

Switchgear and Protection (315334)

MSBTE K-Scheme · Model Question Paper — Set B · Model Answers

Q.1

a) Components of protective system.

2 M

1. **Instrument transformers (CT and PT)** — feed reduced current and voltage to relays.
2. **Protective relay** — senses the fault and closes the trip circuit.
3. **Circuit breaker** — interrupts the fault current and isolates the faulty section.
4. **Trip circuit with DC battery** — energises the trip coil of the CB (also fuses and pilot wires where used).

(Any four, ½ M each)

b) Pre-arcing time and cut-off current.

2 M

i) Pre-arcing (melting) time: the time from the start of the fault current to the instant the fuse element melts and the arc is initiated.

ii) Cut-off current: the maximum (instantaneous) value of current actually reached before the fuse element melts. In an HRC fuse it is much less than the peak of the prospective current.

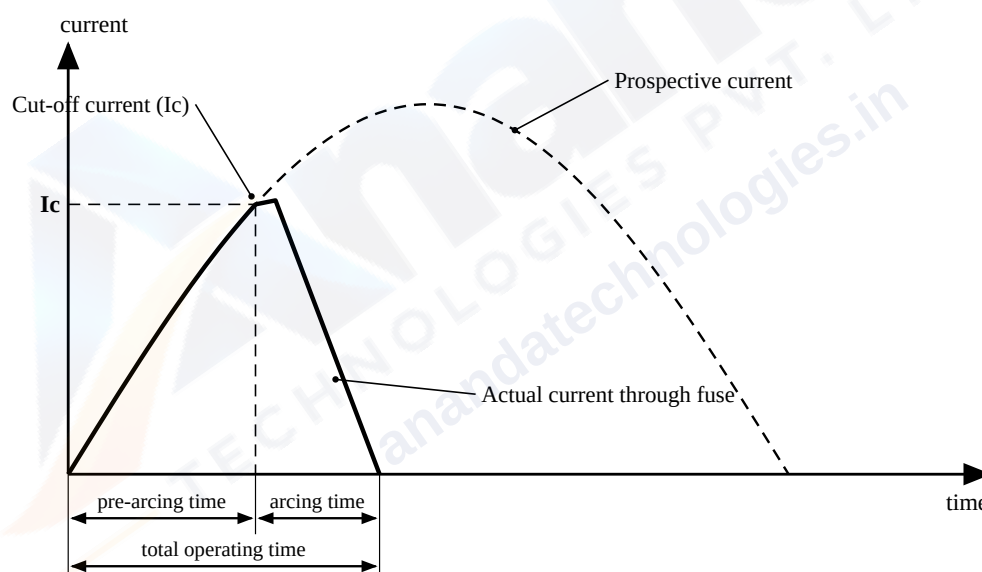


Fig.: Cut-off action of HRC fuse — terms related to fuse operation

(1 M each)

c) Selectivity and reliability.

2 M

Selectivity: the ability of the protective system to select and disconnect only the faulty part, leaving the rest of the system in service (also called discrimination).

Reliability: the ability of the relay to operate correctly whenever a fault occurs within its zone and not to operate otherwise. It depends on good design, simple construction, quality components and proper maintenance.

(1 M each)

d) Pick-up and reset current.

2 M

i) Pick-up current: the minimum current in the relay coil at which the relay just starts to operate and closes its contacts.

ii) Reset (drop-off) current: the maximum current below which an operated relay returns to its original (reset) position. Reset ratio = reset current / pick-up current (less than 1).

(1 M each)

e) Limitations of static relays.

2 M

1. Characteristics of semiconductor devices change with **temperature** and ageing.
2. Voltage transients / spikes can damage the components; surge protection is needed.
3. Need a separate **auxiliary DC supply**.
4. Low short-time overload capacity compared to electromagnetic relays; need skilled persons for maintenance.

(Any two, 1 M each)

f) Faults in power transformer.

2 M

1. Winding faults — phase-to-earth and phase-to-phase faults
2. Inter-turn faults
3. Core faults (insulation failure of laminations, hot spots)
4. Tank faults — oil leakage, low oil level
5. Overheating due to overload / failure of cooling
6. Through faults (external short circuits) and over-fluxing

(Any four, ½ M each)

g) MCB vs MCCB.

2 M

Sr.	MCB	MCCB
1	Current rating up to about 100 – 125 A.	Current rating from about 10 A up to about 2500 A.
2	Breaking capacity low — up to about 10 kA.	Breaking capacity high — up to about 100 kA.
3	Trip setting is fixed (not adjustable).	Trip setting (thermal / magnetic) is generally adjustable.
4	Used in domestic and light commercial circuits.	Used in industrial feeders and main incomers.

(Any two, 1 M each)

Q.2

a) Need of reactors; ring and tie-bar systems.

4 M

Need: A current limiting reactor (coil of large inductive reactance, low resistance) limits the short-circuit current to a value which the circuit breakers can safely interrupt, reduces mechanical and

thermal stresses on equipment, localises the fault and keeps the voltage of healthy sections, and helps to maintain stability.

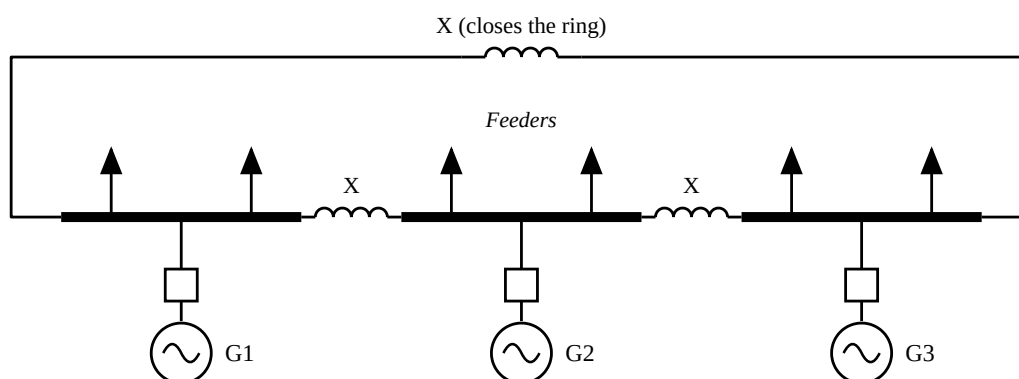


Fig.: Bus-bar reactors — ring system

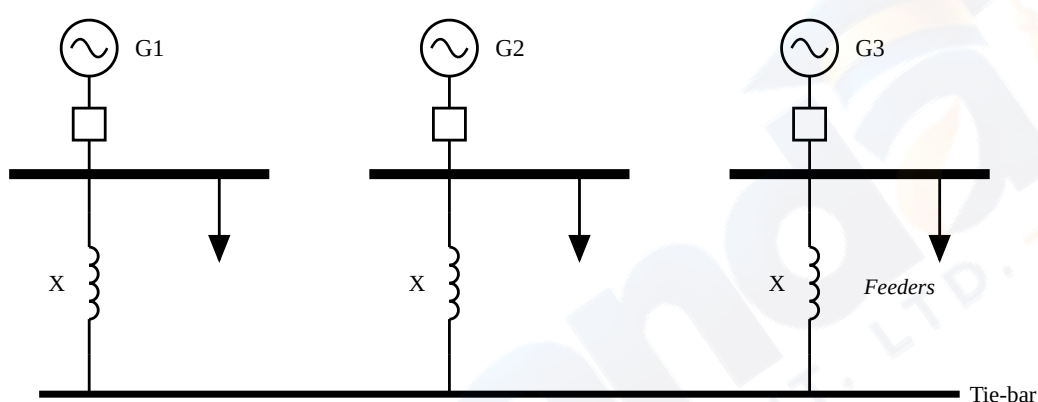


Fig.: Bus-bar reactors — tie-bar system

- **Ring system:** each bus section (fed by one generator) is connected to the adjacent sections through a reactor. Normally very little current flows through the reactors; for a fault on one section, the feed from other sections is limited by the reactors.
- **Tie-bar system:** each section is connected to a common tie-bar through a reactor. Current between any two sections passes through two reactors in series, so each reactor can have half the value; sections can be added without changing the reactors (needs an extra bus-bar).

(Need 1 M, two diagrams 2 M, explanation 1 M)

b) Arc voltage, restriking voltage, recovery voltage, RRRV.

4 M

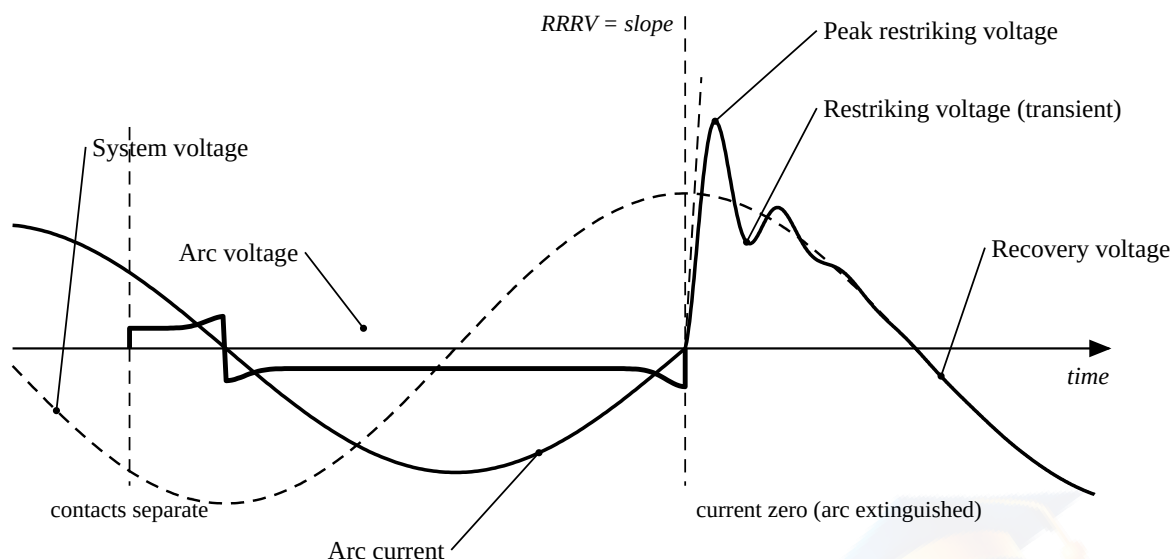


Fig.: Arc voltage, restriking voltage and recovery voltage

- **Arc voltage:** the voltage across the contacts while the arc persists. It is low, nearly flat (in phase with the current) and rises to a peak near current zero.
- **Restriking voltage:** the transient (high-frequency) voltage that appears across the contacts at or near current zero during the arcing period.
- **Recovery voltage:** the normal power-frequency (RMS) voltage that appears across the contacts after final arc extinction.
- **RRRV (rate of rise of restriking voltage):** slope of the restriking voltage curve, expressed in kV/ μ s. Higher RRRV gives more chance of the arc restriking.

(Waveform 2 M, four terms 2 M)

c) HRC cartridge fuse.

4 M

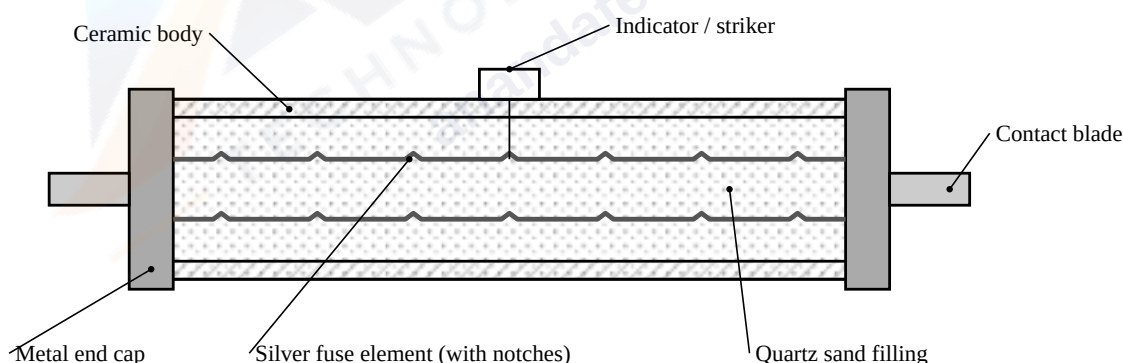


Fig.: Construction of HRC cartridge fuse

- Heat-resisting **ceramic body** with metal **end caps** and contact blades.
- **Silver fuse elements** (with notches / reduced sections) welded to the end caps.
- Space inside filled with **quartz sand** (arc-quenching filler). An indicator / striker shows the operated fuse.

- **Working:** on a short circuit the element melts at the notches before the current reaches its peak; silver vapour reacts with quartz to form high-resistance glass-like substance which quenches the arc — current is cut off early.

Advantages: high breaking capacity; current-limiting (cut-off) action; very fast; no maintenance and consistent performance; cheaper than a CB of equal breaking capacity.

(Sketch 2 M, construction 1 M, advantages 1 M)

d) Principle of impedance relay.

4 M

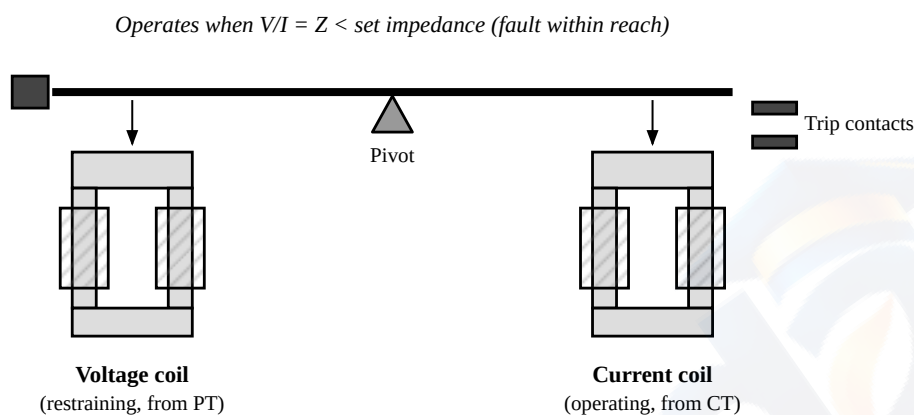


Fig.: Impedance (distance) relay — balanced beam type

- It compares the **voltage** (from PT) with the **current** (from CT) at the relay point, i.e. measures the impedance V/I up to the fault.
- The current coil produces the operating torque ($\propto I^2$); the voltage coil produces the restraining torque ($\propto V^2$).
- Under normal load, V/I is large (load impedance) and the beam stays reset. For a fault within the protected length, V falls and I rises, so $V/I = Z$ becomes **less than the set impedance** — the beam tilts and the trip contacts close.
- Since line impedance is proportional to length, the relay operates for faults up to a set distance — hence called a distance relay. On the R–X diagram its characteristic is a circle with centre at the origin.

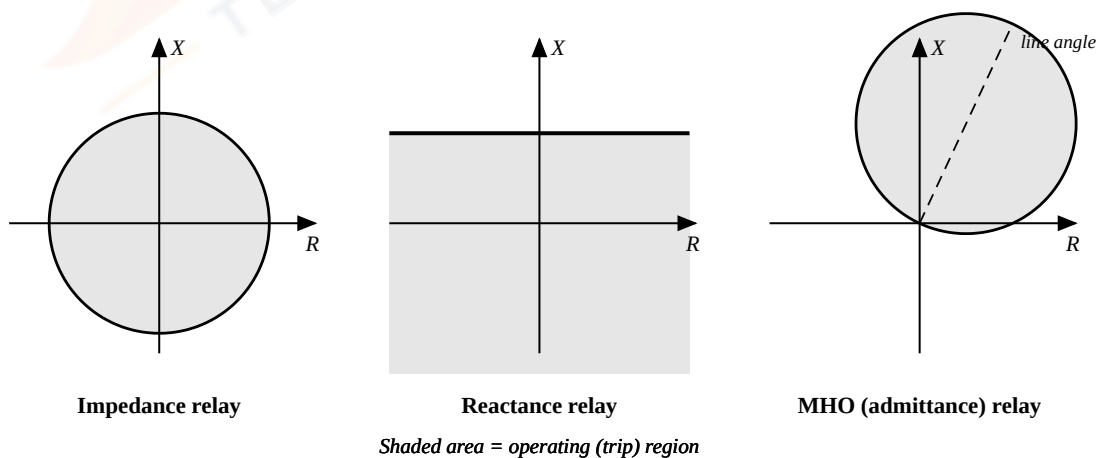


Fig.: Operating characteristics of distance relays on R–X diagram

(Diagram 2 M, principle 2 M)

Q.3

a) Fault MVA and fault current (two generators).

4 M

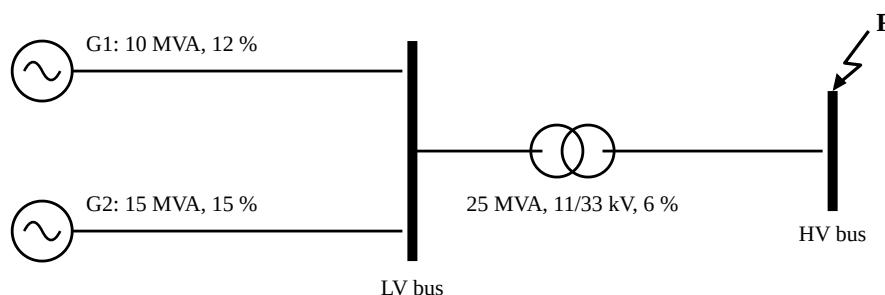


Fig.: Single-line diagram

Choose **base = 25 MVA**.

%X of G1 on base = $12 \times 25/10 = 30.00\%$; %X of G2 on base = $15 \times 25/15 = 25.00\%$; %X of transformer = **6 %**

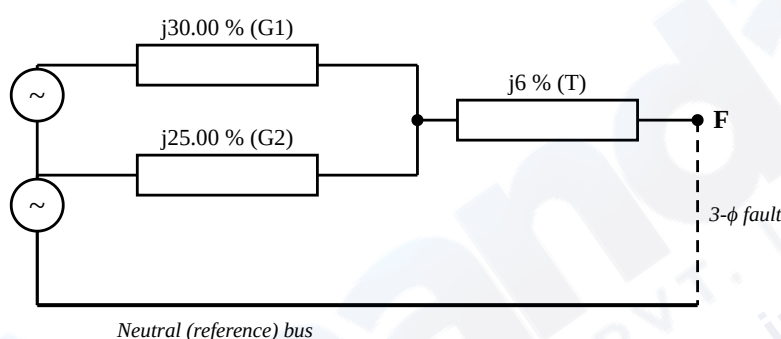


Fig.: Reactance diagram (per-unit on common base)

G1 and G2 are in parallel: $X_p = (30.00 \times 25.00) / (30.00 + 25.00) = 13.636\%$

Total reactance up to fault = $13.636 + 6 = 19.636\%$

Fault MVA = Base MVA $\times 100 / \%X = 25 \times 100 / 19.636 = 127.31$ MVA

Full-load current at base on 33 kV side = $25,000 / (\sqrt{3} \times 33) = 437.39$ A

Fault current = $437.39 \times 100 / 19.636 = 2,227.4$ A (check: $127.31 \times 10^6 / (\sqrt{3} \times 33 \times 10^3) = 2,227.4$ A)

(Base conversion 1 M, equivalent reactance 1 M, fault MVA 1 M, fault current 1 M)

b) Isolator vs fuse vs circuit breaker.

4 M

Point	Isolator	Fuse	Circuit breaker
Function	Isolates a circuit for maintenance (no-load switch)	Detects and interrupts over-current / fault	Interrupts load and fault current; detection by relay
Operation on load	Off-load only	Operates automatically on fault	On-load and on fault
Arc quenching	No arc-quenching arrangement	Filler (quartz) quenches arc	Arc quenched by oil, air, SF6 or vacuum

Point	Isolator	Fuse	Circuit breaker
Operation	Manual (or motor) operated	Automatic, one time; element replaced	Manual / automatic, repeated operation; reset
Cost	Cheapest	Cheap	Costly

(Any four points, 1 M each)

c) Back-up protection.

4 M

Back-up protection is a second line of defence which operates (after a time delay) when the primary protection fails to clear the fault — due to failure of the relay, CT/PT, DC supply, trip circuit or circuit breaker.

- **Relay back-up (local):** a duplicate relay at the same station trips the same circuit breaker if the main relay fails.
- **Breaker back-up (local):** if the CB fails to open, the adjacent breakers at the same station are tripped.
- **Remote back-up:** relays at the neighbouring (upstream) station trip their own breaker after a time delay Δt . Independent of the faulty station, but a larger part of the system is disconnected.

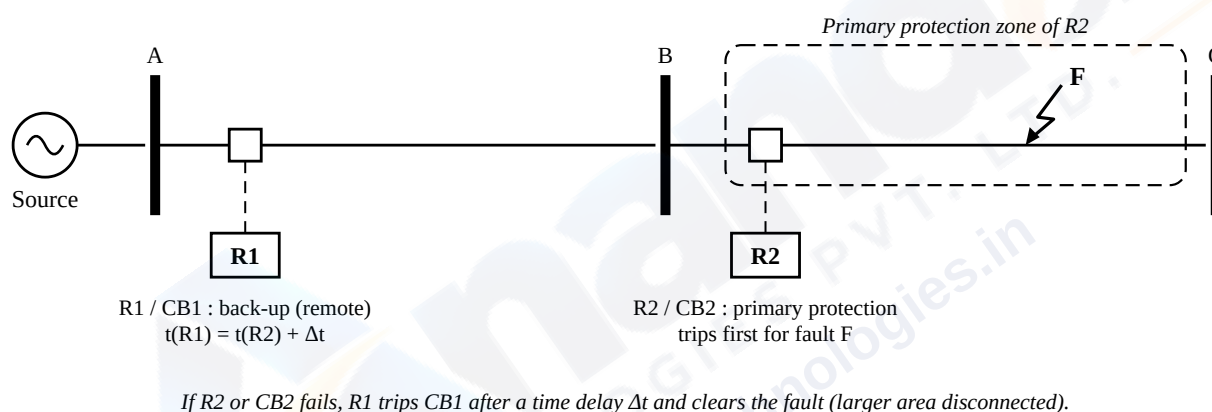


Fig.: Back-up protection of a radial system

(Definition 1 M, types 1 M, diagram 2 M)

d) Thermal overload relay.

4 M

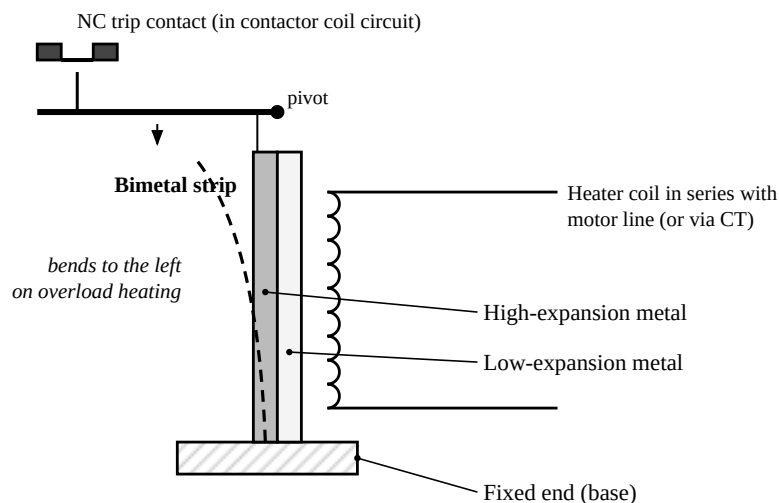


Fig.: Thermal (bimetallic) overload relay

- A **bimetallic strip** made of two metals of different coefficients of expansion (e.g. invar and brass / steel) is fixed at one end.
- A **heater coil** carrying the motor current (directly or through CT) is wound near / around the strip.
- On overload, extra heat bends the strip towards the low-expansion side; after a time depending on the overload (inverse time), it pushes the trip lever and opens the NC contact in the contactor coil circuit — the motor is disconnected.
- It has a time lag, so it does not trip on short starting currents; reset is manual or automatic after cooling.

(Sketch 2 M, working 2 M)

Q.4

a) IDMT relay: operating time and TMS.

4 M

Pick-up current = 100 % of 5 A = **5.00 A**; relay current = $5000 \times 5/500 = \mathbf{50.00\ A}$

PSM = $50.00 / 5.00 = \mathbf{10}$; from the curve, time at PSM 10 (TMS = 1) = **2.97 s**

i) Operating time = TMS $\times$ curve time = $0.3 \times 2.97 = \mathbf{0.891\ s}$

ii) Required TMS for 1.2 s = $1.2 / 2.97 = \mathbf{0.404}$ (set TMS ≈ 0.4 , giving 1.188 s)

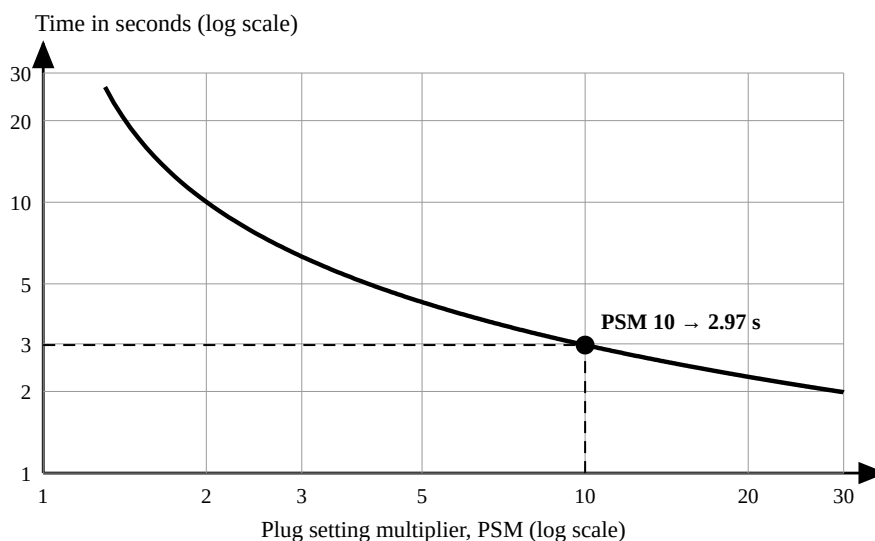


Fig.: Time / PSM curve of a standard IDMT relay (TMS = 1)

(PSM 1 M, curve time 1 M, operating time 1 M, TMS 1 M)

b) Buchholz relay — construction and operation.

4 M

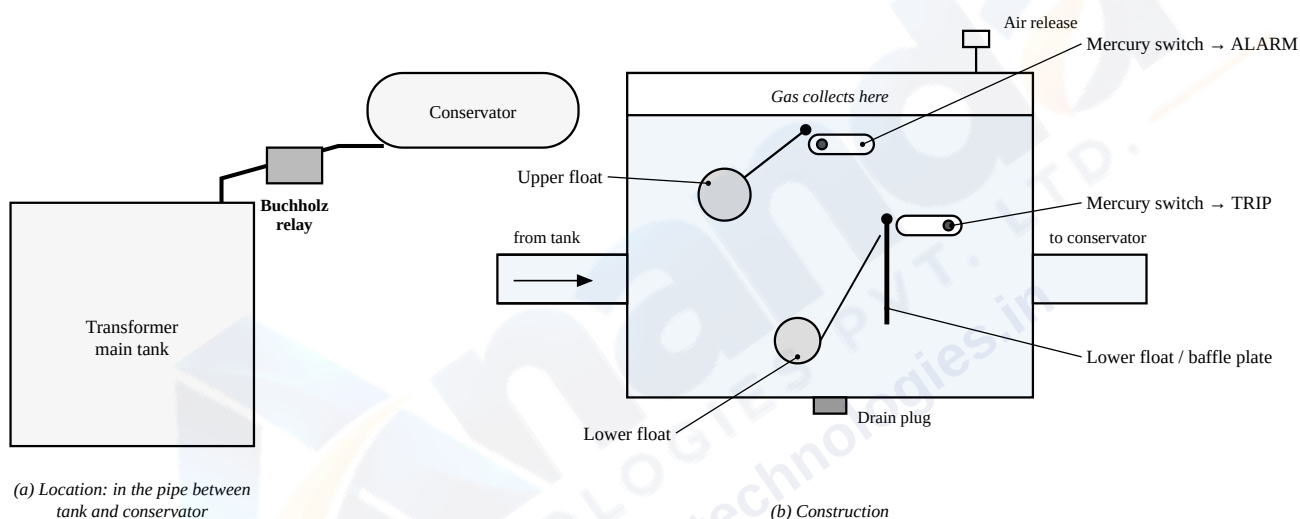


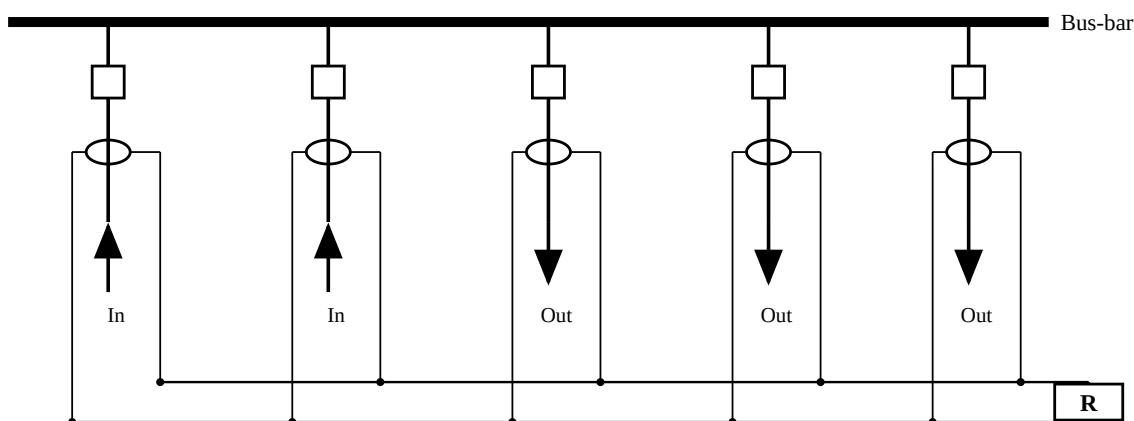
Fig.: Buchholz relay — construction and location

- **Construction:** an oil-filled domed chamber in the pipe between transformer tank and conservator. It contains an **upper float** with a mercury switch connected to the **alarm** circuit and a **lower float / baffle plate** with a mercury switch connected to the **trip** circuit; an air-release cock at top and a drain plug at bottom.
- **Incipient (minor) fault:** heat decomposes the oil slowly; gas bubbles rise and collect at the top of the chamber, the oil level falls, the upper float tilts and closes the **alarm** circuit.
- **Severe fault:** a large volume of gas is produced suddenly; the oil surges towards the conservator, deflects the lower float / baffle and closes the **trip** circuit — CB opens.
- The collected gas can be tested to know the nature of the fault.

(Sketch 2 M, operation 2 M)

c) Differential protection of bus-bars.

4 M



In = incoming feeder, Out = outgoing feeder.

All CT secondaries in parallel: $\Sigma \text{ incoming} = \Sigma \text{ outgoing} \rightarrow \text{no relay current. Bus fault} \rightarrow \text{relay trips all breakers.}$

Fig.: Differential (circulating current) protection of bus-bars

- CTs of identical ratio are provided in every circuit (incoming and outgoing) connected to the bus-bar; their secondaries are connected in **parallel** with a relay across them.
- By Kirchhoff's current law, under normal load and external faults the sum of incoming currents equals the sum of outgoing currents, so the CT secondary currents cancel and **no current** flows through the relay.
- For a fault on the bus-bar (inside the zone), the currents no longer balance; the difference flows through the relay, which trips all breakers connected to the bus.
- High-impedance relays are used so that CT saturation during heavy through faults does not cause mal-operation.

(Diagram 2 M, explanation 2 M)

d) Single phasing: causes, effects, protection.

4 M

Causes: blowing of one fuse, broken conductor / open circuit in one line, loose or defective contact in starter / switch, failure of one phase of the supply transformer.

Effects: a running motor continues to run on two phases, so the remaining phases draw much higher current (about $\sqrt{3}$ times or more); negative-sequence current causes rotor heating; reduced torque, noise and vibration; the stator winding overheats and may burn. A stationary motor does not start but hums and draws heavy current.

Protection: a **single phasing preventer (SPP)** senses the unbalance (negative sequence voltage / current) and de-energises the contactor; thermal overload relays with differential (single-phasing) mechanism also help.

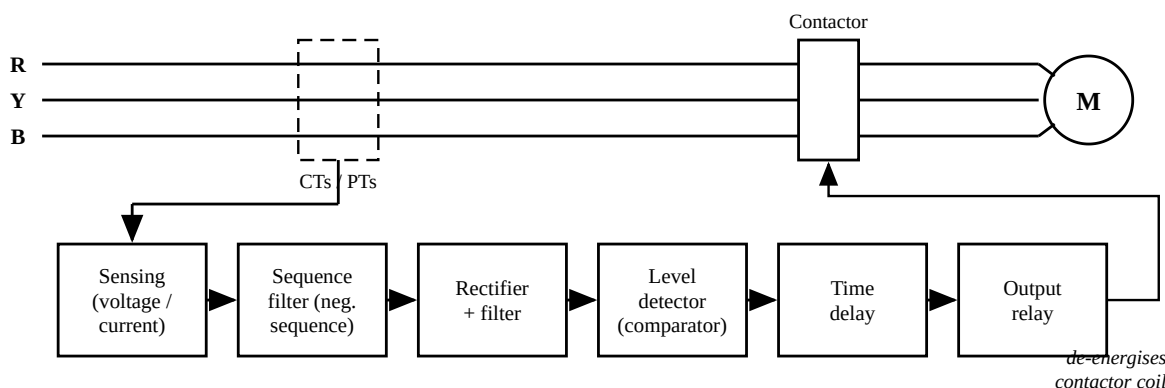


Fig.: Block diagram of a single phasing preventer

(Causes 1 M, effects 1 M, protection with sketch 2 M)

e) Specifications of protective CT and PT.

4 M

Current transformer (protection):

- Rated primary current (e.g. 400 A) and rated secondary current (1 A or 5 A).
- Rated burden in VA (e.g. 5, 10, 15, 30 VA).
- Accuracy class for protection — **5P or 10P** with accuracy limit factor (e.g. **15 VA 5P10**).
- Rated short-time thermal current (kA for 1 s or 3 s), insulation level / highest system voltage and frequency.

Potential transformer (protection):

- Rated primary voltage (e.g. 11 kV or $11/\sqrt{3}$ kV) and secondary voltage (110 V or $110/\sqrt{3}$ V).
- Rated burden in VA.
- Accuracy class for protection — **3P or 6P**.
- Rated voltage factor (e.g. 1.2 continuous, 1.5 / 1.9 for 30 s), insulation level, number of phases and connection.

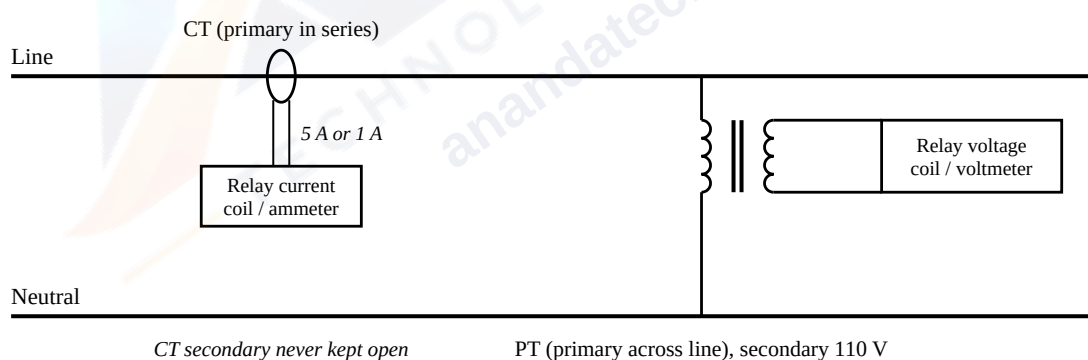


Fig.: Connection of protective CT and PT

(CT specifications 2 M, PT specifications 2 M)

Q.5

a) Vacuum circuit breaker.

6 M

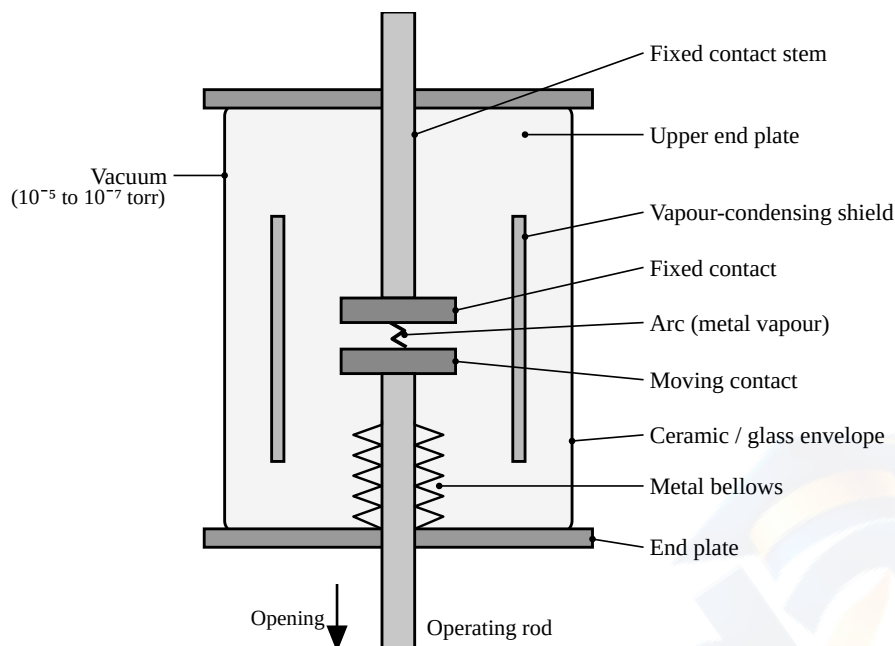


Fig.: Vacuum interrupter of a VCB (contacts open)

Working: When the contacts separate in vacuum, the arc is formed only by **metal vapour** released from the contact surfaces. As the current approaches zero, the rate of vapour emission falls; at current zero the vapour condenses on the contacts and on the metal shield within a few microseconds. Since there is practically no gas to ionise, the **dielectric strength recovers very rapidly** and the arc does not restrike. Metal bellows allow the moving contact to move without breaking the vacuum.

Advantages:

1. Compact, light and reliable; sealed interrupter needs almost no maintenance.
2. Very fast recovery of dielectric strength; short arc and low arc energy.
3. Long contact life — suitable for frequent operation.
4. No fire or explosion hazard; silent operation; no gas or oil to handle.

Applications: indoor switchgear from 3.3 kV to 33 kV, ring main units, switching of capacitor banks, furnaces, motors and traction.

(Sketch 2 M, working 2 M, advantages and applications 2 M)

b) Microprocessor based IDMT relay — flow chart.

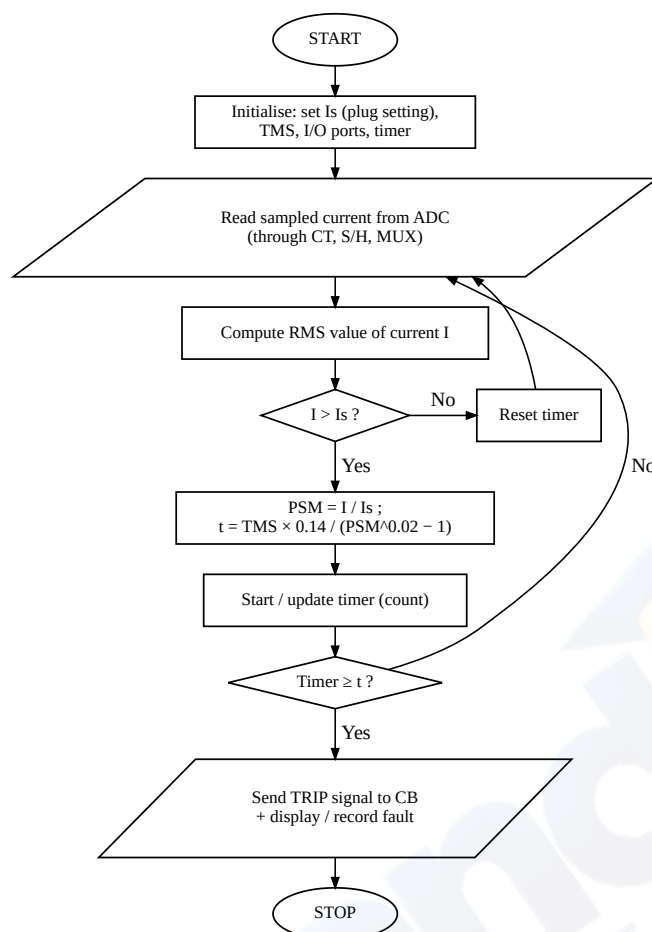


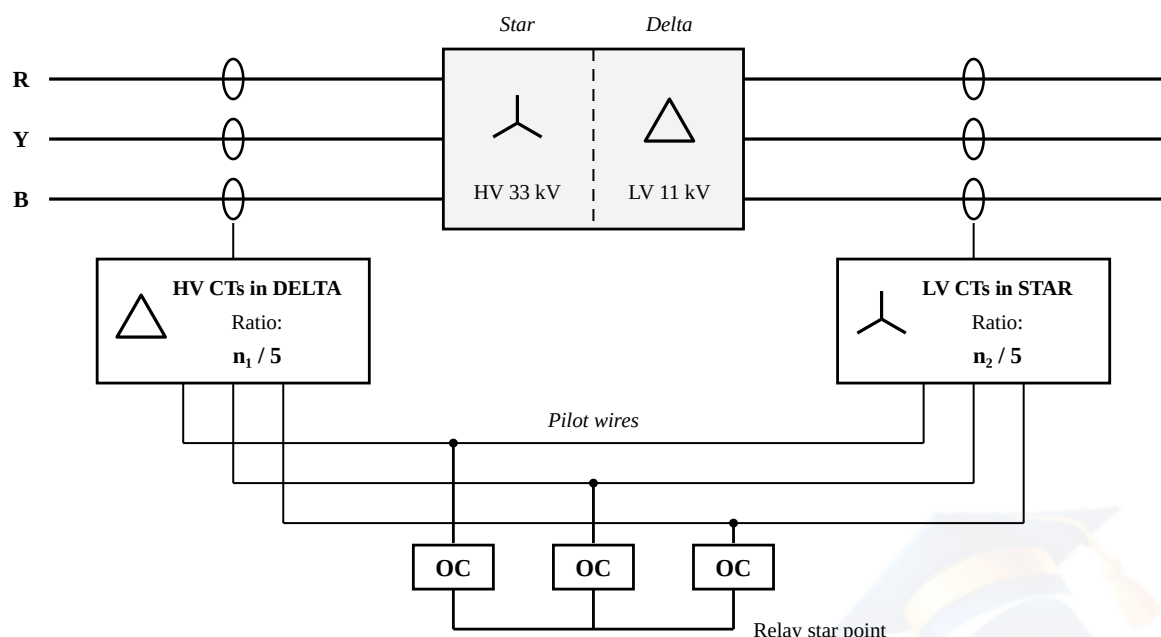
Fig.: Flow chart of microprocessor based IDMT over-current relay

1. The relay settings (plug setting I_s , TMS) are stored in memory; the microprocessor initialises I/O ports and timer.
2. The CT current is conditioned, sampled (S/H), multiplexed and converted by the ADC; the microprocessor reads the samples.
3. The RMS value of current is computed and compared with the pick-up value.
4. If $I > I_s$, PSM is calculated and the operating time is computed from the stored IDMT equation (or look-up table) and multiplied by TMS.
5. A timer / counter is started. If the current remains above pick-up till the time elapses, a **trip signal** is sent through the output interface to the trip coil; the fault is displayed and recorded.
6. If the current falls below pick-up, the timer is reset and monitoring continues.

(Flow chart 3 M, explanation 3 M)

c) Merz-Price protection of power transformer; difficulties.

6 M



CTs on the star winding side are connected in delta and on the delta side in star (corrects 30° shift).

Fig.: Merz-Price (differential) protection of a star-delta transformer

Working: CTs are provided on both sides of the transformer and their secondaries are connected by pilot wires with relay operating coils between them. CT ratios are chosen so that the secondary currents are equal under normal load and external faults — no current flows in the relays. An internal fault upsets this balance and the differential current operates the relay, which trips the CBs on both sides.

Difficulty	How it is overcome
Primary and secondary currents differ by the turns ratio; CT ratios may not match exactly	CT ratios chosen in inverse ratio of voltage; interposing (auxiliary) CTs for fine matching
30° phase shift between primary and secondary line currents of a star-delta transformer	CTs on the star side are connected in delta and CTs on the delta side in star
Magnetising inrush current (up to 6–10 times rated) flows only in the primary on switching — appears as differential current	Harmonic restraint (second harmonic) relay, or time delay
On-load tap changing changes the ratio and causes unbalance	Percentage (biased) differential relay
Zero-sequence current on earthed star side for external earth faults	Delta-connected CTs on star side filter out zero-sequence current

(Diagram 2 M, working 2 M, difficulties with remedies 2 M)

Q.6

a) Selection of CB; Ring Main Unit.

6 M

i) Factors for selection of circuit breaker:

1. Rated voltage and insulation level of the system
2. Rated normal current
3. Rated breaking capacity (symmetrical / asymmetrical) and making capacity
4. Rated short-time current and operating duty / frequency of operation
5. Type of installation (indoor / outdoor) and arc-quenching medium
6. Space, maintenance and cost

ii) Ring Main Unit (RMU): a compact, factory-assembled, totally enclosed switchgear unit used at distribution substations on a ring main (11 kV / 22 kV). It normally contains **two load-break switches** for the incoming and outgoing ring cables and **one circuit breaker or fuse-switch** for the distribution transformer, with earthing switches.

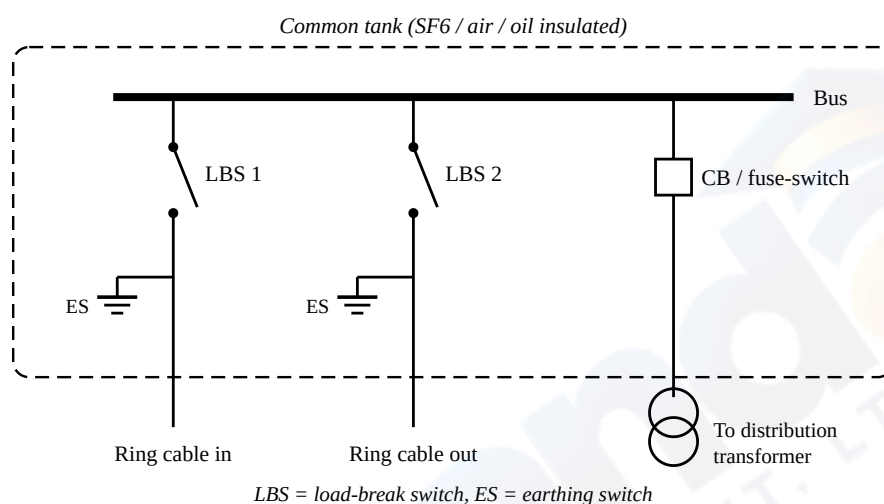


Fig.: Ring Main Unit (2 load-break switches + 1 circuit-breaker / fuse-switch)

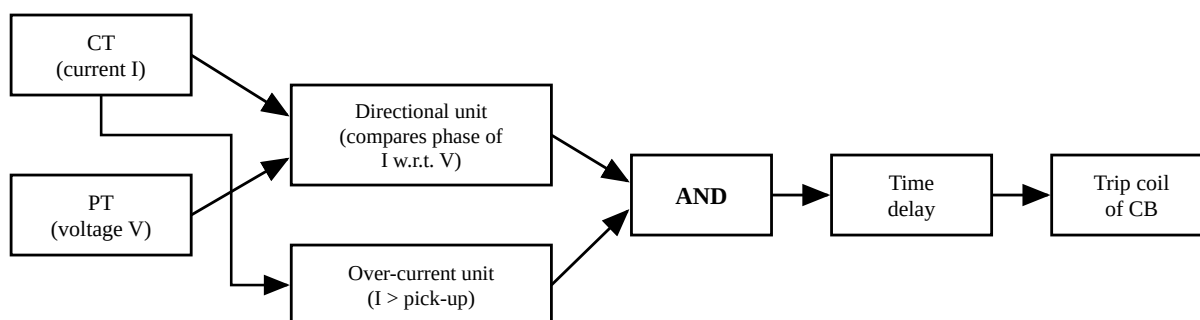
Classification: (a) By insulation — gas (SF₆) insulated, oil insulated, air insulated (solid / air). (b) By installation — indoor and outdoor. (c) By design — extensible and non-extensible.

(Four factors 2 M, RMU 2 M, classification 2 M)

b) Directional relay — need and operation.

6 M

Need: In ring mains, parallel feeders and interconnected systems, fault current can flow in either direction through a relay location. A non-directional over-current relay cannot tell the direction and may trip a healthy line. A **directional relay** operates only when the current (power) flows in a particular direction (normally away from the bus into the line) and exceeds the setting, so correct selectivity is obtained.



Relay trips only when the fault current flows in the set (reverse) direction AND exceeds the pick-up value.

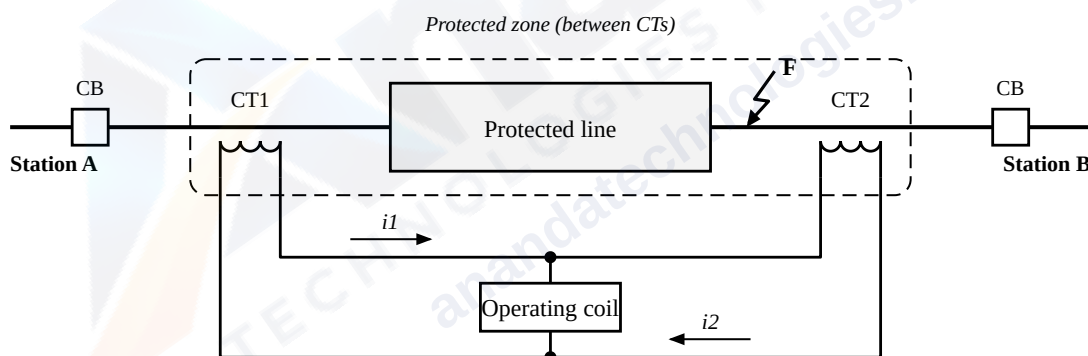
Fig.: Block diagram of directional over-current relay

- The relay gets **current** from the CT and a **polarising voltage** from the PT.
- The **directional unit** compares the phase angle of the current with that of the voltage. Torque $\propto V I \cos(\theta - \tau)$; it is positive only when the current lies within $\pm 90^\circ$ of the maximum-torque line — i.e. power flows in the tripping direction.
- The **over-current unit** checks that the current is above the pick-up value.
- When both conditions are satisfied (AND), after the set time delay the trip coil of the CB is energised.
- In the induction-type construction the voltage coil is on the upper magnet and the current coil on the lower magnet; the directional contacts are in series with the over-current element.

(Need 2 M, block diagram 2 M, operation 2 M)

c) Circulating current pilot-wire protection of a line; limitations.

6 M



Healthy / external fault: $i_1 = i_2$, no current in relay. Internal fault: $(i_1 - i_2)$ flows $\rightarrow$ relay operates.

Fig.: Circulating current (Merz-Price) pilot-wire protection of a transmission line

- Identical CTs are installed at both ends of the protected line; their secondaries are connected by pilot wires so that the secondary current **circulates** round the pilot loop.
- The relay operating coil is connected across the pilots at the mid (equipotential) point.
- Normal load / external fault: currents entering and leaving the line are equal, so CT secondary currents are equal — no current in the relay.
- Internal fault: the currents at the two ends differ (or the far end feeds in the reverse direction); the difference current flows through the relay, which trips the breakers at both ends.

Limitations:

1. Cost of pilot wires is high for long lines — used only for short lines / feeders.
2. Pilot-wire resistance and capacitance cause unbalance and spill current; CTs must be exactly matched.
3. An open or short circuit in the pilot wires causes mal-operation or failure to trip; pilot supervision is required.
4. Voltages induced in pilots by parallel power lines / earth faults; relays at both ends need accurate equipotential connection.

(Diagram 2 M, working 2 M, limitations 2 M)

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