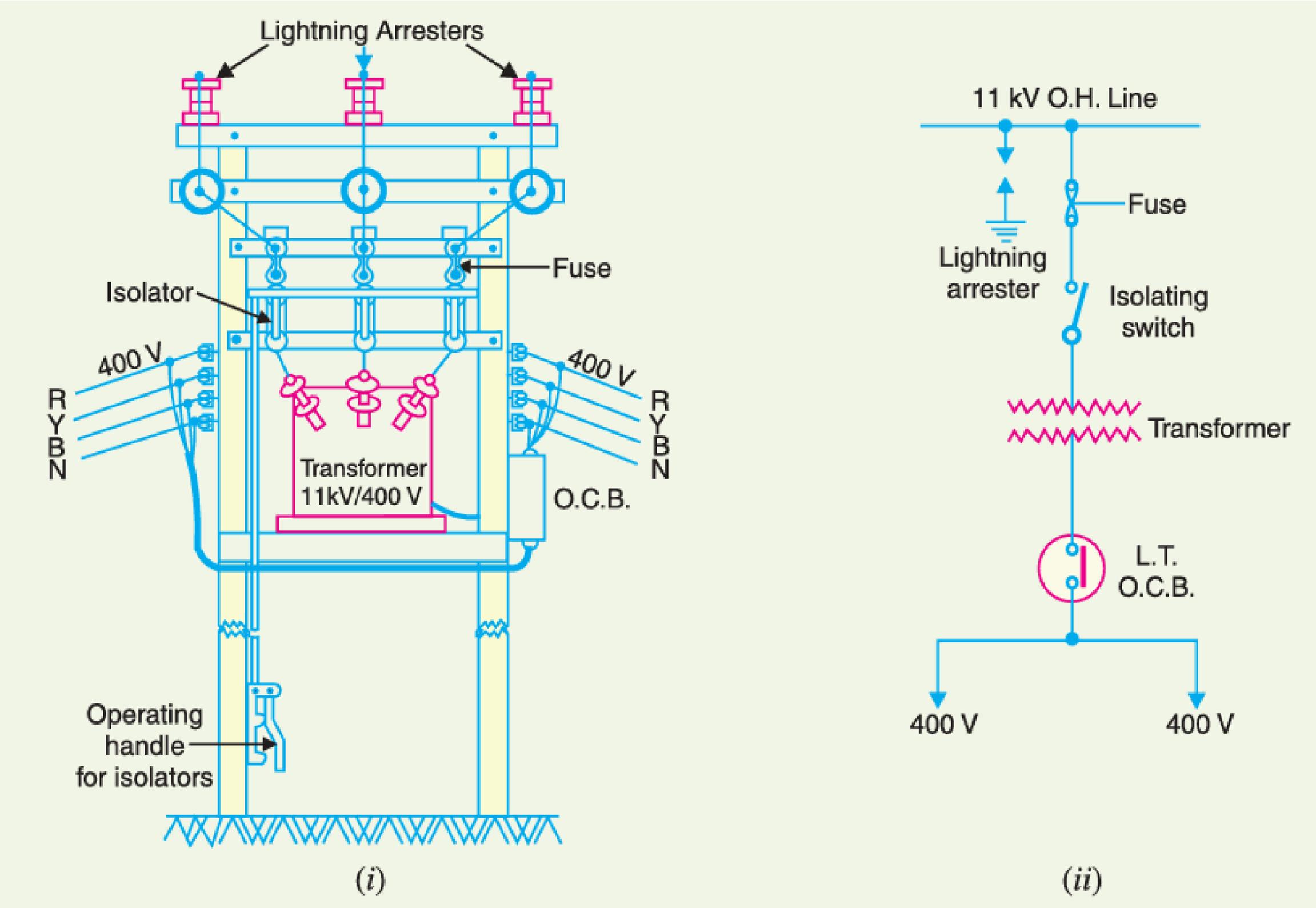# Week 08
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Pole-Mounted Sub-Station

It is a distribution sub-station placed overhead on a pole. It is the cheapest form of sub-station as it does not involve any building work. Fig 25.2 (*i*) shows the layout of pole-mounted sub-station whereas Fig. 25.2 (*ii*) shows the schematic connections. The transformer and other equipment are mounted on H-type pole (or 4-pole structure).

The 11 kV line is connected to the transformer (11kV / 400 V) through gang isolator and fuses. The lightning arresters are installed on the H.T. side to protect the sub-station from lightning strokes. The transformer steps down the voltage to 400V, 3-phase, 4-wire supply. The voltage between any two lines is 400V whereas the voltage between any line and neutral is 230 V. The oil circuit breaker (O.C.B.) installed on the L.T. side automatically isolates the transformer from the consumers in the event of any fault. The pole-mounted
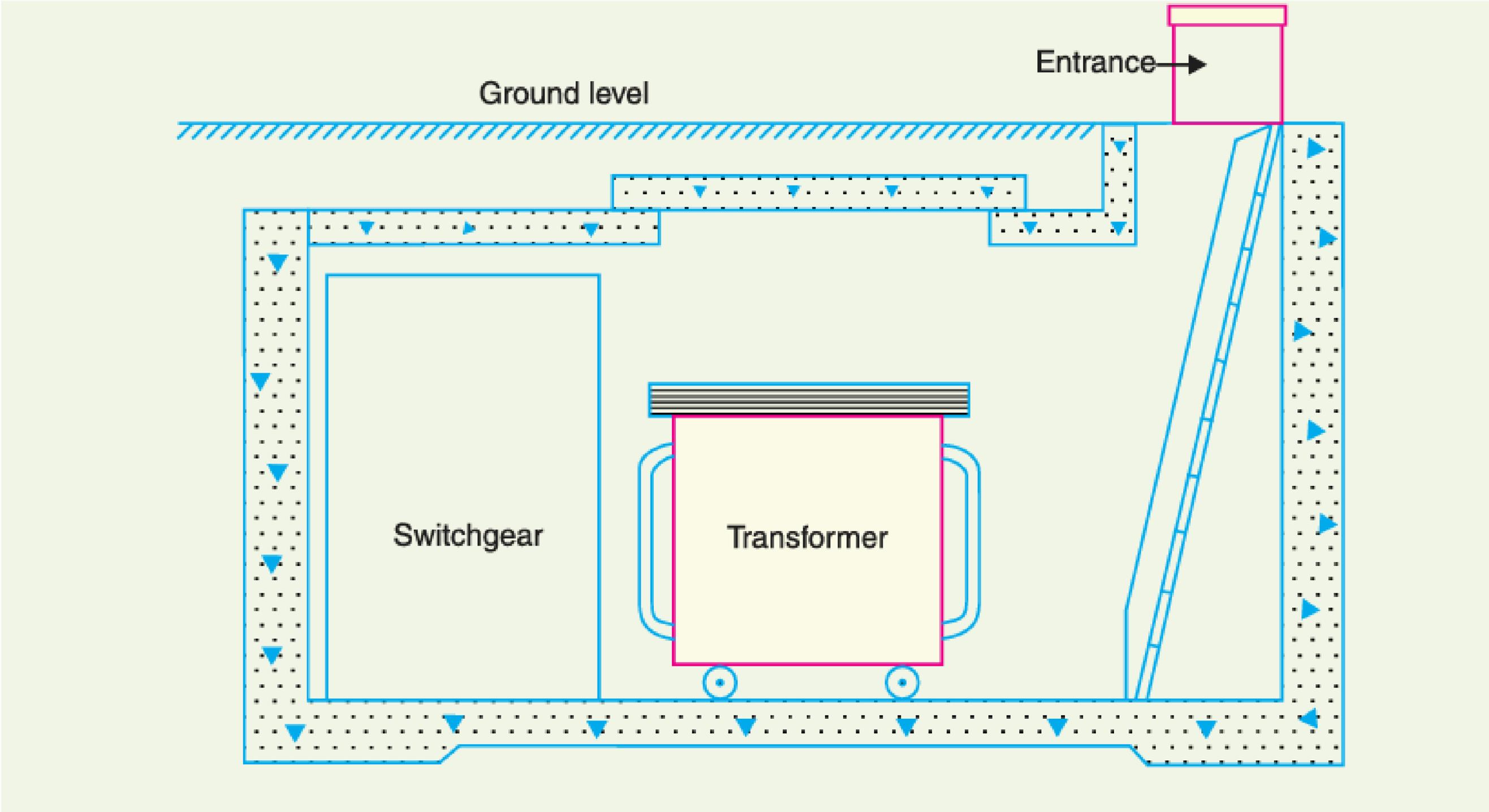

Sub-Station

Pole-Mounted Sub-Station

Lightning Arresters

Isolator

Fuse

400 V

R Y B N

400 V

R Y B N

Transformer 11kV/400 V

O.C.B.

Operating handle for isolators

(i)

11 kV O.H. Line

Fuse

Lightning arrester

Isolating switch

Transformer

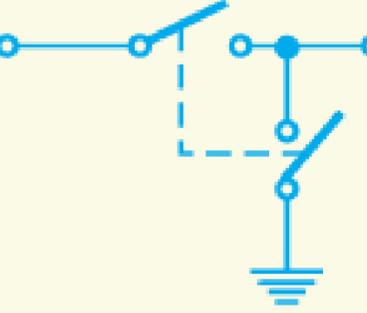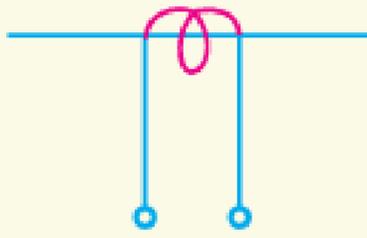L.T. O.C.B.

400 V

400 V

(ii)

Underground Sub-Station

Underground Sub-Station

The design of underground sub-station requires more careful consideration than other types of sub-stations. While laying out an underground sub-station, the following points must be kept in view:
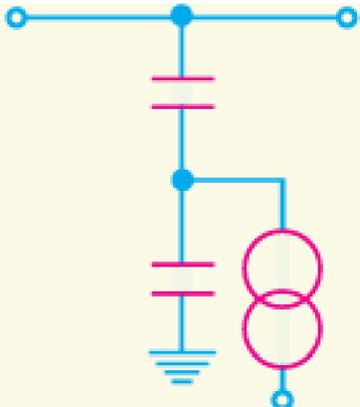
(i) The size of the station should be as minimum as possible.

(ii) There should be reasonable access for both equipment and personnel.

(iii) There should be provision for emergency lighting and protection against fire.

(iv) There should be good ventilation.

(v) There should be provision for remote indication of excessive rise in temperature so that H.V. supply can be disconnected.

(vi) The transformers, switches and fuses should be air cooled to avoid bringing oil into the premises.

Symbols for Equipment in Sub-Stations

S.No.	Circuit element	Symbol
1	Bus-bar	
2	Single-break isolating switch	
3	Double-break isolating switch	
4	On load isolating switch	
5	Isolating switch with earth Blade	
6	Current transformer	
7	Potential transformer	
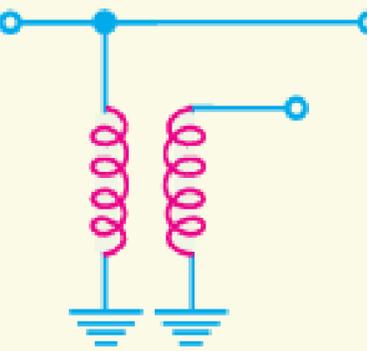
Symbols for Equipment in Sub-Stations

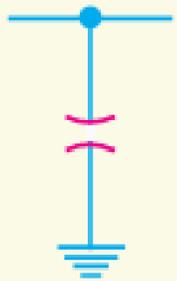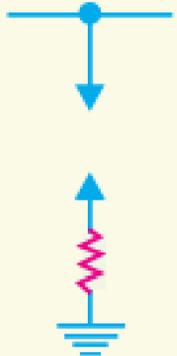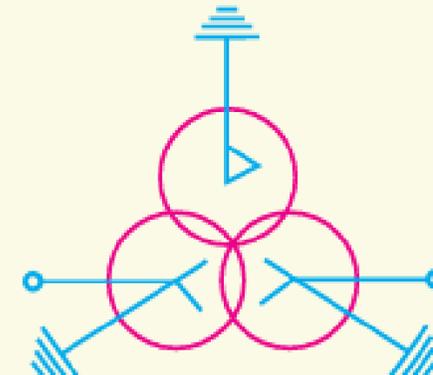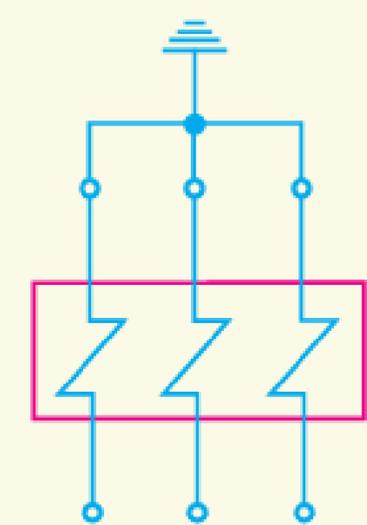|		
8	Capacitive voltage transformer	
9	Oil circuit breaker	
10	Air circuit breaker with overcurrent tripping device	
11	Air blast circuit breaker	
12	Lightning arrester (active gap)	
13	Lightning arrester (valve type)	

Symbols for Equipment in Sub-Stations

S.No.	Circuit element	Symbol
14	Arcing horn	
15	3-ϕ Power transformer	
16	Overcurrent relay	

Equipment in Sub-Stations

The equipment required for a transformer sub-station depends upon the type of sub-station, service requirement and the degree of protection desired. However, in general, a transformer sub-station has the following main equipment :

    1. **Bus-bars.** When a number of lines operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical component. Bus-bars are copper or aluminium bars (generally of rectangular x-section) and operate at constant voltage. The incoming and outgoing lines in a sub-station are connected to the bus-bars. The most commonly used bus-bar arrangements in sub-stations are :

      (i) Single bus-bar arrangement

    (ii) Single bus-bar system with sectionalisation

 *(iii)* Double bus-bar arrangement

    A detailed discussion on these bus-bar arrangements has already been made in Art. 16.3. However, their practical applications in sub-stations are discussed in Art. 25.9.

    2. **Insulators.** The insulators serve two purposes. They support the conductors (or bus-bars)

Equipment in Sub-Stations

and confine the current to the conductors. The most commonly used material for the manufacture of insulators is porcelain. There are several types of insulators (*e.g.* pin type, suspension type, post insulator etc.) and their use in the sub-station will depend upon the service requirement. For example, post insulator is used for bus-bars. A post insulator consists of a porcelain body, cast iron cap and flanged cast iron base. The hole in the cap is threaded so that bus-bars can be directly bolted to the cap.

3. **Isolating switches.** In sub-stations, it is often desired to disconnect a part of the system for general maintenance and repairs. This is accomplished by an isolating switch or isolator. An isolator is essentially a knife switch and is designed to open a circuit under *no load.* In other words, isolator switches are operated only when the lines in which they are connected carry *no current.
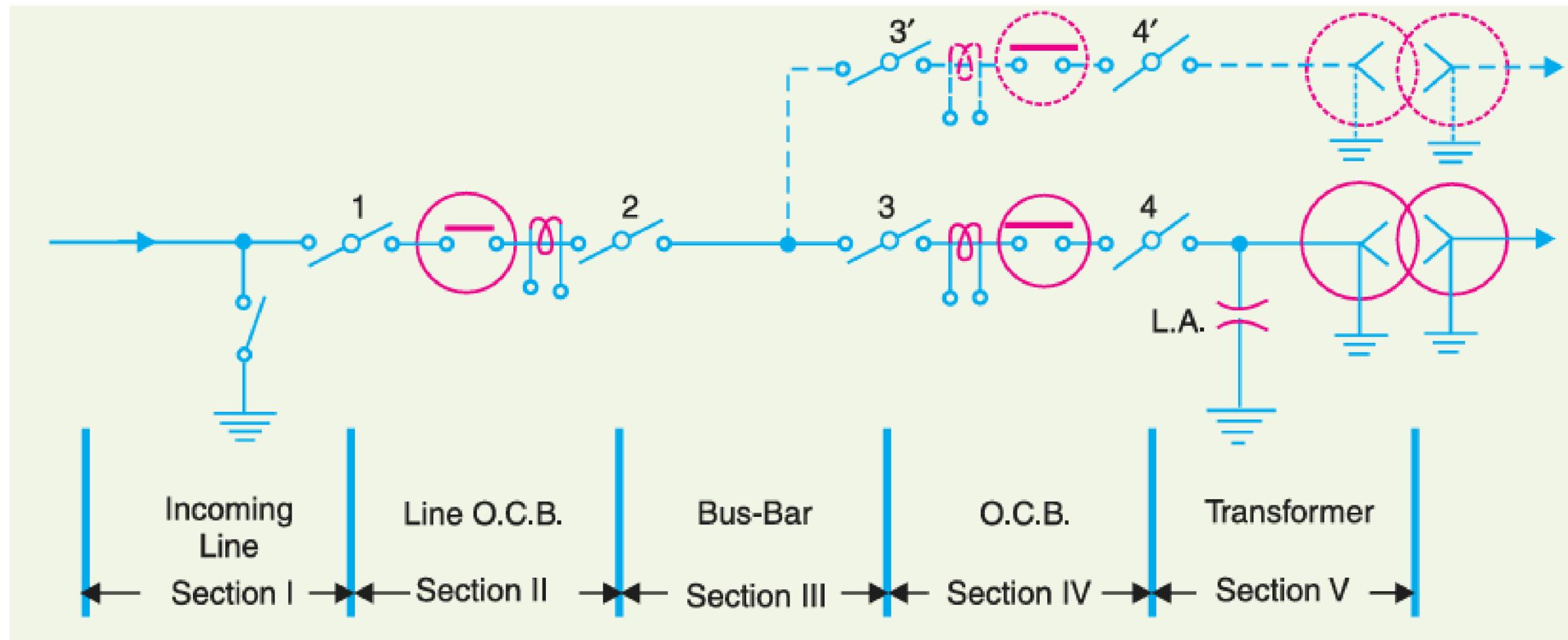
Equipment in Sub-Stations

4. Circuit breaker. A circuit breaker is an equipment which can open or close a circuit under **normal as well as fault conditions. It is so designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions. For the latter operation, a relay circuit is used with a circuit breaker. Generally, bulk oil circuit breakers are used for voltages upto 66kV while for high (>66 kV) voltages, low oil circuit breakers are used. For still higher voltages, air-blast, vacuum or SF_6 circuit breakers are used. For detailed discussion of these breakers, the reader may refer to chapter 19.

5. Power Transformers. A power transformer is used in a sub-station to step-up or step-down the voltage. Except at the *****power station, all the subsequent sub-stations use step-down transformers to gradually reduce the voltage of electric supply and finally deliver it at utilisation voltage. The modern practice is to use 3-phase transformers in sub-stations ; although 3 single phase bank of

transformers can also be used. The use of 3-phase transformer (instead of 3 single phase bank of transformers) permits two advantages. Firstly, only one 3-phase load-tap changing mechanism can be used. Secondly, its installation is much simpler than the three single phase transformers.

The power transformer is generally installed upon lengths of rails fixed on concrete slabs having foundations 1 to 1·5 m deep. For ratings upto 10 MVA, naturally cooled, oil immersed transformers are used. For higher ratings, the transformers are generally air blast cooled.

6. Instrument transformers. The lines in sub-stations operate at high voltages and carry current of thousands of amperes. The measuring instruments and protective devices are designed for low voltages (generally 110 V) and currents (about 5 A). Therefore, they will not work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing *instrument transformers* on the power lines. The function of these instrument transformers is to transfer voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays. There are two types of instrument transformers *viz.*

(*i*) Current transformer (C.T.)   (*ii*) Potential transformer (P.T.)

Equipment in Sub-Stations

  (*i*) Current transformer (C.T.)   (*ii*) Potential transformer (P.T.)

  (*i*) **Current transformer (C.T.).** A current transformer in essentially a step-up transformer which steps down the current to a known ratio. The primary of this transformer consists of one or more turns of thick wire connected in series with the line. The secondary consists of a large number of turns of fine wire and provides for the measuring instruments and relays a current which is a constant fraction of the current in the line. Suppose a current transformer rated at 100/5 A is connected in the line to measure current. If the current in the line is 100 A, then current in the secondary will be 5A. Similarly, if current in the line is 50A, then secondary of C.T. will have a current of 2·5 A. Thus the C.T. under consideration will step down the line current by a factor of 20.

  (*ii*) **Voltage transformer.** It is essentially a step down transformer and steps down the voltage to a known ratio. The primary of this transformer consists of a large number of turns of fine wire connected across the line. The secondary winding consists of a few turns and provides for measuring instruments and relays a voltage which is a known fraction of the line voltage. Suppose a potential transformer rated at 66kV/110V is connected to a power line. If line voltage is 66kV, then voltage across the secondary will be 110 V.

  7. **Metering and Indicating Instruments.** There are several metering and indicating instruments (*e.g.* ammeters, voltmeters, energy meters etc.) installed in a sub-station to maintain watch over the circuit quantities. The instrument transformers are invariably used with them for satisfactory operation.

  8. **Miscellaneous equipment.** In addition to above, there may be following equipment in a sub-station :

  (*i*) fuses
  (*ii*) carrier-current equipment
 (*iii*) sub-station auxiliary supplies

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Bus-Bar Arrangements in Sub-Stations

(*i*) **Single bus-bar system.** As the name suggests, it consists of a single bus-bar and all the incoming and outgoing lines are connected to it. The chief advantages of this type of arrangement are low initial cost, less maintenance and simple operation. However, the principal disadvantage of single bus-bar system is that if repair is to be done on the bus-bar or a fault occurs on the bus, there is a complete interruption of the supply. This arrangement is not used for voltages exceeding 33kV. The indoor 11kV sub-stations often use single bus-bar arrangement.
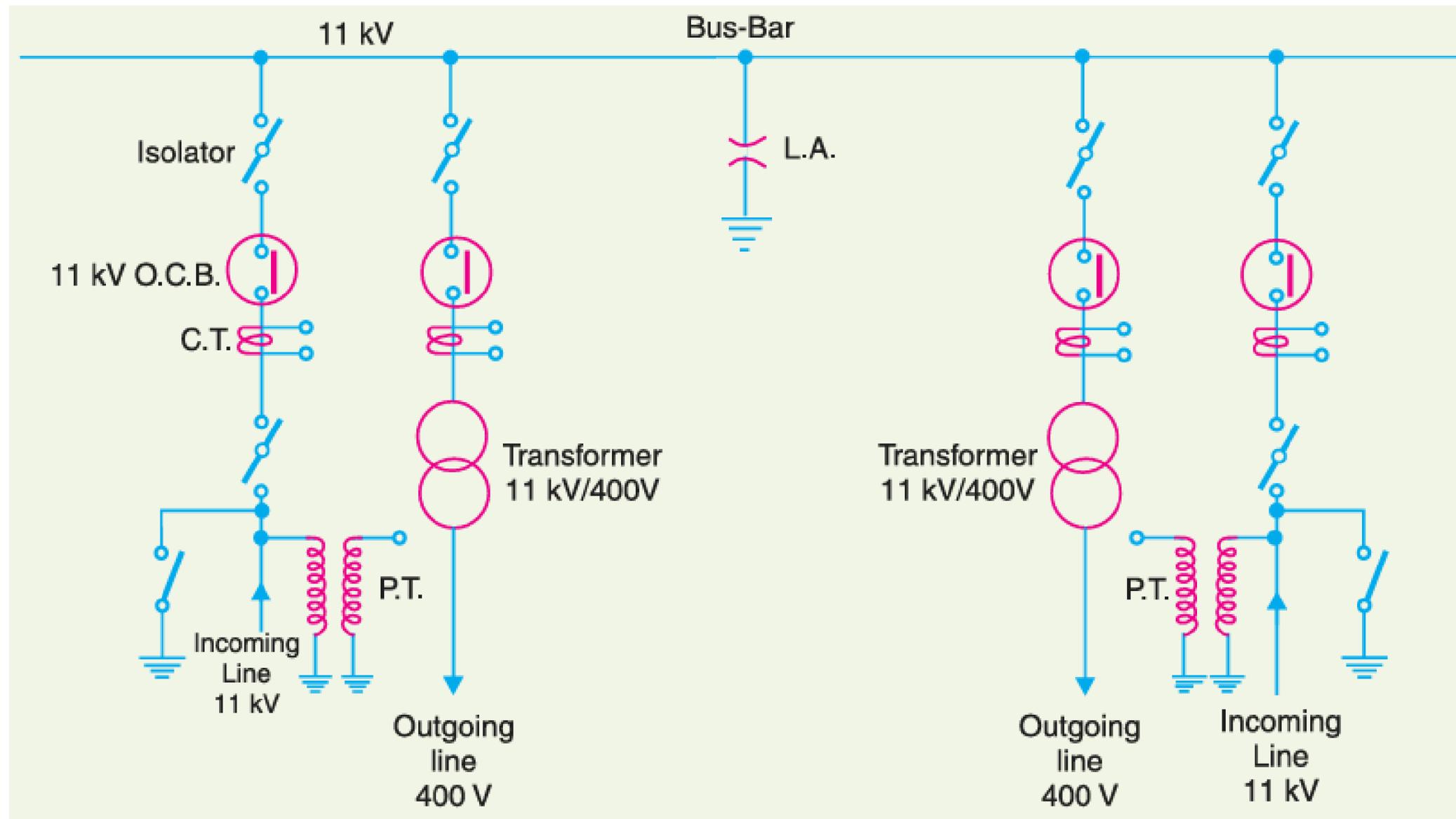
Bus-Bar Arrangements in Sub-Stations

(*ii*) **Single bus-bar system with sectionalisation.** In this arrangement, the single bus-bar is divided into sections and load is equally distributed on all the sections. Any two sections of the bus-bar are connected by a circuit breaker and isolators. Two principal advantages are claimed for this arrangement. Firstly, if a fault occurs on any section of the bus, that section can be isolated without affecting the supply from other sections. Secondly, repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of complete shut down. This arrangement is used for voltages upto 33 kV.

Fig. 25.6 shows bus-bar with sectionalisation where the bus has been divided into two sections. There are two 33 kV incoming lines connected to sections I and II as shown through circuit breaker and isolators. Each 11 kV outgoing line is connected to one section through transformer (33/11 kV) and circuit breaker. It is easy to see that each bus-section behaves as a separate bus-bar.
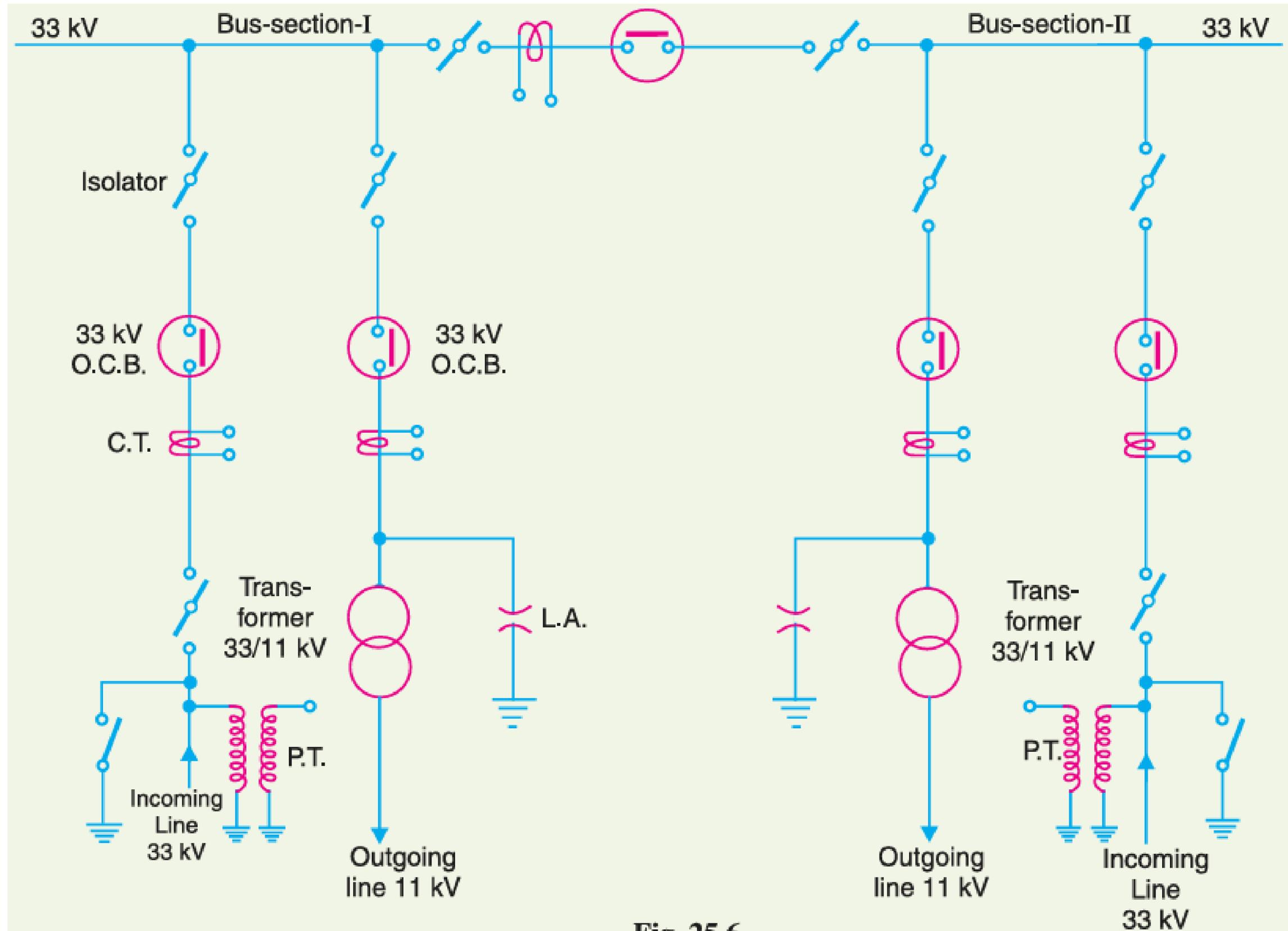
Bus-Bar Arrangements in Sub-Stations

Fig. 25.6

Bus-Bar Arrangements in Sub-Stations

(*iii*) **Duplicate bus-bar system.** This system consists of two bus-bars, a "main" bus-bar and a "spare" bus-bar. Each bus-bar has the capacity to take up the entire sub-station load. The incoming and outgoing lines can be connected to either bus-bar with the help of a bus-bar coupler which consists of a circuit breaker and isolators. Ordinarily, the incoming and outgoing lines remain connected to the main bus-bar. However, in case of repair of main bus-bar or fault occuring on it, the continuity of supply to the circuit can be maintained by transferring it to the spare bus-bar. For voltages exceeding 33kV, duplicate bus-bar system is frequently used.

Bus-Bar Arrangements in Sub-Stations

Fig. 25.7
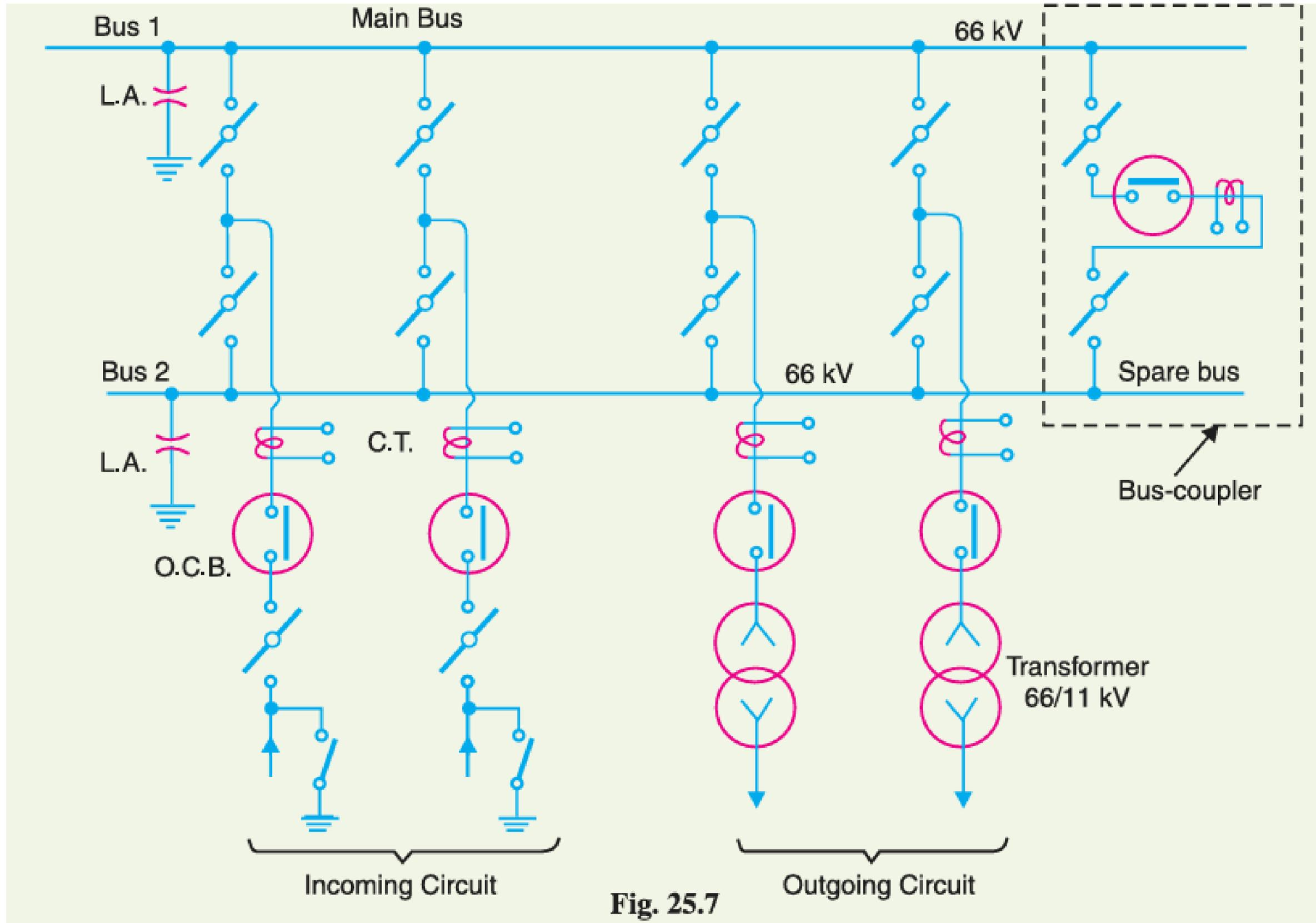
(i) **Terminal sub-station.** A terminal sub-station is one in which the line supplying to the sub-station terminates or ends. It may be located at the end of the main line or it may be situated at a point away from main line route. In the latter case, a tapping is taken from the main line to supply to the sub-station. Fig. 25.8 shows the schematic connections of a terminal sub-station. It is clear that incoming 11 kV main line terminates at the sub-station. Most of the distribution sub-stations are of this type.
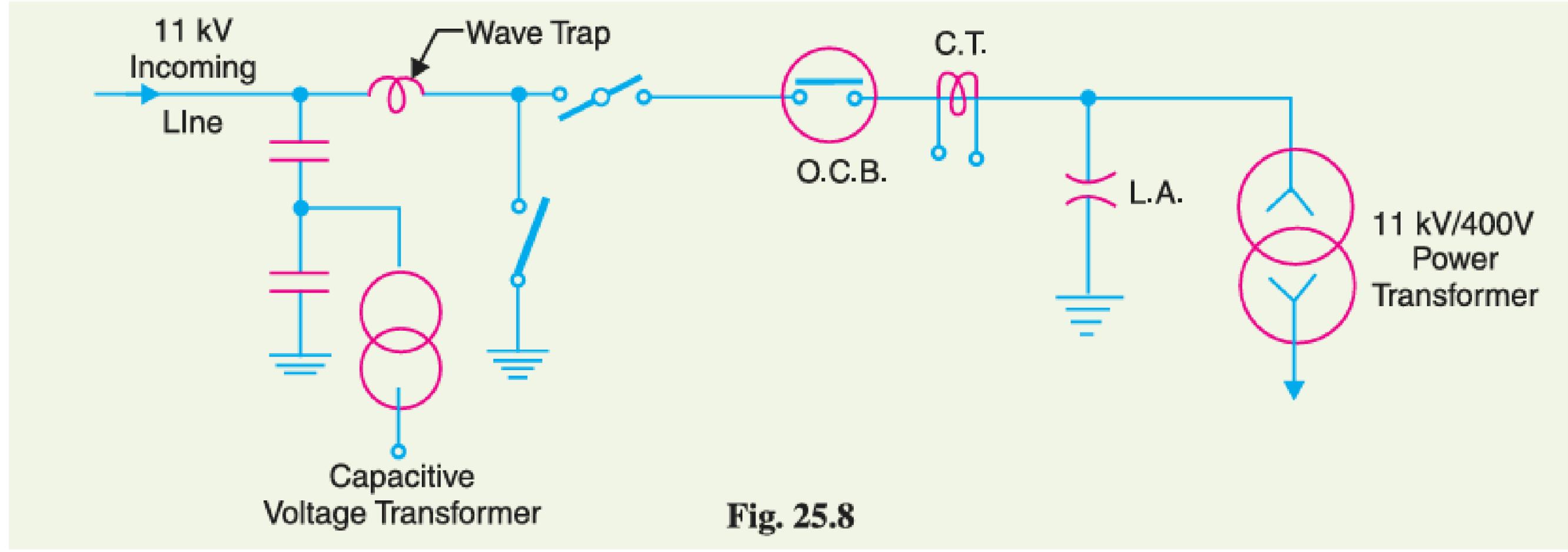
Fig. 25.8

(*ii*) **Through sub-station.** A through sub-station is one in which the incoming line passes 'through' at the same voltage. A tapping is generally taken from the line to feed to the transformer to reduce the voltage to the desired level. Fig. 25.9 shows the schematic connections of a through sub-station. The incoming 66 kV line passes through the sub-station as 66kV outgoing line. At the same time, the incoming line is tapped in the sub-station to reduce the voltage to 11 kV for secondary distribution.

Fig. 25.9

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Substation Design
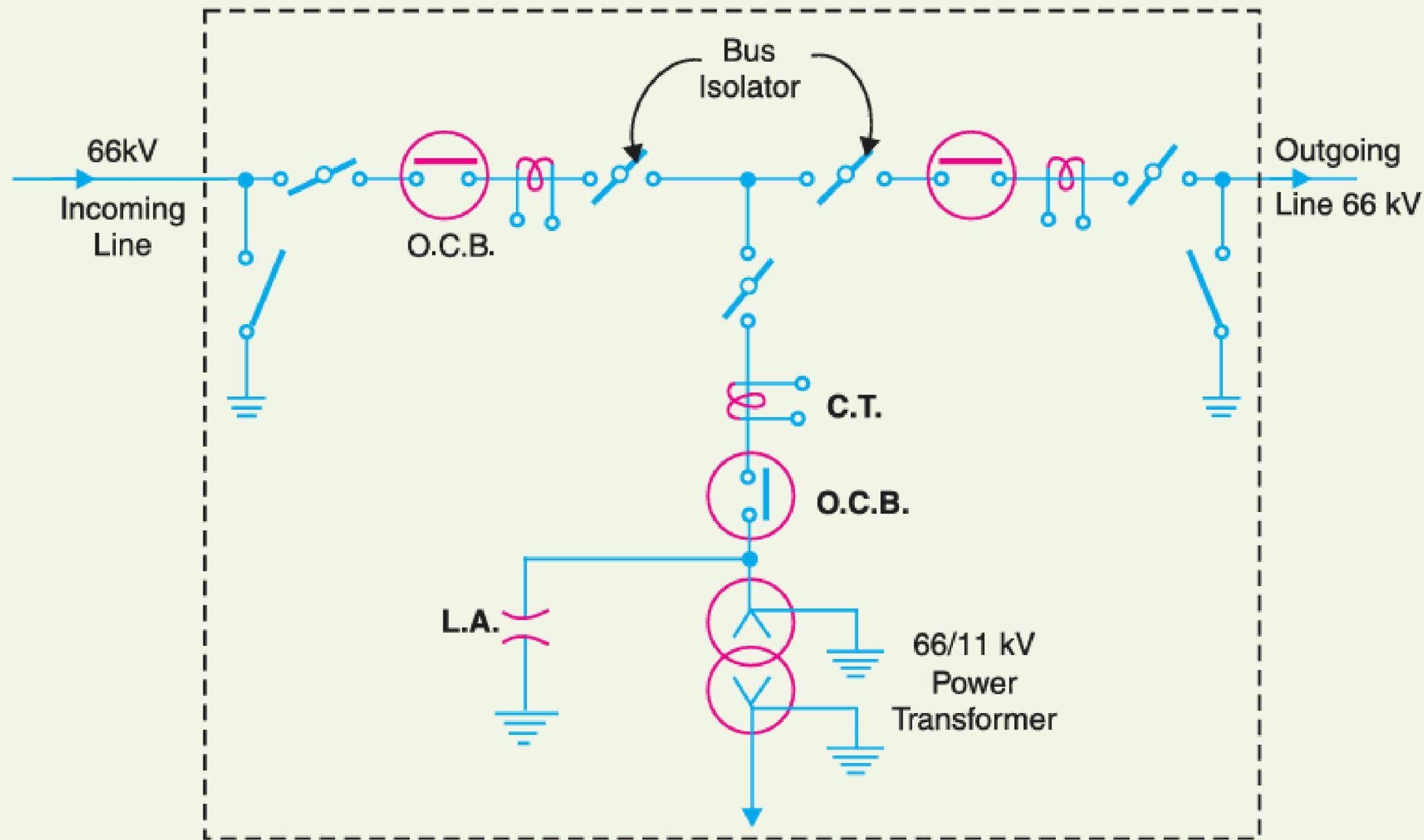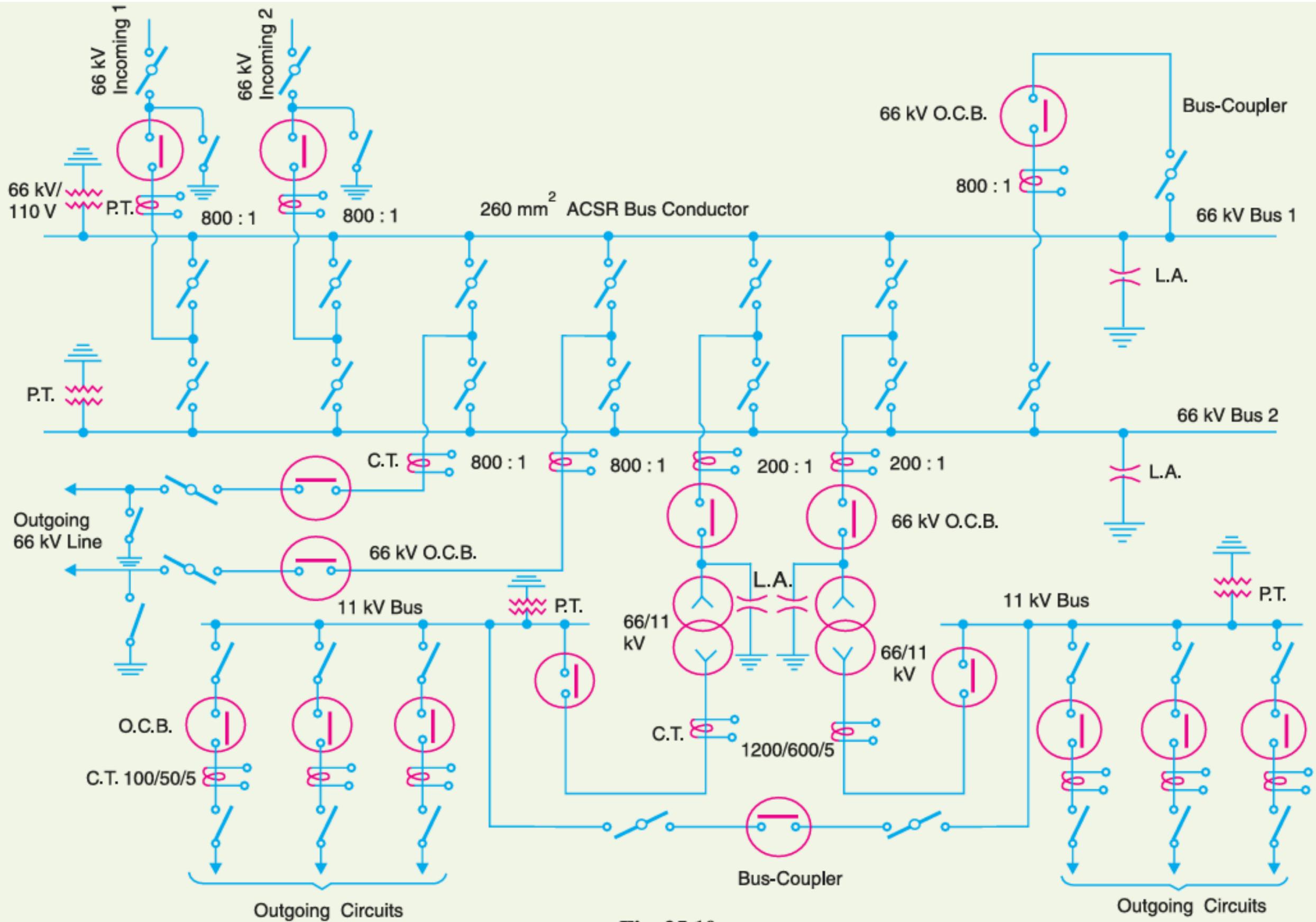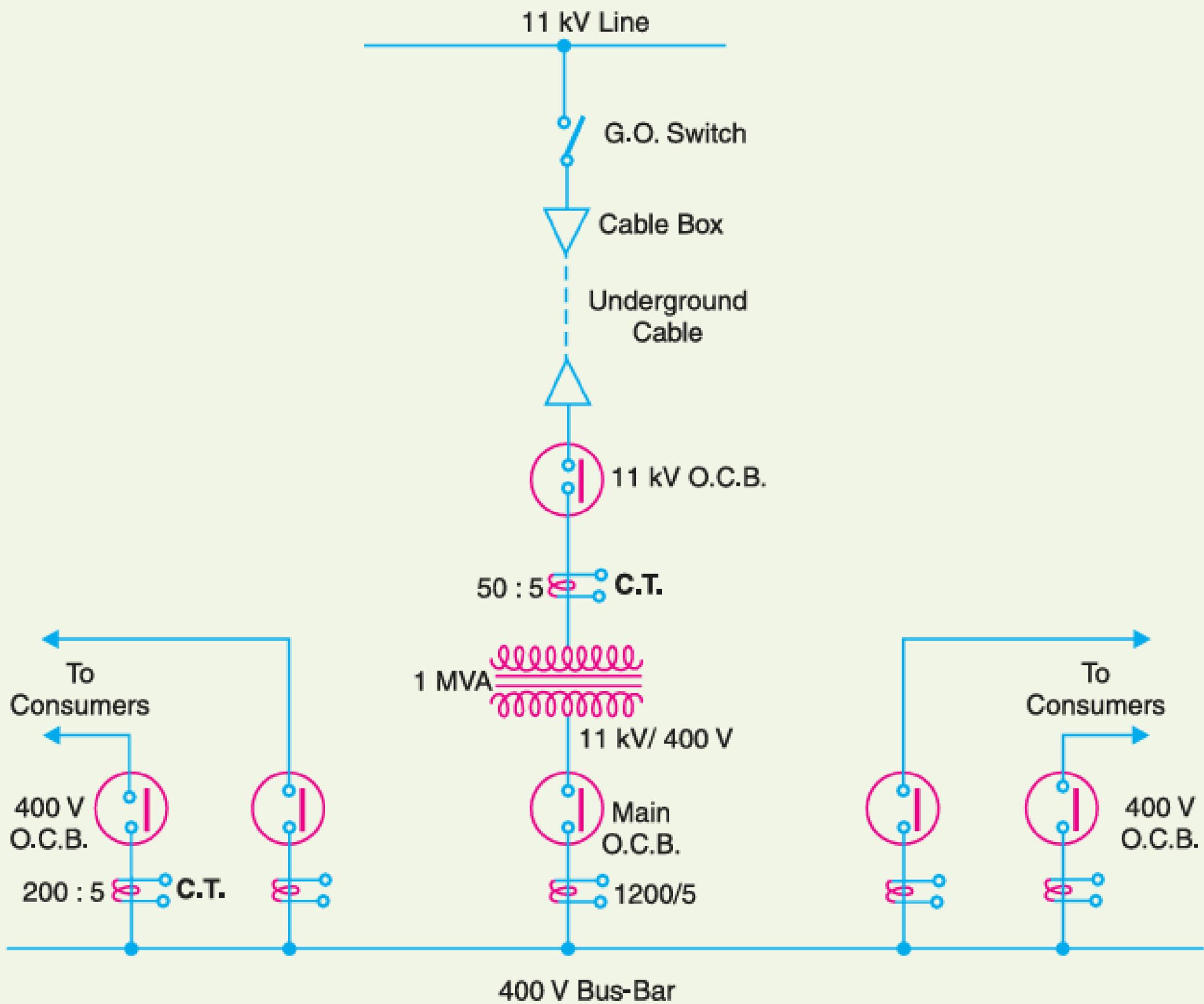
Key Diagram of 66/11 kV Sub-Station

Fig. 25.10

Substation Design

Key Diagram of 11 kV/400 V Indoor Sub-Station

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Circuit Breakers

A circuit breaker is a piece of equipment which can

(*i*)   make or break a circuit either manually or by remote control under normal conditions

(*ii*)   break a circuit *automatically* under fault conditions

(*iii*) make a circuit either manually or by remote control under fault conditions

Thus a circuit breaker incorporates manual (or remote control) as well as automatic control for switching functions. The latter control employs relays and operates only under fault conditions. The mechanism of opening of the circuit breaker under fault conditions has already been briefed in chap-

Operating principle. A circuit breaker essentially consists of fixed and moving contacts, called electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. Of course, the contacts can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the circuit breaker get energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases. The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the circuit breaker itself. Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Arc Phenomenon

When a short-circuit occurs, a heavy current flows through the contacts of the *circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate, the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature. The heat produced in the medium between contacts (usually the medium is oil or air) is sufficient to ionise the air or vapourise and ionise the oil. The ionised air or vapour acts as conductor and an arc is struck between the contacts. The p.d. between the contacts is quite small and is just sufficient to maintain the arc. The arc provides a low resistance path and consequently the current in the circuit remains uninterrupted so long as the arc persists.

During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts. The arc resistance depends upon the following factors :

(*i*) *Degree of ionisation*— the arc resistance increases with the decrease in the number of ionised particles between the contacts.

(*ii*) *Length of the arc*— the arc resistance increases with the length of the arc *i.e.,* separation of contacts.

(*iii*) *Cross-section of arc*— the arc resistance increases with the decrease in area of X-section of the arc.

Principles of Arc Extinction

Before discussing the methods of arc extinction, it is necessary to examine the factors responsible for the maintenance of arc between the contacts. These are :

(*i*) p.d. between the contacts

(*ii*) ionised particles between contacts

Taking these in turn,

(*i*) When the contacts have a small separation, the p.d. between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that p.d. becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many metres may be required.

(*ii*) The ionised particles between the contacts tend to maintain the arc. If the arc path is deionised, the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodily removing the ionised particles from the space between the contacts.

Methods of Arc Extinction

There are two methods of extinguishing the arc in circuit breakers *viz.*

1. High resistance method.   **2.** Low resistance or current zero method

1. **High resistance method.** In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. Consequently, the current is interrupted or the arc is extinguished. The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in d.c. circuit breakers and low-capacity a.c. circuit breakers.

The resistance of the arc may be increased by :

(*i*) *Lengthening the arc.* The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between contacts.

(*ii*) *Cooling the arc.* Cooling helps in the deionisation of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

Methods of Arc Extinction

(iii) *Reducing X-section of the arc.* If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased. In other words, the resistance of the arc path is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.

(iv) *Splitting the arc.* The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

Methods of Arc Extinction

2.   Low resistance or Current zero method. This method is employed for arc extinction in a.c. circuits only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking inspite of the rising voltage across the contacts. All modern high power a.c. circuit breakers employ this method for arc extinction.

In an a.c. system, current drops to zero after every half-cycle. At every current zero, the arc extinguishes for a brief moment. Now the medium between the contacts contains ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage known as *restriking voltage.* If such a breakdown does occur, the arc will persist for another half-cycle. If immediately after current zero, the dielectric strength of the medium between contacts is built up more rapidly than the voltage across the contacts, the arc fails to restrike and the current will

Methods of Arc Extinction

be interrupted. The rapid increase of dielectric strength of the medium near current zero can be achieved by :

    (**a**) causing the ionised particles in the space between contacts to recombine into neutral molecules.

    (**b**) sweeping the ionised particles away and replacing them by un-ionised particles

       Therefore, the real problem in a.c. arc interruption is to rapidly deionise the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts. The de-ionisation of the medium can be achieved by:

    (**i**) *lengthening of the gap.* The dielectric strength of the medium is proportional to the length of the gap between contacts. Therefore, by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.

    (**ii**) *high pressure.* If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionisation and consequently the dielectric strength of the medium between contacts is increased.

    (**iii**) *cooling.* Natural combination of ionised particles takes place more rapidly if they are allowed to cool. Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.

    (**iv**) *blast effect.* If the ionised particles between the contacts are swept away and replaced by un-ionised particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

Important Terms

(i) **Arc Voltage.** *It is the voltage that appears across the contacts of the circuit breaker during the arcing period.*

As soon as the contacts of the circuit breaker separate, an arc is formed. The voltage that appears across the contacts during arcing period is called the arc voltage. Its value is low except for the *period the fault current is at or near zero current point. At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

(ii) **Restriking voltage.** *It is the transient voltage that appears across the contacts at or near current zero during arcing period.*

At current zero, a high-frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and transmission lines of the system. This transient voltage is known as restriking voltage (Fig. 19.1). The current interruption in the circuit depends upon this voltage. If the restriking voltage rises more rapidly than the dielectric strength of the medium between the contacts, the arc will persist for another half-cycle. On the other hand, if the dielectric strength of the medium builds up more rapidly than the restriking voltage, the arc fails to restrike and the current will be interrupted.
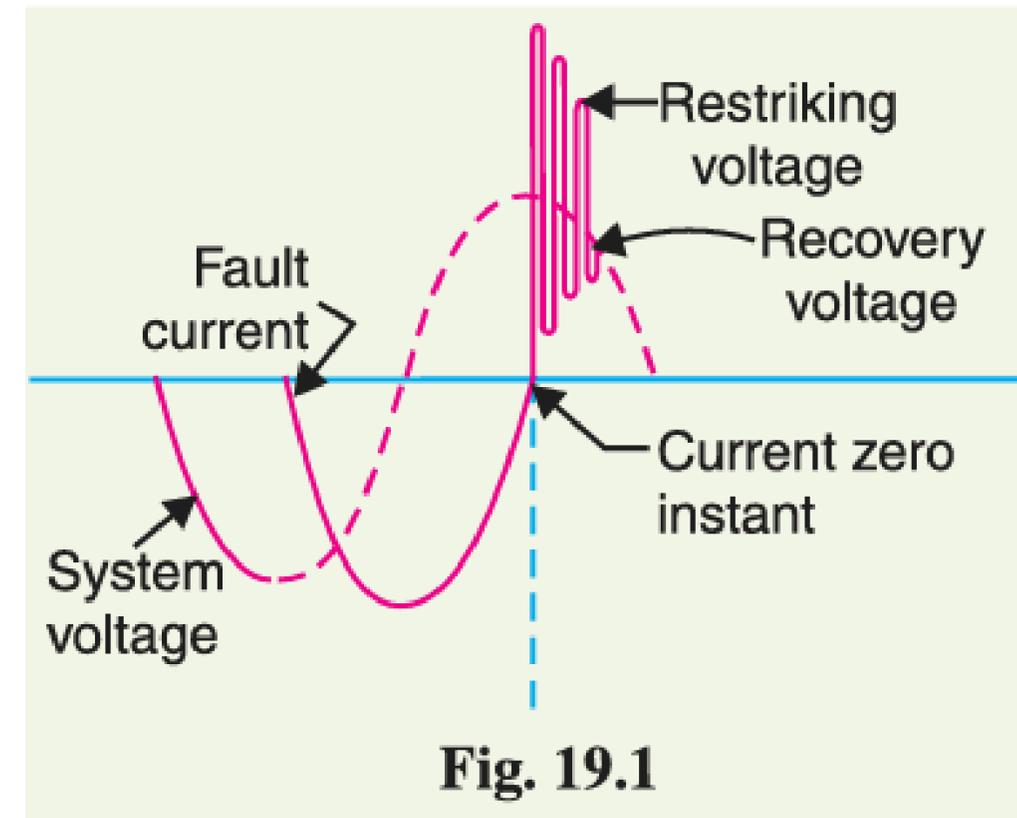

Fig. 19.1

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Classification of Circuit Breakers

There are several ways of classifying the circuit breakers. However, the most general way of classification is on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF_6) or vacuum. Accordingly, circuit breakers may be classified into :

    (*i*)   *Oil circuit breakers* which employ some insulating oil (*e.g.,* transformer oil) for arc extinction.

    (*ii*)   *Air-blast circuit breakers* in which high pressure air-blast is used for extinguishing the arc.

    (*iii*)   *Sulphur hexafluroide circuit breakers* in which sulphur hexafluoride (SF_6) gas is used for arc extinction.

    (*iv*)   *Vacuum circuit breakers* in which vacuum is used for arc extinction.

    Each type of circuit breaker has its own advantages and disadvantages. In the following sections, we shall discuss the construction and working of these circuit breakers with special emphasis on the way the arc extinction is facilitated.

Oil Circuit Breakers

In such circuit breakers, some insulating oil (*e.g.*, transformer oil) is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into a substantial volume of gaseous *hydrogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contacts (See Fig. 19.2). The arc extinction is facilitated mainly by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionisation of the medium between the contacts. Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arcing products from the arc path. The result is that arc is extinguished and circuit current †interrupted.
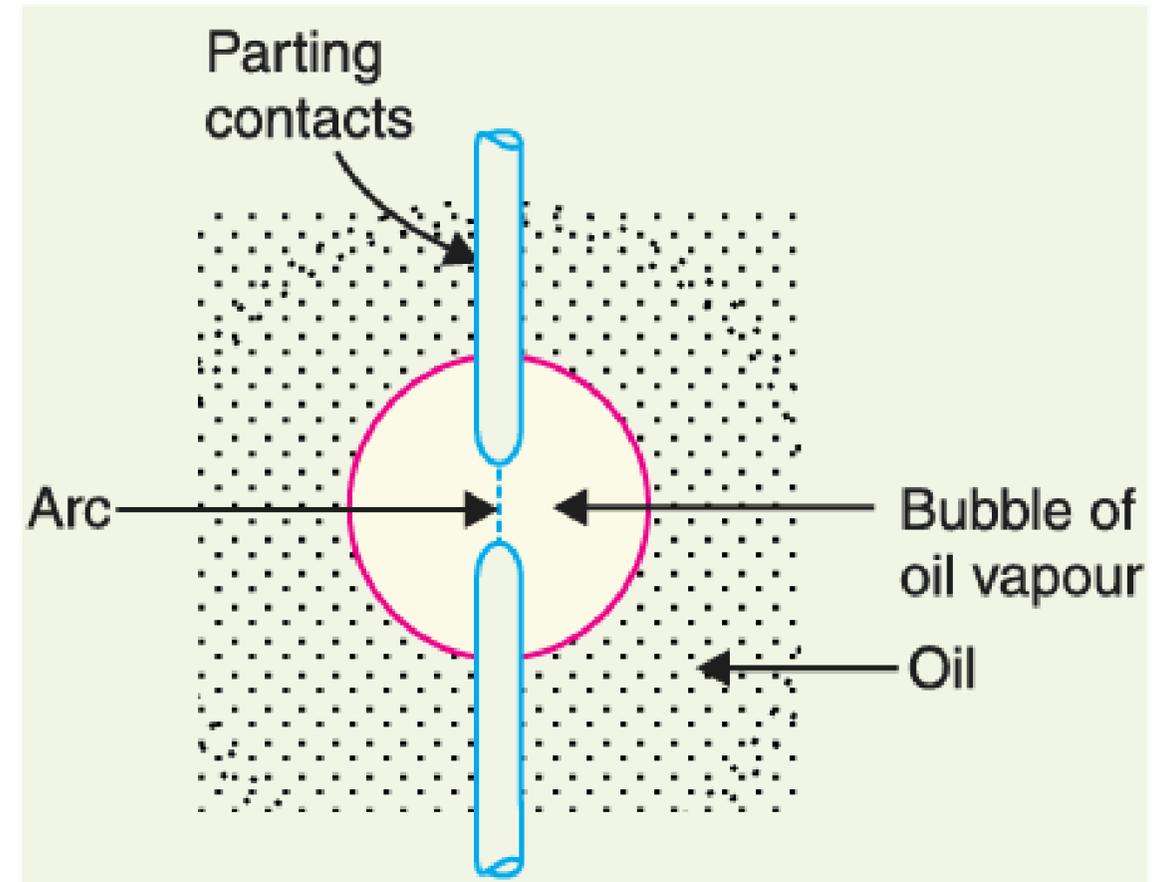

Fig. 19.2

Oil Circuit Breakers

Advantages. The advantages of oil as an arc quenching medium are :

(*i*) It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

(*ii*) It acts as an insulator and permits smaller clearance between live conductors and earthed components.

(*iii*) The surrounding oil presents cooling surface in close proximity to the arc.

Disadvantages. The disadvantages of oil as an arc quenching medium are :

(*i*) It is inflammable and there is a risk of a fire.

(*ii*) It may form an explosive mixture with air

(*iii*) The arcing products (*e.g.*, carbon) remain in the oil and its quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.

Types of Oil Circuit Breakers

The oil circuit breakers find extensive use in the power system. These can be classified into the following types :

(*i*) *Bulk oil circuit breakers* which use a large quantity of oil. The oil has to serve two purposes. Firstly, it extinguishes the arc during opening of contacts and secondly, it insulates the current conducting parts from one another and from the earthed tank. Such circuit breakers may be classified into :

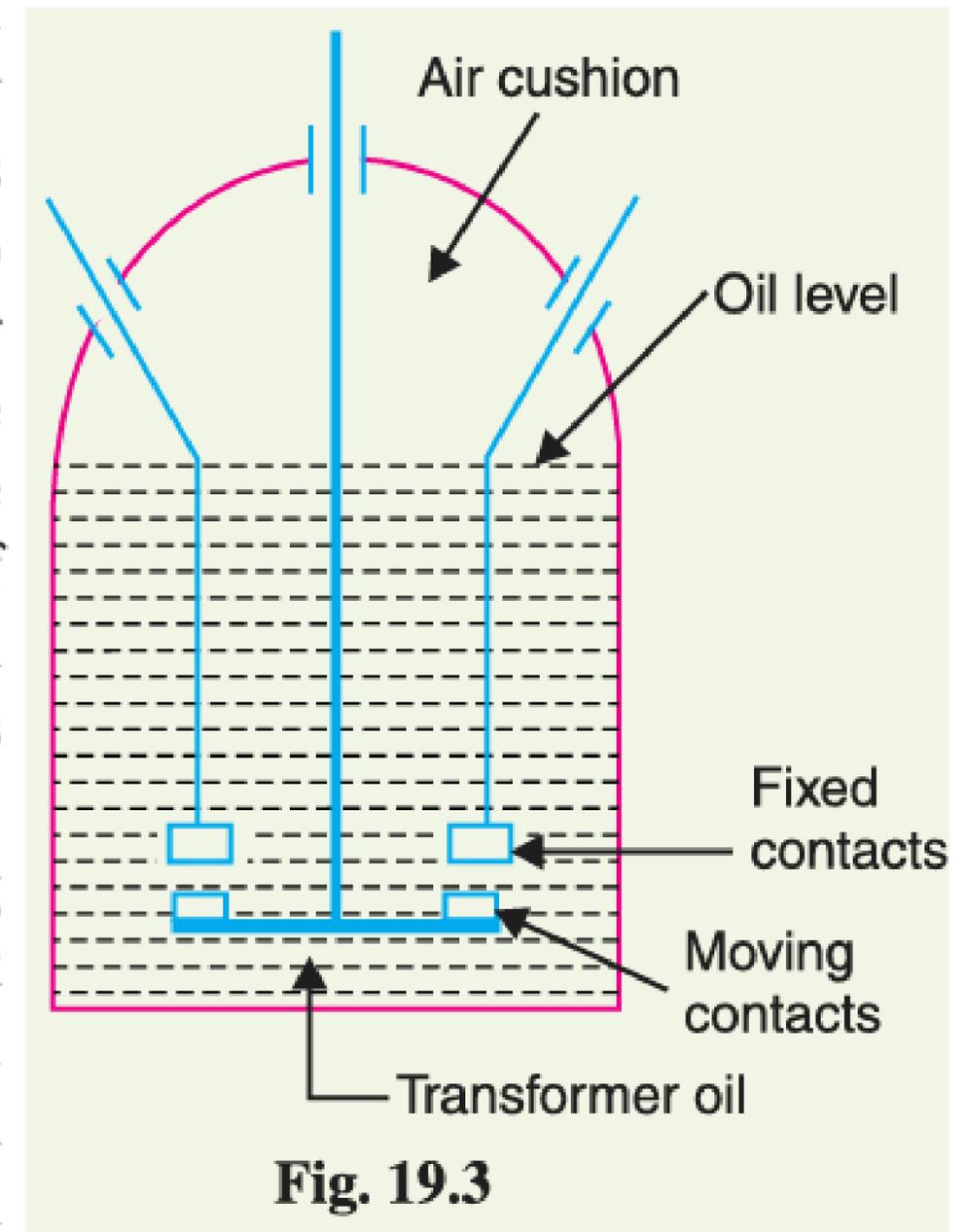(*a*) Plain break oil circuit breakers (*b*) Arc control oil circuit breakers.

In the former type, no special means is available for controlling the arc and the contacts are directly exposed to the whole of the oil in the tank. However, in the latter type, special arc control devices are employed to get the beneficial action of the arc as efficiently as possible.

(*ii*) *Low oil circuit breakers* which use minimum amount of oil. In such circuit breakers, oil is used *only* for arc extinction; the current conducting parts are insulated by air or porcelain or organic insulating material.

Plain Break Oil Circuit Breakers

The plain-break oil circuit breaker is the earliest type from which all other circuit breakers have developed. It has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil upto a certain level and an air cushion above the oil level. The air cushion provides sufficient room to allow for the reception of the arc gases without the generation of unsafe pressure in the dome of the circuit breaker. It also absorbs the mechanical shock of the upward oil movement. Fig. 19.3 shows a *double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

Under normal operating conditions, the fixed and moving contacts remain closed and the breaker carries the normal circuit current. When a fault occurs, the moving contacts are pulled down by the protective system and an arc is struck which vapourises the oil mainly into hydrogen gas. The arc extinction is facilitated by the following processes :

Fig. 19.3

Plain Break Oil Circuit Breakers

(*i*) The hydrogen gas bubble generated around the arc cools the arc column and aids the de-ionisation of the medium between the contacts.

(*ii*) The gas sets up turbulence in the oil and helps in eliminating the arcing products from the arc path.

(*iii*) As the arc lengthens due to the separating contacts, the dielectric strength of the medium is increased.

The result of these actions is that at some critical gap length, the arc is extinguished and the circuit current is interrupted.

Disadvantages

(*i*) There is no special control over the arc other than the increase in length by separating the moving contacts.   Therefore, for successful interruption, long arc length is necessary.

(*ii*) These breakers have long and inconsistent arcing times.

(*iii*) These breakers do not permit high speed interruption.

Due to these disadvantages, plain-break oil circuit breakers are used only for low-voltage applications where high breaking-capacities are not important. It is a usual practice to use such breakers for low capacity installations for voltages not exceeding †11 kV.

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Arc Control Oil Circuit Breakers

In case of plain-break oil circuit breaker discussed above, there is very little artificial control over the arc. Therefore, comparatively long arc length is essential in order that turbulence in the oil caused by the gas may assist in quenching it. However, it is necessary and desirable that final arc extinction should occur while the contact gap is still short. For this purpose, some arc control is incorporated and the breakers are then called arc control circuit breakers. There are two types of such breakers, namely :

(*i*)   *Self-blast oil circuit breakers*— in which arc control is provided by internal means *i.e.* the arc itself is employed for its own extinction efficiently.

(*ii*) *Forced-blast oil circuit breakers*— in which arc control is provided by mechanical means external to the circuit breaker.

Arc Control Oil Circuit Breakers

(*i*) **Self-blast oil circuit breakers.** In this type of circuit breaker, the gases produced during arcing are confined to a small volume by the use of an insulating rigid pressure chamber or pot surrounding the contacts. Since the space available for the arc gases is restricted by the chamber, a very high pressure is developed to force the oil and gas through or around the arc to extinguish it. The magnitude of pressure developed depends upon the value of fault current to be interrupted. As the pressure is generated by the arc itself, therefore, such breakers are some-times called self-generated pressure oil circuit breakers.

The pressure chamber is relatively cheap to make and gives reduced final arc extinction gap length and arcing time as against the plain-break oil circuit breaker. Several designs of pressure chambers (sometimes called explosion pots) have been developed and a few of them are described below :

(*a*) **Plain explosion pot.** It is a rigid cylinder of insulating material and encloses the fixed and moving contacts (See Fig. 19.4). The moving contact is a cylindrical rod passing through a restricted opening (called throat) at the bottom. When a fault occurs, the contacts get separated and an arc is struck between them. The heat of the arc decomposes oil into a gas at very high pressure in the pot. This high pressure forces the oil and
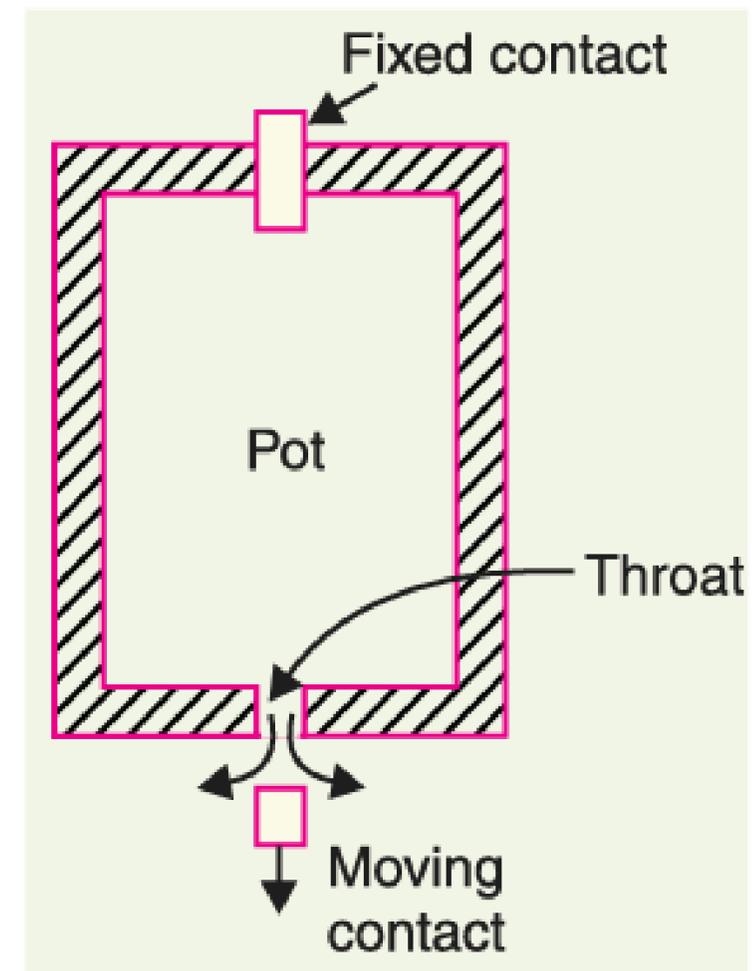

Fig. 19.4

Arc Control Oil Circuit Breakers

gas through and round the arc to extinguish it. If the final arc extinction does not take place while the moving contact is still within the pot, it occurs immediately after the moving contact leaves the pot. It is because emergence of the moving contact from the pot is followed by a violent rush of gas and oil through the throat producing rapid extinction.

The principal limitation of this type of pot is that it cannot be used for very low or for very high fault currents. With low fault currents, the pressure developed is small, thereby increasing the arcing time. On the other hand, with high fault currents, the gas is produced so rapidly that explosion pot is liable to burst due to high pressure. For this reason, plain explosion pot operates well on moderate short-circuit currents only where the rate of gas evolution is moderate.

(*b*) **Cross jet explosion pot.** This type of pot is just a modification of plain explosion pot and is illustrated in Fig. 19.5. It is made of insulating material and has channels on one side which act as arc splitters. The arc splitters help in increasing the arc length, thus facilitating arc extinction. When a fault occurs, the moving contact of the circuit breaker begins to separate. As the moving contact is withdrawn, the arc is initially struck in the top of the pot. The gas generated by the arc exerts pressure on the oil in the back passage. When the moving contact uncovers the arc splitter ducts, fresh oil is forced *across the arc path. The arc is, therefore, driven sideways into the "arc splitters" which increase the arc length, causing arc extinction.

Arc Control Oil Circuit Breakers
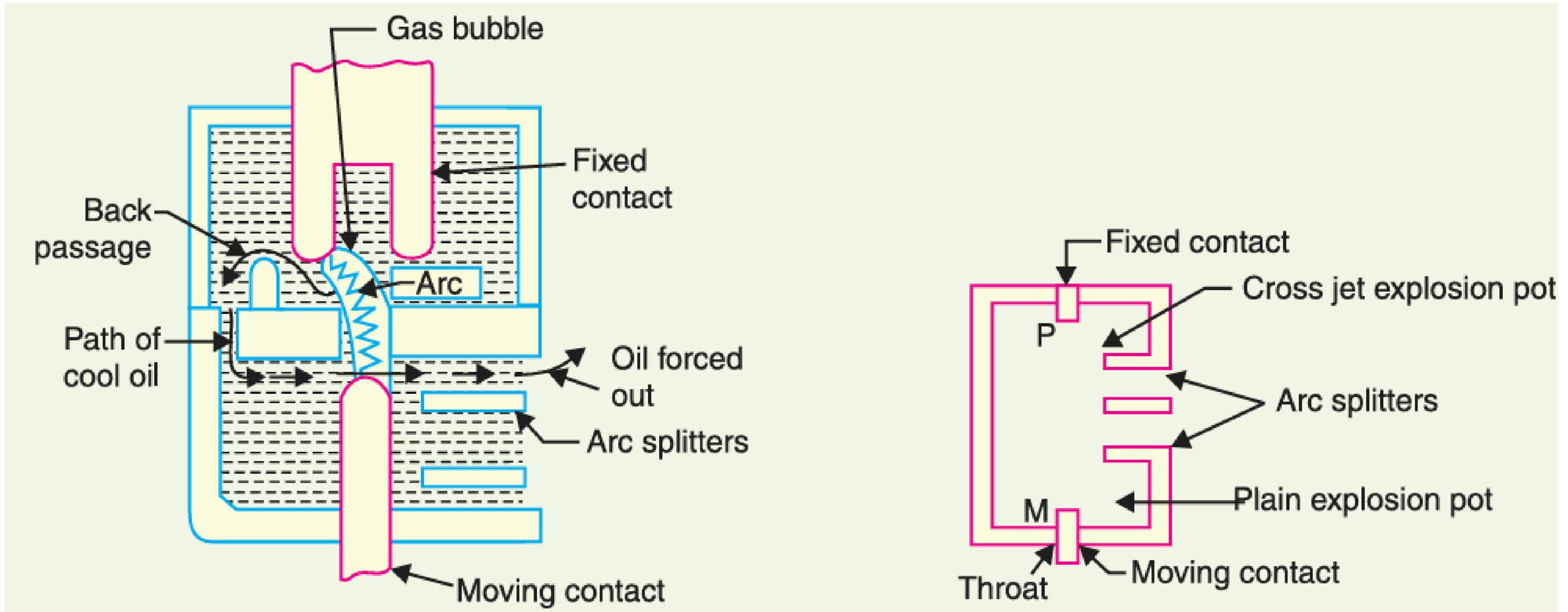
Arc Control Oil Circuit Breakers

The cross-jet explosion pot is quite efficient for interrupting heavy fault currents. However, for low fault currents, the gas pressure is †small and consequently the pot does not give a satisfactory operation.

(*c*) **Self-compensated explosion pot.** This type of pot is essentially a combination of plain explosion pot and cross jet explosion pot. Therefore, it can interrupt low as well as heavy short circuit currents with reasonable accuracy.

Fig. 19.6 shows the schematic diagram of self-compensated explosion pot. It consists of two chambers, the upper chamber is the cross-jet explosion pot with two arc splitter ducts while the lower one is the plain explosion pot. When the short-circuit current is heavy, the rate of generation of gas is very high and the device behaves as a cross-jet explosion pot. The arc extinction takes place when the moving contact uncovers the first or second arc splitter duct. However, on low short-circuit currents, the rate of gas generation is small and the tip of the moving contact has the time to reach the lower chamber. During this time, the gas builds up sufficient pressure as there is very little leakage through

Arc Control Oil Circuit Breakers

arc splitter ducts due to the obstruction offered by the arc path and right angle bends. When the moving contact comes out of the throat, the arc is extinguished by plain pot action.

It may be noted that as the severity of the short-circuit current increases, the device operates less and less as a plain explosion pot and more and more as a cross-jet explosion pot. Thus the tendency is to make the control self-compensating over the full range of fault currents to be interrupted.

(*ii*) **Forced-blast oil circuit breakers.** In the self-blast oil circuit breakers discussed above, the arc itself generates the necessary pressure to force the oil across the arc path. The major limitation of such breakers is that arcing times tend to be long and inconsistent when operating against currents considerably less than the rated currents. It is becasue the gas generated is much reduced at low values of fault currents. This difficulty is overcome in forced-blast oil circuit breakers in which the necessary pressure is generated by external mechanical means independent of the fault currents to be broken.

In a forced -blast oil circuit breaker, oil pressure is created by the piston-cylinder arrangement. The movement of the piston is mechanically coupled to the moving contact. When a fault occurs, the contacts get separated by the protective system and an arc is struck between the contacts. The piston forces a jet of oil towards the contact gap to extinguish the arc. It may be noted that necessary oil pressure produced does not in any way depend upon the fault current to be broken.

Advantages

    (*a*) Since oil pressure developed is independent of the fault current to be interrupted, the perfor-mance at low currents is more consistent than with self-blast oil circuit breakers.

    (*b*) The quantity of oil required is reduced considerably.

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Low Oil Circuit Breakers

In the bulk oil circuit breakers discussed so far, the oil has to perform two functions. Firstly, it acts as an arc quenching medium and secondly, it insulates the live parts from earth. It has been found that only a small percentage of oil is actually used for arc extinction while the major part is utilised for insulation purposes. For this reason, the quantity of oil in bulk oil circuit breakers reaches a very high figure as the system voltage increases. This not only increases the expenses, tank size and weight of the breaker but it also increases the fire risk and maintenance problems.

The fact that only a small percentage of oil (about 10% of total) in the bulk oil circuit breaker is actually used for arc extinction leads to the question as to why the remainder of the oil, that is not immediately surrounding the device, should not be omitted with consequent saving in bulk, weight and fire risk. This led to the development of low-oil circuit breaker. A low oil circuit breaker employs solid materials for insulation purposes and uses a small quantity of oil which is just sufficient for arc extinction. As regards quenching the arc, the oil behaves identically in bulk as well as low oil circuit breaker. By using suitable arc control devices, the arc extinction can be further facilitated in a low oil circuit breaker.

Low Oil Circuit Breakers

Construction. Fig 19.7 shows the cross section of a single phase low oil circuit breaker. There are two compartments separated from each other but both filled with oil. The upper chamber is the circuit breaking chamber while the lower one is the supporting chamber. The two chambers are separated by a partition and oil from one chamber is prevented from mixing with the other chamber. This arrangement permits two advantages. Firstly, the circuit breaking chamber requires a small volume of oil which is just enough for arc extinction. Secondly, the amount of oil to be replaced is reduced as the oil in the supporting chamber does not get contaminated by the arc.

(*i*) *Supporting chamber.* It is a porcelain chamber mounted on a metal chamber. It is filled with oil which is physically separated from the oil in the circuit breaking compartment. The oil inside the supporting chamber and the annular space formed between the porcelain insulation and bakelised paper is employed for insulation purposes only.

(*ii*) *Circuit-breaking chamber.* It is a porcelain enclosure mounted on the top of the supporting compartment. It is filled with oil and has the following parts :

(*a*) upper and lower fixed contacts

(*b*) moving contact

(*c*) turbulator

Low Oil Circuit Breakers

(iii) Top chamber. It is a metal chamber and is mouted on the circuit-breaking chamber. It provides expansion space for the oil in the circuit breaking compartment. The top chamber is also provided with a separator which prevents any loss of oil by centrifugal action caused by circuit breaker operation during fault conditions.
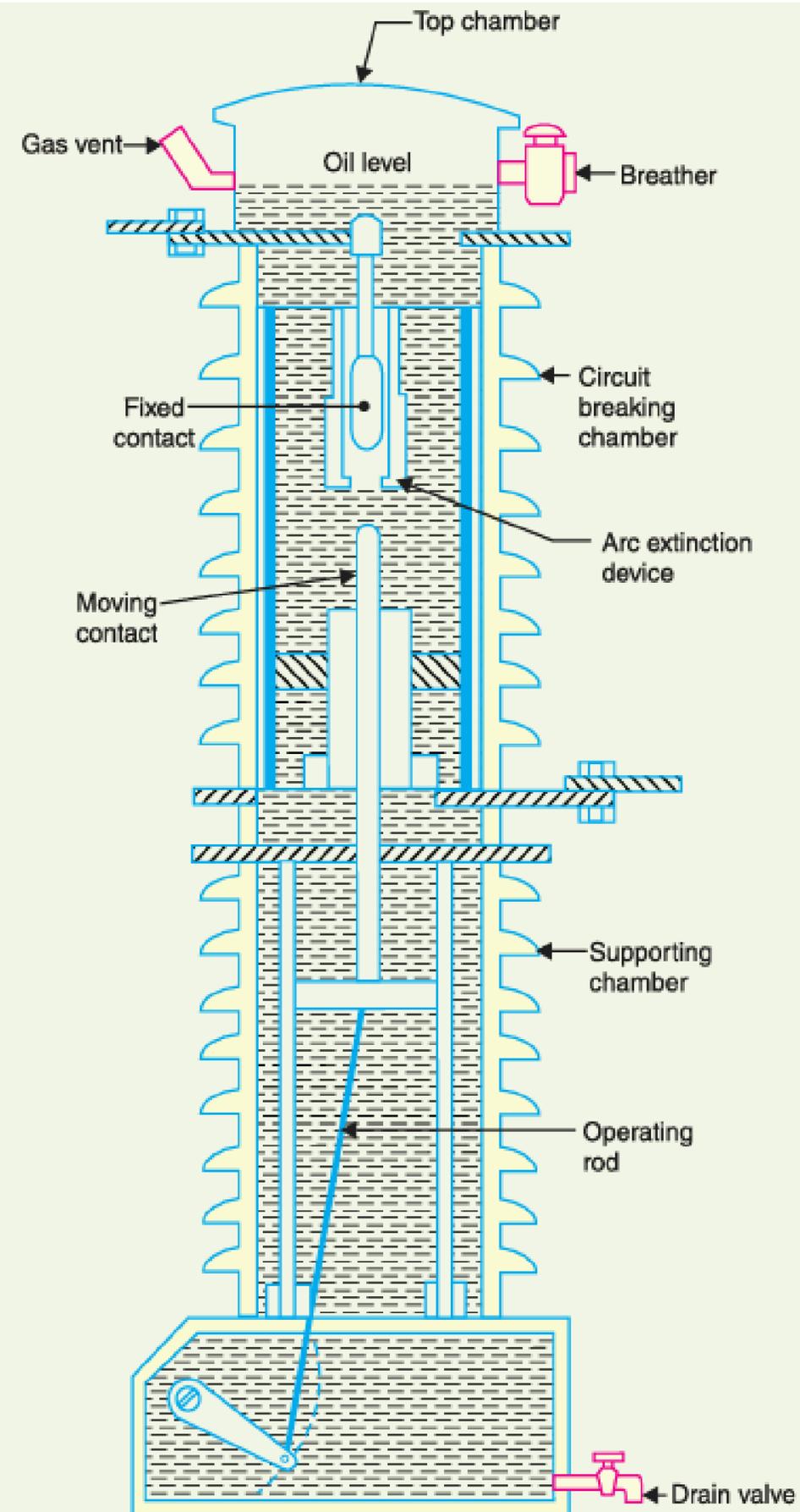

Fig. 19.7 Low-oil Circuit Breaker

Low Oil Circuit Breakers

Operation. Under normal operating conditions, the moving contact remains engaged with the upper fixed contact. When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck. The arc energy vaporises the oil and produces gases under high pressure. This action constrains the oil to pass through a central hole in the moving contact and results in forcing series of oil through the respective passages of the turbulator. The process of turbulation is orderly one, in which the sections of the arc are successively quenched by the effect of separate streams of oil moving across each section in turn and bearing away its gases.

Advantages. A low oil circuit breaker has the following advantages over a bulk oil circuit breaker:

(*i*)   It requires lesser quantity of oil.

(*ii*)   It requires smaller space.

(*iii*)   There is reduced risk of fire.

(*iv*)   Maintenance problems are reduced.

Disadvantages. A low oil circuit breaker has the following disadvantages as compared to a bulk oil circuit breaker :

(*i*)   Due to smaller quantity of oil, the degree of carbonisation is increased.

(*ii*)   There is a difficulty of removing the gases from the contact space in time.

(*iii*)   The dielectric strength of the oil deteriorates rapidly due to high degree of carbonisation.

Maintenance of Oil Circuit Breakers

The maintenance of oil circuit breaker is generally concerned with the checking of contacts and dielectric strength of oil. After a circuit breaker has interrupted fault currents a few times or load currents several times, its contacts may get burnt by arcing and the oil may lose some of its dielectric strength due to carbonisation. This results in the reduced rupturing capacity of the breaker. Therefore, it is a good practice to inspect the circuit breaker at regular intervals of 3 or 6 months. During inspection of the breaker, the following points should be kept in view :

(i) Check the current carrying parts and arcing contacts. If the burning is severe, the contacts should be replaced.

(ii) Check the dielectric strength of the oil. If the oil is badly discoloured, it should be changed or reconditioned. The oil in good condition should withstand 30 kV for one minute in a standard oil testing cup with 4 mm gap between electrodes.

(iii) Check the insulation for possible damage. Clean the surface and remove carbon deposits with a strong and dry fabric.

(iv) Check the oil level.

(v) Check closing and tripping mechanism.

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Air-Blast Circuit Breakers

Advantages. An air-blast circuit breaker has the following advantages over an oil circuit breaker:

(*i*)   The risk of fire is eliminated.

(*ii*) The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.

(*iii*) The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.

(*iv*) The arcing time is very small due to the rapid build up of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit breakers, thus resulting in less burning of contacts.

(*v*)   Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.

(*vi*) The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

Disadvantages. The use of air as the arc quenching medium offers the following disadvantges :

(*i*)   The air has relatively inferior arc extinguishing properties.

(*ii*) The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restriking voltage.

Types of Air-Blast Circuit Breakers

Depending upon the direction of air-blast in relation to the arc, air-blast circuit breakers are classified into :

(*i*) *Axial-blast type* in which the air-blast is directed along the arc path as shown in Fig. 19.8 (*i*).
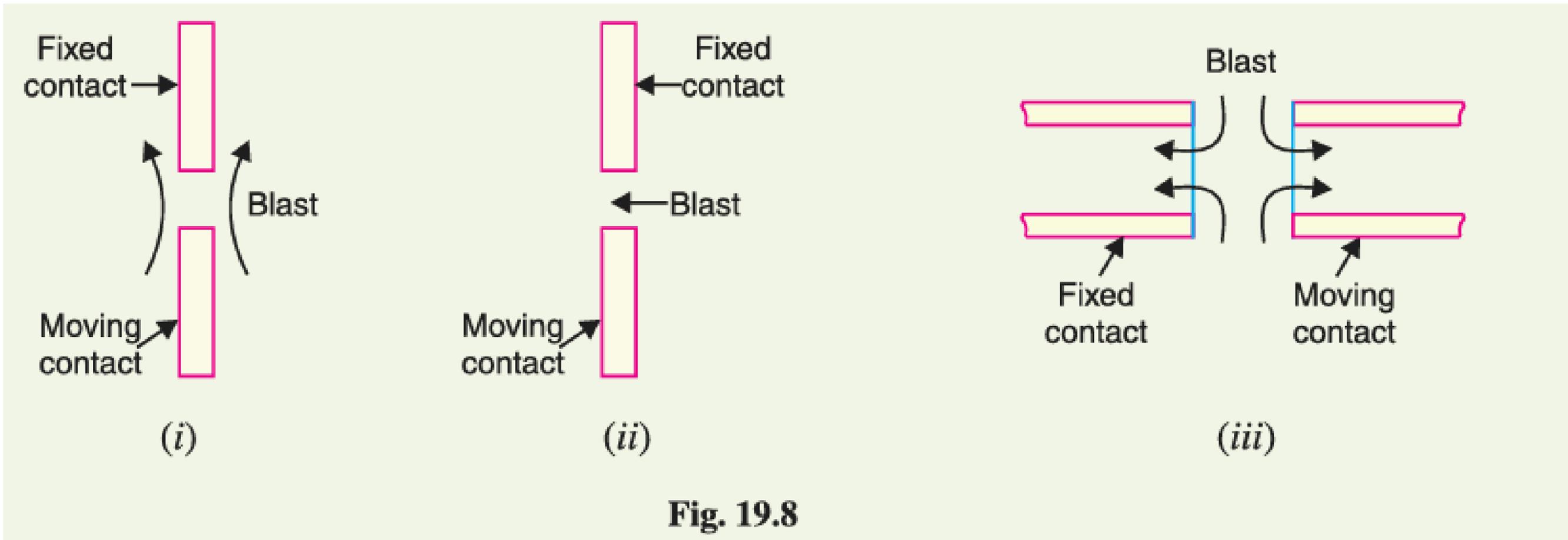
Fig. 19.8

Types of Air-Blast Circuit Breakers

   (ii) *Cross-blast type* in which the air-blast is directed at right angles to the arc path as shown in Fig. 19.8 (*ii*).

   (iii) *Radial-blast type* in which the air-blast is directed radially as shown in Fig. 19.8 (*iii*).

   (i) **Axial-blast air circuit breaker.** Fig 19.9 shows the essential components of a typical axial-blast air circuit breaker. The fixed and moving contacts are held in the closed position by spring pressure under normal conditions. The air reservoir is connected to the arcing chamber through an air valve. This valve remains closed under normal conditions but opens automatically by the tripping impulse when a fault occurs on the system.
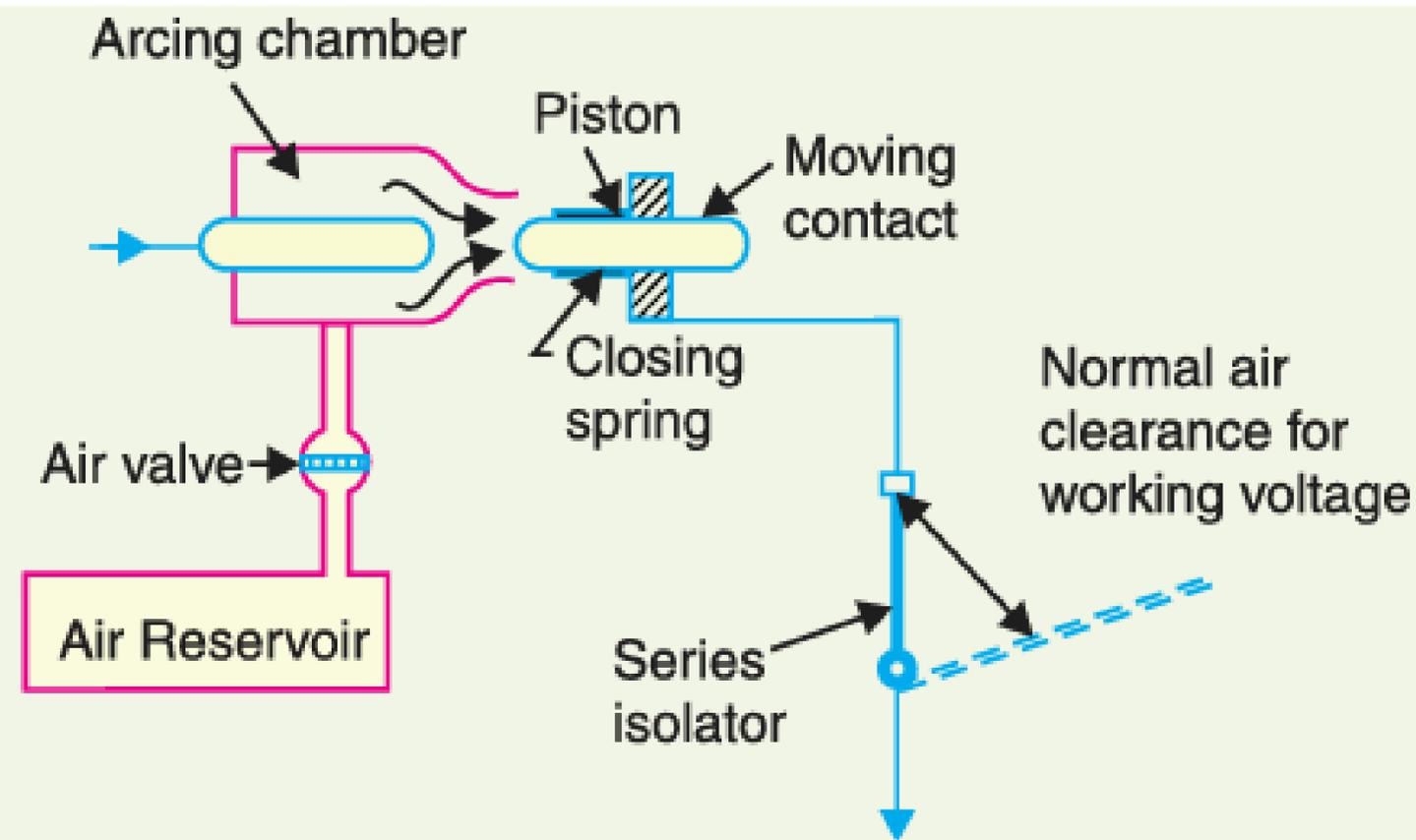
When a fault occurs, the tripping impulse causes opening of the air valve which connects the circuit breaker reservoir to the arcing chamber. The high pressure air entering the arcing chamber pushes away the moving contact against spring pressure. The moving contact is separated and an arc is struck. At the same time, high pressure air blast flows along the arc and takes away the ionised gases along with it. Consequently, the arc is extinguished and current flow is interrupted.

It may be noted that in such circuit breakers, the contact separation required for interruption is generally small (1·75 cm or so). Such a small gap may constitute inadequate clearance for the normal service voltage. Therefore, an isolating switch is incorporated as a part of this type of circuit breaker. This switch opens immediately after fault interruption to provide the necessary clearance for insulation.

(*ii*) **Cross-blast air breaker.** In this type of circuit breaker, an air-blast is directed at right angles to the arc. The cross-blast lengthens and forces the arc into a suitable chute for arc extinction. Fig. 19.10 shows the essential parts of a typical cross-blast air circuit breaker. When the moving contact is withdrawn, an arc is struck between the fixed and moving contacts. The high pressure cross-blast forces the arc into a chute consisting of arc splitters and baffles. The splitters serve to increase the length of the arc and baffles give improved cooling. The result is that arc is extinguished and flow of current is interrupted. Since blast pressure is same for all currents, the

Fig. 19.10

inefficiency at low currents is eliminated. The final gap for interruption is great enough to give normal insulation clearance so that a series isolating switch is not necessary.
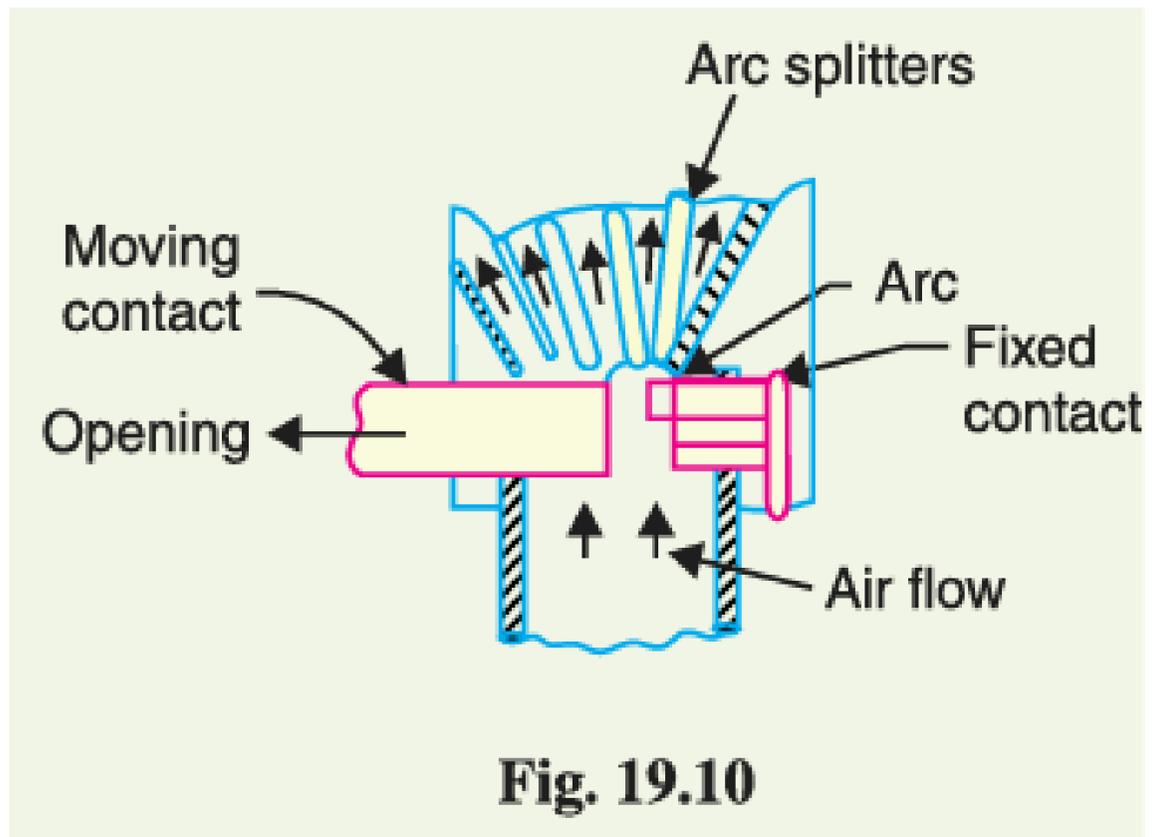
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Sulphur Hexaflouride (SF6) Circuit Breakers

Construction. Fig. 19.11 shows the parts of a typical SF_6 circuit breaker. It consists of fixed and moving contacts enclosed in a chamber (called arc interruption chamber) containing SF_6 gas. This chamber is connected to SF_6 gas reservior. When the contacts of breaker are opened, the valve mechanism permits a high pressure SF_6 gas from the reservoir to flow towards the arc interruption chamber. The fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the SF_6 gas to let out through these holes after flowing along and across the arc. The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material. Since SF_6 gas is costly, it is reconditioned and reclaimed by suitable auxiliary sytem after each operation of the breaker.

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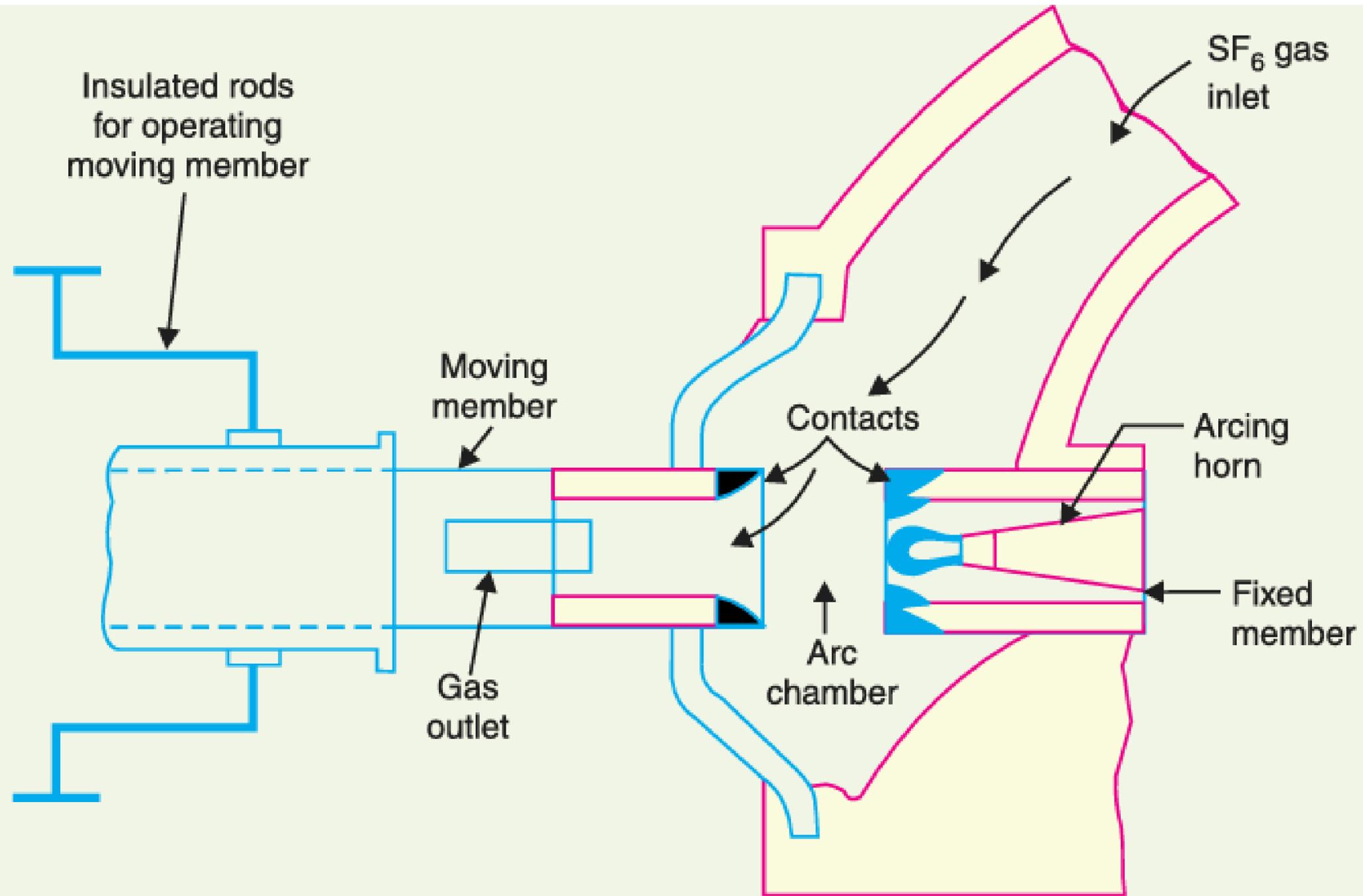
Sulphur Hexaflouride (SF6) Circuit Breakers

Fig. 19.11

Sulphur Hexaflouride (SF6) Circuit Breakers

    Advantages. Due to the superior arc quenching properties of SF_6 gas, the SF_6 circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below :

    (*i*) Due to the superior arc quenching property of SF_6, such circuit breakers have very short arcing time.

    (*ii*) Since the dielectric strength of SF_6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.

    (*iii*) The SF_6 circuit breaker gives noiselss operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.

    (*iv*) The closed gas enclosure keeps the interior dry so that there is no moisture problem.

    (*v*) There is no risk of fire in such breakers because SF_6 gas is non-inflammable.

    (*vi*) There are no carbon deposits so that tracking and insulation problems are eliminated.

    (*vii*) The SF_6 breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.

    (*viii*) Since SF_6 breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists *e.g.,* coal mines.

Disadvantages

    (*i*) SF_6 breakers are costly due to the high cost of SF_6.

    (*ii*) Since SF_6 gas has to be reconditioned after every operation of the breaker, additional equip-ment is requried for this purpose.

Vacuum Circuit Breakers (VCB)

Principle. The production of arc in a vacuum circuit breaker and its extinction can be explained as follows : When the contacts of the breaker are opened in vacuum (10^{-7} to 10^{-5} torr), an arc is produced between the contacts by the ionisation of metal vapours of contacts*. However, the arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc rapidly condense on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. The reader may note the salient feature of vacuum as an arc quenching medium. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fast rate of recovery of dielectric strength in vacuum.

Construction. Fig. 19.12 shows the parts of a typical vacuum circuit breaker. It consists of fixed contact, moving contact and arc shield mounted inside a vacuum chamber. The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak. A glass vessel or ceramic vessel is used as the outer insulating body. The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.

Vacuum Circuit Breakers (VCB)

Working. When the breaker operates, the moving contact separates from the fixed contact and an arc is struck between the contacts. The production of arc is due to the ionisation of metal ions and depends very much upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (say 0·625 cm).

Applications. For a country like India, where distances are quite large and accessibility to remote areas difficult, the installation of such outdoor, maintenance free circuit breakers should prove a definite advantage. Vacuum circuit breakers are being employed for outdoor applications ranging from 22 kV to 66 kV. Even with limited rating of say 60 to 100 MVA, they are suitable for a majority of applications in rural areas.
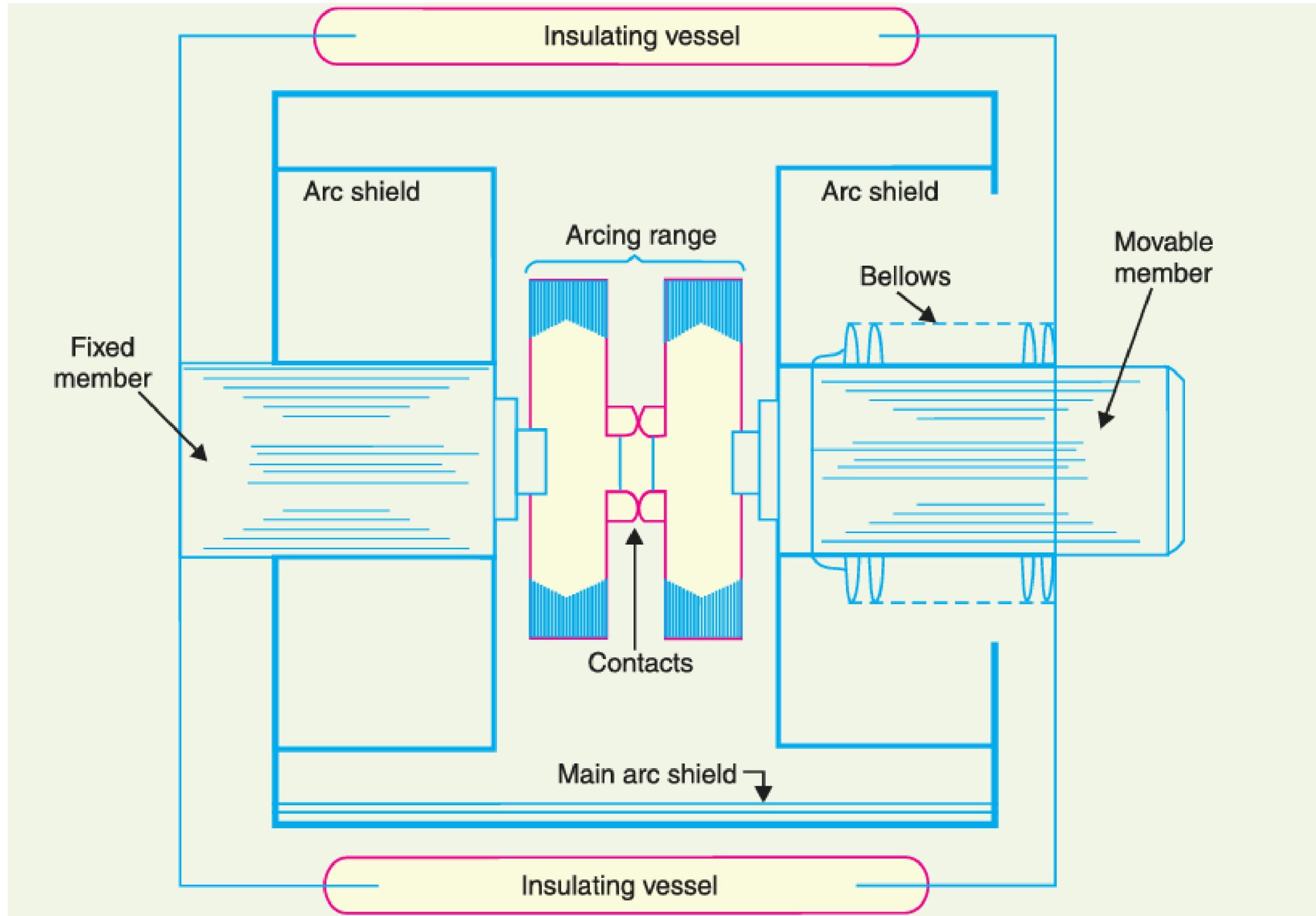
Vacuum Circuit Breakers (VCB)

Fig. 19.12

Vacuum Circuit Breakers (VCB)

Advantages. Vacuum circuit breakers have the following advantages :

(i) They are compact, reliable and have longer life.

(ii) There are no fire hazards.

(iii) There is no generation of gas during and after operation.

(iv) They can interrupt any fault current. The outstanding feature of a VCB is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.

(v) They require little maintenance and are quiet in operation.

(vi) They can successfully withstand lightning surges.

(vii) They have low arc energy.

(viii) They have low inertia and hence require smaller power for control mechanism.

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Review Class

University of Global Village (UGV), Barishal

THANK YOU

End of Content