

Switchgear and Protection (315334)

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

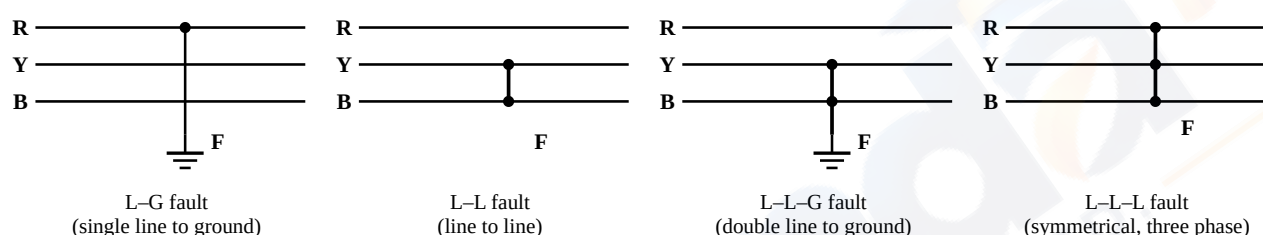
Q.1

a) Types of faults in a 3-phase system.

2 M

1. **Line to ground (L–G) fault** — most frequent (about 70–80 % of faults).
2. **Line to line (L–L) fault.**
3. **Double line to ground (L–L–G) fault.**
4. **Three phase (L–L–L or L–L–L–G) fault** — symmetrical fault, most severe.

(Open-conductor / series faults are also possible.) The first three are **unsymmetrical** faults.



L–G, L–L, L–L–G : unsymmetrical faults · L–L–L (and L–L–L–G) : symmetrical faults

Fig.: Types of faults in a 3-phase system

(Any four, ½ M each)

b) Fusing factor.

2 M

Fusing factor = Minimum fusing current ÷ Current rating of the fuse element.

It is always **greater than 1** because a fuse must carry its rated (normal) current continuously without melting; it should melt only when the current exceeds the rated value by some margin. Hence minimum fusing current > rated current. Typical values: about 1.1 to 1.45 for HRC fuse (close fuse protection) and about 2 for semi-enclosed rewirable fuse.

(Definition 1 M, reason 1 M)

c) Essential qualities of a protective relay.

2 M

1. **Selectivity** — trips only the faulty section, keeping the healthy part in service.
2. **Speed** — operates in the shortest possible time to reduce damage and maintain stability.
3. **Sensitivity** — operates even for the smallest fault current (low pick-up value).
4. **Reliability** — operates correctly every time it is required.
5. **Simplicity** and **Economy** — simple design, low maintenance and cost in proportion to the equipment protected.

(Any four, ½ M each)

d) PSM and TSM.

2 M

i) Plug setting multiplier (PSM): ratio of the fault current in the relay coil to the pick-up (current-setting) current of the relay.

$$\text{PSM} = \text{Secondary fault current} \div (\text{Rated secondary current} \times \text{Current setting})$$

ii) Time setting multiplier (TSM / TMS): the adjustment (0.1 to 1.0) of the travel of the moving system that sets the actual operating time as a fraction of the time obtained from the time/PSM curve at TMS = 1.

$$\text{Actual operating time} = \text{TMS} \times \text{Time from curve (for the given PSM)}$$

(1 M each)

e) Location and purpose of Buchholz relay.

2 M

Location: It is fitted in the pipe connecting the main tank of an oil-immersed transformer to the conservator (used on transformers generally above about 500 kVA).

Purpose: It is a gas-actuated relay which detects internal (incipient) faults below oil level — gives an **alarm** for slow gas formation (minor faults) and **trips** the circuit breaker for severe faults (oil surge).

(Location 1 M, purpose 1 M)

f) Types of isolators.

2 M

1. **Vertical break** type isolator
2. **Horizontal break** type — centre break (double break) and single side break
3. **Pantograph** type isolator

Isolators are off-load devices; they are opened only after the circuit breaker has opened.

(Any three types / correct list 2 M)

g) Abnormal conditions in induction motor.

2 M

1. Overload (mechanical overloading) and overheating
2. Single phasing (loss of one phase)
3. Stator winding faults — phase-to-phase and phase-to-earth faults, inter-turn faults
4. Unbalanced supply voltage / phase reversal
5. Under-voltage
6. Rotor locking (stalling) and bearing failure

(Any four, ½ M each)

Q.2

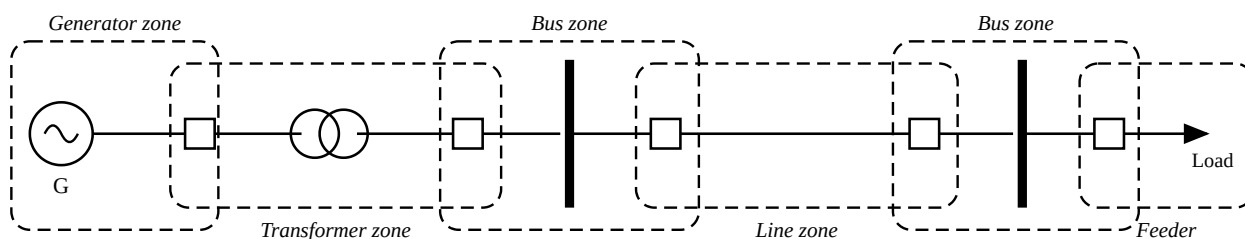
a) Need of protective zones; overlapping zones.

4 M

The power system is divided into a number of **protective zones** — generator, transformer, bus-bar, transmission line, feeder / motor. Each zone has its own protective relays and circuit breakers.

- When a fault occurs within a zone, only the circuit breakers of that zone trip, so the **minimum part** of the system is disconnected (selectivity).

- Adjacent zones are made to **overlap** around each circuit breaker (CTs on both sides of the CB), so that no part of the system is left unprotected (no blind spot).
- The overlap is kept small; a fault in the overlap region trips the breakers of both zones.



CB = circuit breaker. Each breaker lies in the overlap of two zones, so no part of the system is left unprotected.

Fig.: Protective zones (adjacent zones overlap around every circuit breaker)

(Need 2 M, diagram 2 M)

b) Generator and feeder reactors.

4 M

Arrangement	Advantage	Disadvantage
Generator reactor (in series with each generator)	Protects the generator against heavy short-circuit current; useful for old generators of low reactance.	Continuous voltage drop and I^2R loss in the reactor even in normal operation; a feeder fault pulls down the bus voltage, so other feeders are affected.
Feeder reactor (in series with each feeder)	A fault on one feeder does not affect the other feeders; bus-bar voltage is maintained.	No protection to generators for bus-bar faults; voltage drop and copper loss in each feeder under normal load.

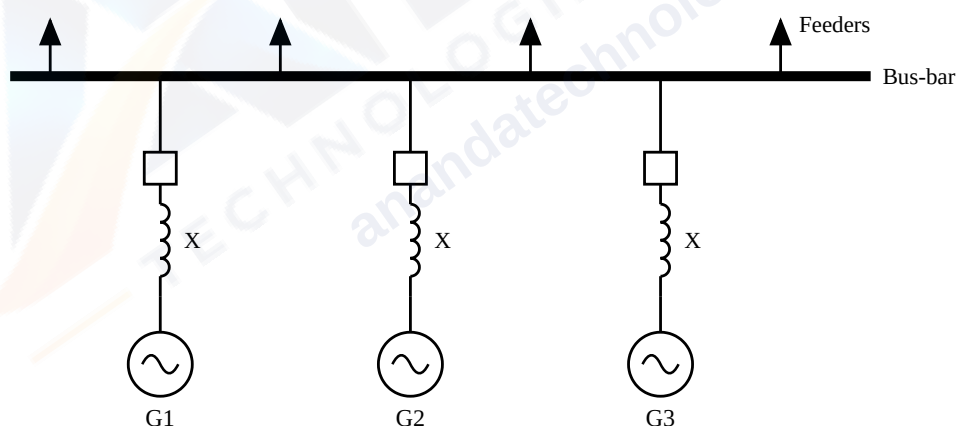


Fig.: Generator reactors (reactor in series with each generator)

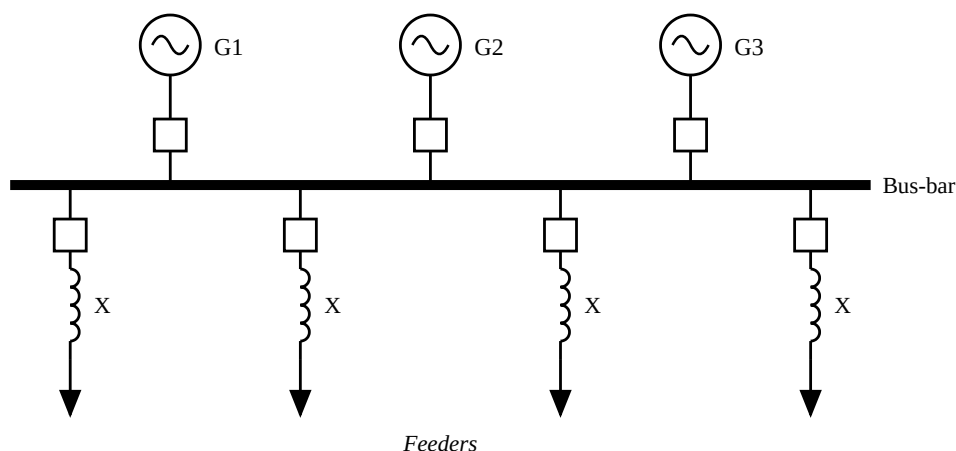


Fig.: Feeder reactors (reactor in series with each feeder)

(Two diagrams 2 M, advantage/disadvantage 2 M)

c) High resistance method of arc extinction.

4 M

In this method the **arc resistance is increased rapidly** with time, so that the arc current is reduced to a value insufficient to maintain the arc and the arc is extinguished. The arc resistance is increased by:

1. **Lengthening the arc** — arc runners (horns) and magnetic blow-out coils drive the arc upwards and make it longer.
2. **Cooling the arc** — contact of the arc with cool chute walls removes heat and de-ionises the gas.
3. **Reducing the cross-section** of the arc — the arc is forced through narrow slots.
4. **Splitting the arc** — splitter plates divide the arc into many short arcs in series, each needing its own voltage drop.

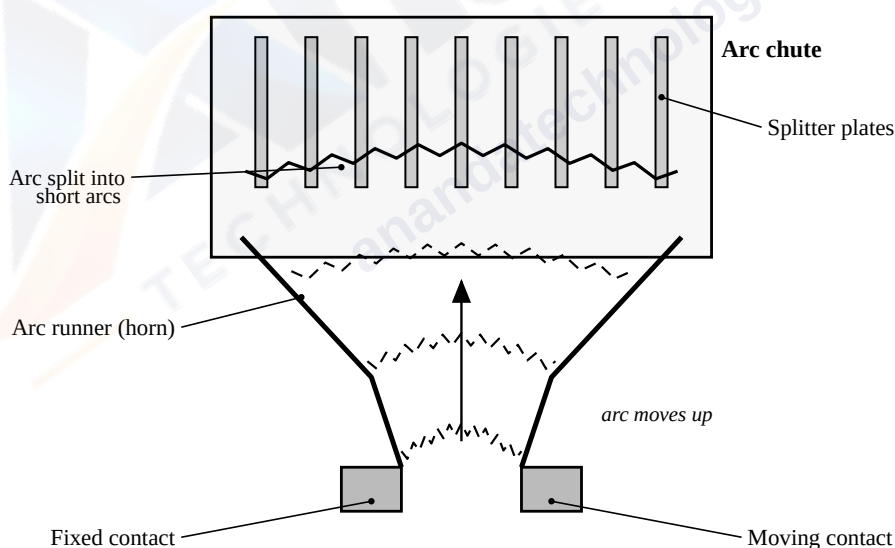


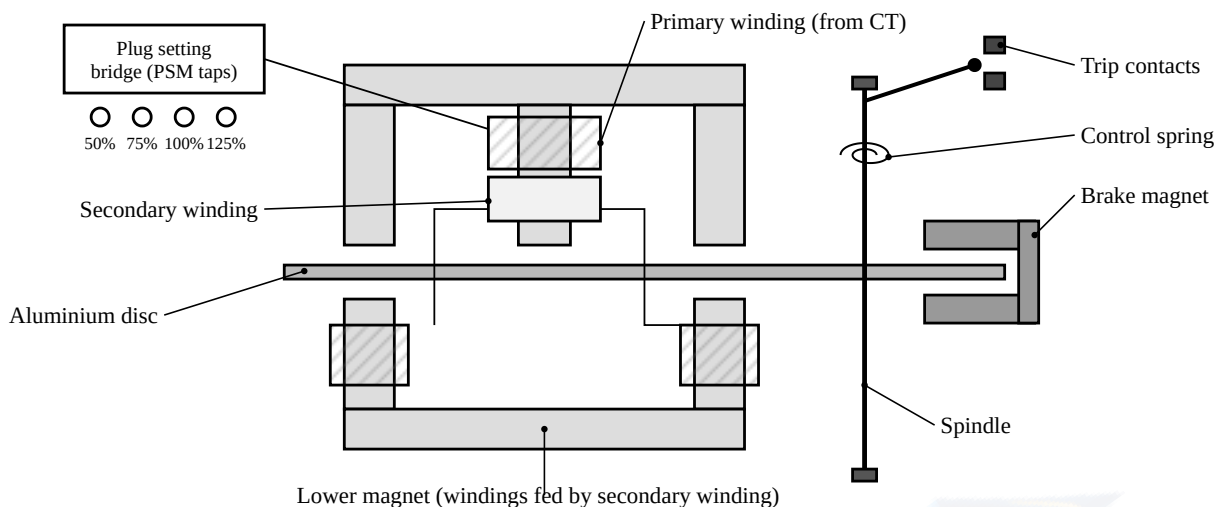
Fig.: High resistance method — arc lengthening, cooling and splitting in an arc chute

The method is used in d.c. breakers and low / medium capacity a.c. breakers (air break CBs). Since large energy is dissipated in the arc, it is not used for high-capacity breakers.

(Explanation 2 M, sketch 2 M)

d) Induction disc type IDMT over-current relay.

4 M



Disc rotates when operating torque exceeds spring torque; disc travel (set by TMS) decides the time.

Fig.: Induction disc type (IDMT) over-current relay — construction

Construction:

- Upper E-shaped electromagnet with **primary winding** on the central limb, fed from the CT; tapings of this winding are brought to a **plug setting bridge** (current setting 50 %–200 %).
- A **secondary winding** on the central limb energises the windings of the **lower magnet**.
- An aluminium **disc** free to rotate between the two magnets, mounted on a spindle carrying the moving contact.
- A **control (spiral) spring** gives restraining torque; a permanent **brake magnet** gives braking torque and controls disc speed.
- The **TMS** adjusts the back-stop, i.e. the distance the disc has to travel to close the contacts.

Working: Fluxes of the upper and lower magnets are displaced in time and space, so eddy currents in the disc produce a driving torque. When the current exceeds the pick-up value, the driving torque exceeds the spring torque and the disc rotates, closing the trip contacts. Larger the current, faster the rotation — inverse time. At high PSM the magnetic circuit saturates, giving a **definite minimum time** (IDMT).

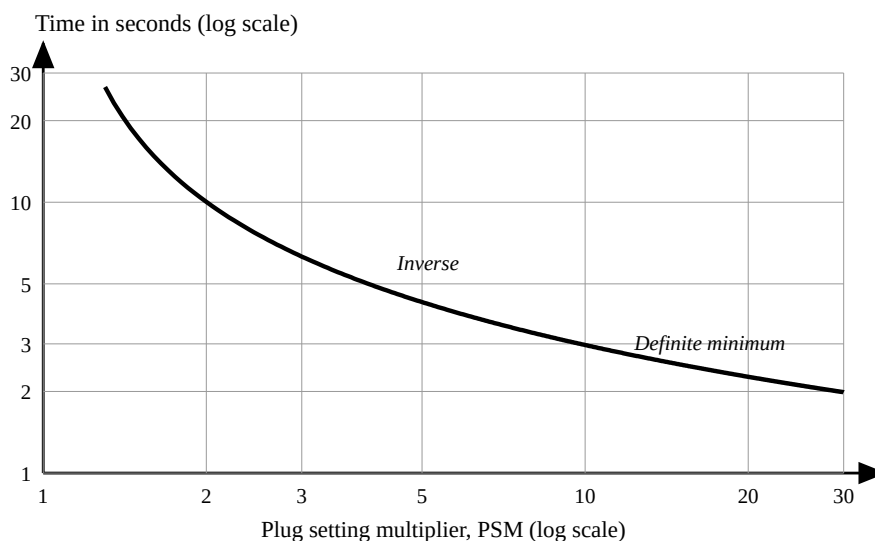


Fig.: Time / PSM curve of a standard IDMT relay (TMS = 1)

(Sketch 2 M, working 2 M)

Q.3

a) Fault current numerical.

4 M

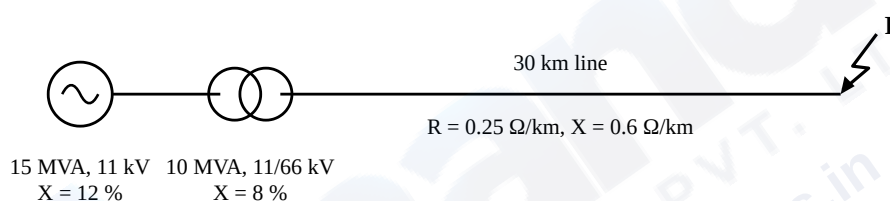


Fig.: Single-line diagram

Choose **base kVA = 10 MVA = 10,000 kVA** (rating of transformer).

Generator: $\%X_G$ on base = $12 \times 10/15 = 8.00 \%$

Transformer: $\%X_T = 8 \%$ (already on 10 MVA)

Line: $R = 30 \times 0.25 = 7.5 \Omega$, $X = 30 \times 0.6 = 18.0 \Omega$ (on 66 kV side)

$$\%R = R \times \text{kVA} / (10 \times \text{kV}^2) = 7.5 \times 10,000 / (10 \times 66^2) = 1.722 \%; \quad \%X = 18.0 \times 10,000 / (10 \times 66^2) = 4.132 \%$$

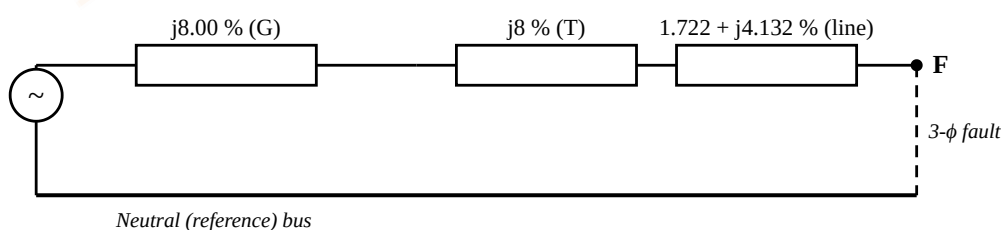


Fig.: Reactance diagram (per-unit on common base)

Total: $\%R = 1.722 \%$, $\%X = 8.00 + 8 + 4.132 = 20.132 \%$; $\%Z = \sqrt{(1.722^2 + 20.132^2)} = 20.206 \%$

Full-load current on 66 kV side at base kVA: $I = 10,000 / (\sqrt{3} \times 66) = 87.48 \text{ A}$

Fault current $I_{SC} = I \times 100 / \%Z = 87.48 \times 100 / 20.206 = 432.9 \text{ A}$ (in the 66 kV line)

Current supplied by the alternator (11 kV side) = $432.9 \times 66/11 = 2,598 \text{ A}$

Fault MVA = Base MVA $\times 100 / \%Z = 10 \times 100 / 20.206 = 49.49 \text{ MVA}$

(Base conversion 1 M, total impedance 1 M, fault current 1 M, fault MVA 1 M)

b) Fuse vs circuit breaker.

4 M

Sr.	Fuse	Circuit breaker
1	Performs both detection and interruption of fault current.	Performs only interruption; detection is done by relay.
2	Works on heating effect of current (thermal).	Works on electromagnetic / mechanical mechanism with relay and trip circuit.
3	Operates only once; element must be replaced after operation.	Can be operated (opened and closed) many times; reset after tripping.
4	Cannot be used for switching (making/breaking) normal load.	Used for normal switching as well as fault interruption, manually or automatically.
5	Very small breaking (operating) time — about 0.002 s for HRC fuse.	Comparatively more operating time — about 0.02 to 0.05 s.
6	Low cost, simple; suitable for low capacity circuits.	Costly; suitable for all capacities, especially HV.

(Any four points, 1 M each)

c) Static relay — block diagram and working.

4 M

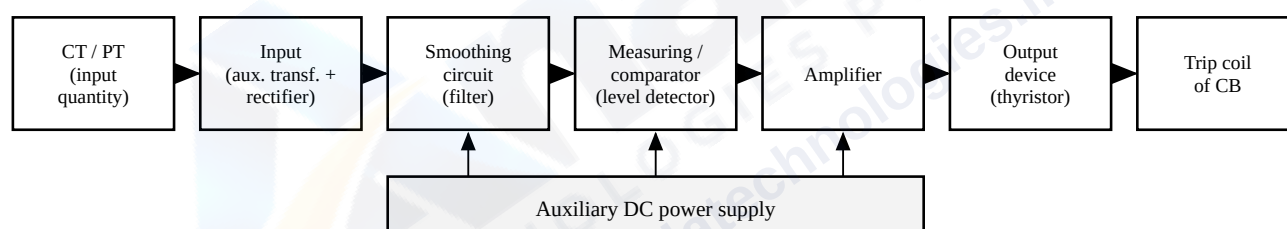


Fig.: Block diagram of a static relay

- **Input (CT/PT):** provides current / voltage proportional to the system quantities.
- **Auxiliary transformer and rectifier:** steps down the quantities and converts a.c. to d.c.
- **Smoothing circuit:** removes ripples from the rectified output.
- **Measuring unit (comparator / level detector):** compares the input with the set value; heart of the relay — uses transistors / ICs.
- **Amplifier:** amplifies the small output of the measuring unit.
- **Output device (thyristor / transistor):** energises the trip coil of the circuit breaker.
- **Auxiliary DC supply:** feeds the electronic circuits.

Since there are no moving parts in the measuring path, the relay is fast, has low burden on CTs and needs little maintenance.

(Block diagram 2 M, explanation 2 M)

d) Residual connection of over-current and earth-fault relays.

4 M

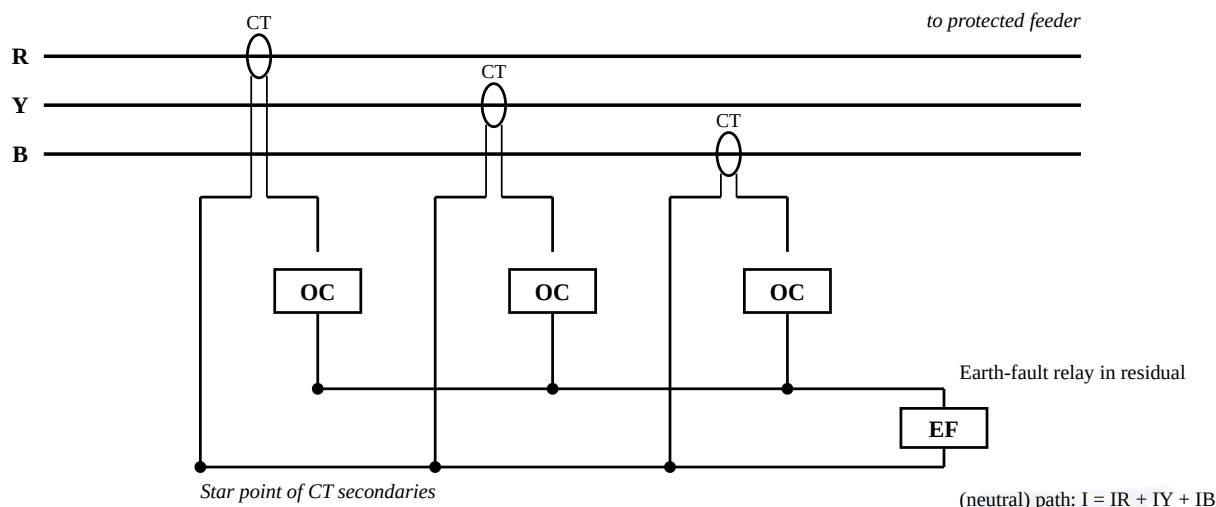


Fig.: Over-current and earth-fault relays — residual connection of CTs

- One CT is provided in each phase; the CT secondaries are connected in **star**.
- An **over-current relay (OC)** is connected in each phase lead; it operates for phase-to-phase and three-phase faults.
- The **earth-fault relay (EF)** is connected in the residual (neutral) path of the CT secondaries.
- Under normal conditions and phase faults, $I_R + I_Y + I_B = 0$, so no current flows through the EF relay.
- During an earth fault, the residual current ($I_R + I_Y + I_B = 3I_0$) flows through the EF relay and it trips the CB. Its setting is kept low (e.g. 20 %–40 %) for sensitivity.

(Diagram 2 M, explanation 2 M)

Q.4

a) Operating time of IDMT relay.

4 M

Relay current setting = 125 % of 5 A = **6.25 A** (pick-up current)

Secondary (relay) current during fault = $6000 \times 5/400 = \mathbf{75.00\ A}$

PSM = Relay current / Pick-up current = $75.00 / 6.25 = \mathbf{12}$

From the time/PSM curve, time for PSM 12 (at TMS = 1) = **2.75 s**

Actual operating time = TMS $\times$ time from curve = $0.5 \times 2.75 = \mathbf{1.375\ s}$

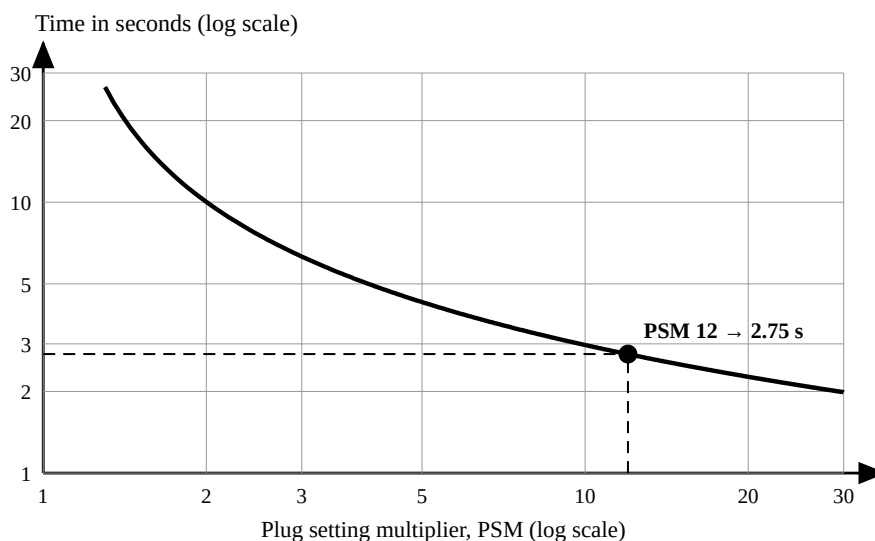


Fig.: Time / PSM curve of a standard IDMT relay (TMS = 1)

(Pick-up and relay current 1 M, PSM 1 M, curve time 1 M, operating time 1 M)

b) Single phasing preventer.

4 M

Single phasing occurs when one phase of the supply to a 3-phase motor is lost (fuse blown, broken conductor, loose contact). The motor continues to run on two phases, draws much higher current in the healthy phases and negative-sequence currents heat the rotor — the winding may burn out.

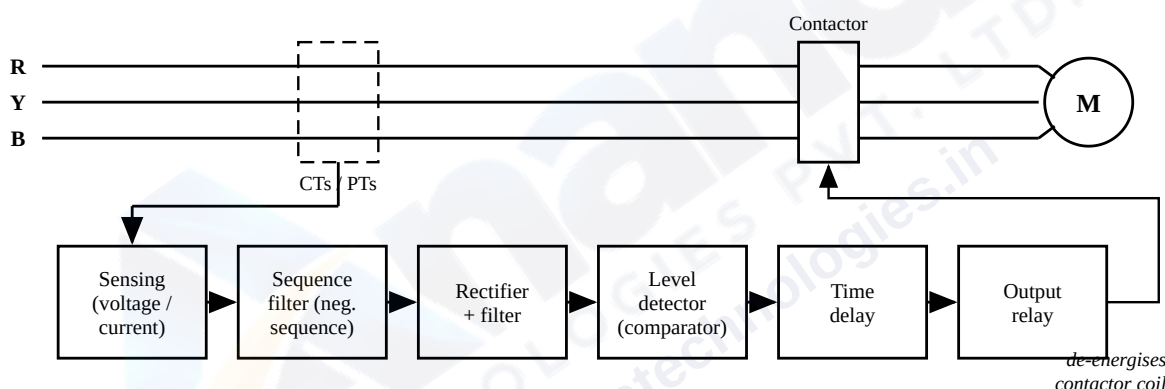


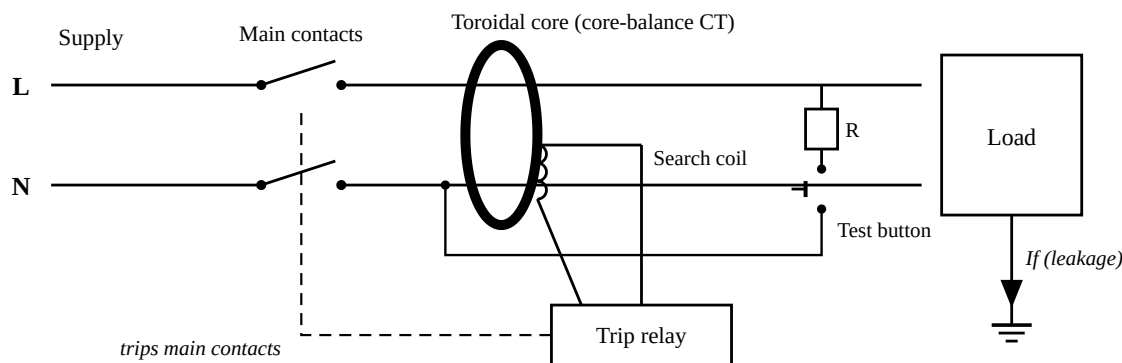
Fig.: Block diagram of a single phasing preventer

- Sensing unit picks up the three line voltages / currents of the motor.
- A **negative-sequence filter** gives an output only when the supply becomes unbalanced (single phasing).
- The output is rectified, filtered and compared with a preset level in the **level detector**.
- After a short **time delay** (to avoid tripping on momentary unbalance), the **output relay** de-energises the contactor coil and the motor is disconnected.

(Need 1 M, block diagram 2 M, working 1 M)

c) RCCB / ELCB.

4 M



Healthy: $I(L) = I(N) \rightarrow$ no flux in core. Earth leakage: $I(L) - I(N) = I_f \rightarrow$ flux $\rightarrow$ relay trips.

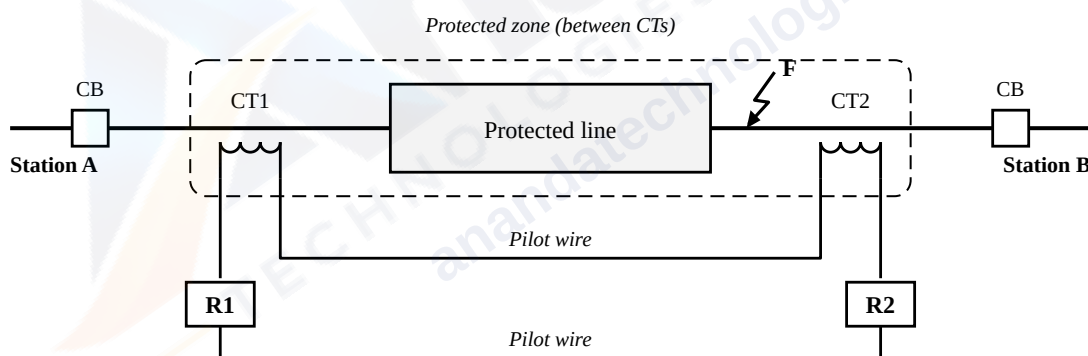
Fig.: Residual current circuit breaker (RCCB / current-operated ELCB)

- Phase and neutral conductors pass through a **toroidal core** (core-balance CT) which carries a search (secondary) coil connected to a sensitive trip relay.
- Under healthy conditions current in phase = current in neutral, their magnetic effects cancel and no emf is induced in the search coil.
- If leakage current flows to earth (insulation failure or a person touching a live part), $I_L \neq I_N$. The residual flux induces emf in the search coil, the trip relay operates and the main contacts open.
- Rated residual operating current: 30 mA for protection of human beings, 100 / 300 mA for fire protection. A **test button** creates an artificial imbalance to check working.

(Diagram 2 M, working 2 M)

d) Merz-Price voltage balance protection of transmission line.

4 M



CT secondaries connected in opposition: healthy $\rightarrow$ equal and opposite voltages, no current. Internal fault $\rightarrow$ current flows, R1, R2 trip.

Fig.: Merz-Price voltage balance system for a transmission line

- Identical CTs are placed at both ends of the line; their secondaries are connected **in opposition** through pilot wires, with a relay in series at each end.
- Under normal load or an external (through) fault, the currents at both ends are equal, so the induced CT voltages are equal and opposite — **no current** flows in the pilot circuit and relays do not operate.
- For a fault on the protected line, the currents at the two ends differ (or reverse); the voltages no longer balance and a current flows through the relays, tripping the CBs at both ends.

- Air-gap (non-saturating) CTs are used so that secondary voltage is proportional to primary current.

(Diagram 2 M, explanation 2 M)

e) Fault bus (frame leakage) protection.

4 M

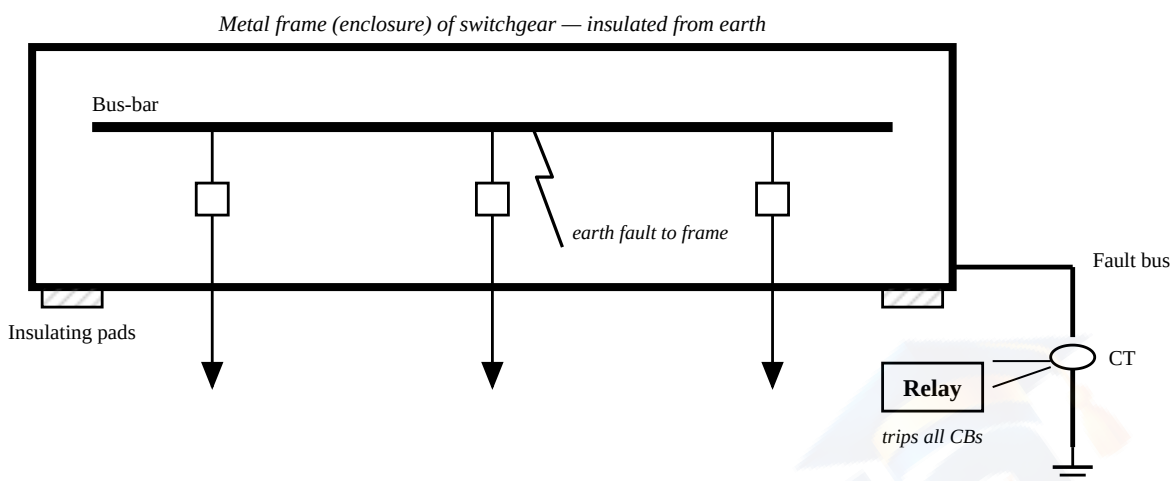


Fig.: Fault bus (frame leakage) protection of bus-bars / switchgear

- The metal frames (enclosures) of all switchgear and bus-bar chambers are **insulated from earth** and connected together by a conductor called the **fault bus**.
- The fault bus is earthed at one point through a **CT**; the CT secondary feeds an over-current relay.
- An earth fault (flash-over to the frame) causes current to flow from the frame through the fault bus and the CT to earth; the relay operates and trips all breakers connected to the bus-bar.
- Simple and economical, but protects only against earth (frame) faults and needs insulated mounting of the switchgear.

(Diagram 2 M, explanation 2 M)

Q.5

a) Puffer type SF₆ circuit breaker; properties of SF₆.

6 M

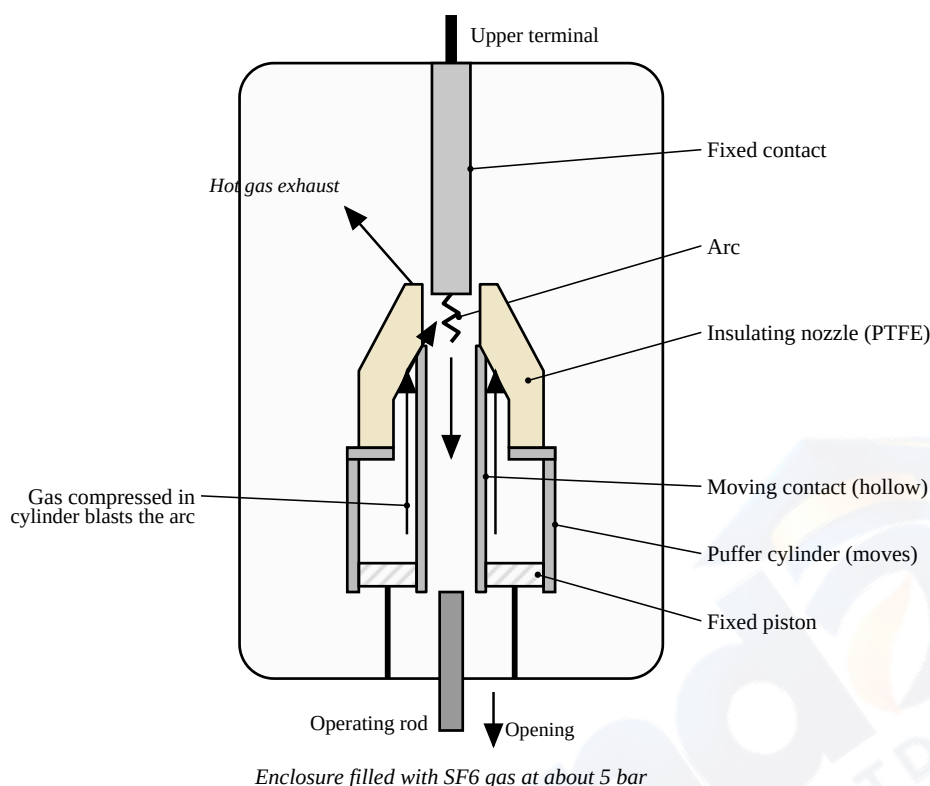


Fig.: SF₆ circuit breaker (puffer type) — contacts opening

Construction:

- Fixed contact and a **hollow moving contact** placed in a closed enclosure filled with SF₆ gas at about 5 bar.
- A **puffer cylinder** and an insulating **PTFE nozzle** are attached to the moving contact; the **piston is fixed**.
- The moving contact is driven by an operating mechanism through an operating rod.

Working: When the breaker opens, the moving contact and puffer cylinder move down together against the fixed piston. The gas inside the cylinder is compressed and forced through the nozzle as a high-velocity **blast** along the arc. SF₆ absorbs free electrons and forms heavy negative ions, so the arc path quickly loses conductivity. At current zero the arc is extinguished and the dielectric strength of the gap recovers rapidly.

Properties of SF₆ gas:

1. High dielectric strength — about 2 to 3 times that of air.
2. **Electronegative** — attracts free electrons, so dielectric strength recovers quickly after current zero.
3. Non-toxic, non-inflammable and chemically inert (stable).
4. Good thermal conductivity and heat transfer — cools the arc quickly.
5. Arc products (metal fluorides) are good insulators; low arcing time.

(Sketch 2 M, construction and working 2 M, four properties 2 M)

b) Microprocessor based over-current relay.

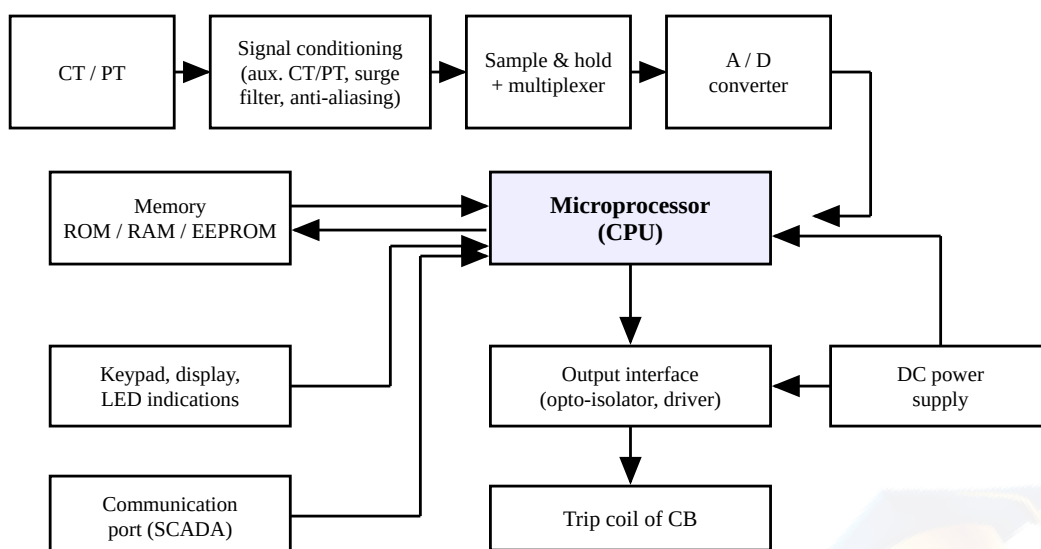


Fig.: Block diagram of a microprocessor based (digital) relay

- **CT/PT:** give current and voltage proportional to line quantities.
- **Signal conditioning:** auxiliary CT/PT reduce the level; surge suppressors and anti-aliasing filters protect and filter the signal.
- **Sample & hold and multiplexer:** sample the analog signals and pass them one by one to the ADC.
- **A/D converter:** converts samples to digital form for the microprocessor.
- **Microprocessor:** computes RMS current, compares with pick-up, computes PSM and the operating time from the stored IDMT equation, and issues trip command.
- **Memory:** ROM/EPROM stores the program and characteristics; RAM stores samples; EEPROM stores settings.
- **Output interface:** opto-isolator and driver energise the trip coil. **Keypad/display** for settings, **communication port** for SCADA.

Advantages:

1. One relay gives many characteristics (definite, IDMT, very inverse) — flexible and programmable.
2. Fast, accurate and very low burden on CTs.
3. Self-monitoring and fault / event recording; communication with SCADA.
4. Compact, reliable, less maintenance; settings easily changed.

(Block diagram 2 M, functions 2 M, advantages 2 M)

c) Merz-Price protection of alternator; biased relay.

6 M

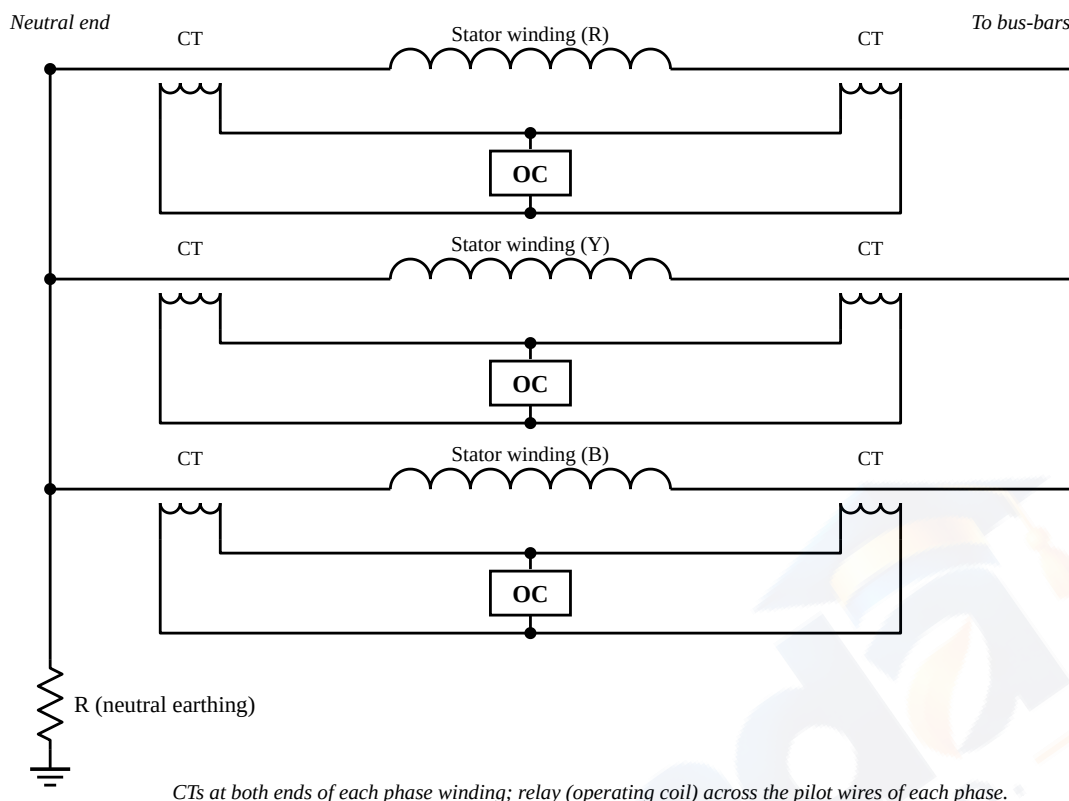


Fig.: Merz-Price circulating current (differential) protection of a 3-phase alternator

- Identical CTs are placed at the neutral end and the line end of each phase winding. Their secondaries are connected by pilot wires so that current **circulates** in the pilot loop.
- The relay (operating coil) is connected across the pilot wires at the equipotential points.
- Normal load / external fault: currents at both ends of the winding are equal, so CT secondary currents are equal; no current flows in the relay.
- Internal fault (phase-to-phase or phase-to-earth in the winding): currents at the two ends become unequal; the differential current flows through the relay, which trips the main CB and the field circuit breaker.

Why percentage (biased) differential relay: During heavy external faults the CTs may saturate unequally and CT ratio errors / pilot impedance cause a spill current in the relay, which may operate a simple differential relay wrongly. In a biased relay a **restraining coil** carrying the through current is added; the relay operates only when the differential current exceeds a fixed **percentage** of the through current. So the relay stays stable for external faults and remains sensitive to internal faults.

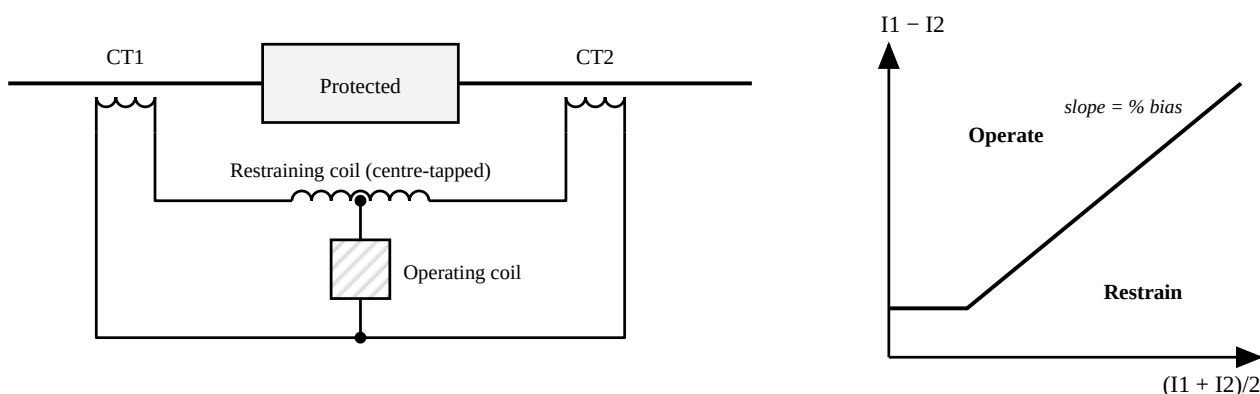


Fig.: Percentage (biased) differential relay and its characteristic

(Diagram 2 M, working 2 M, biased relay 2 M)

Q.6

a) CT ratio on HV side (Merz-Price, delta-star transformer).

6 M

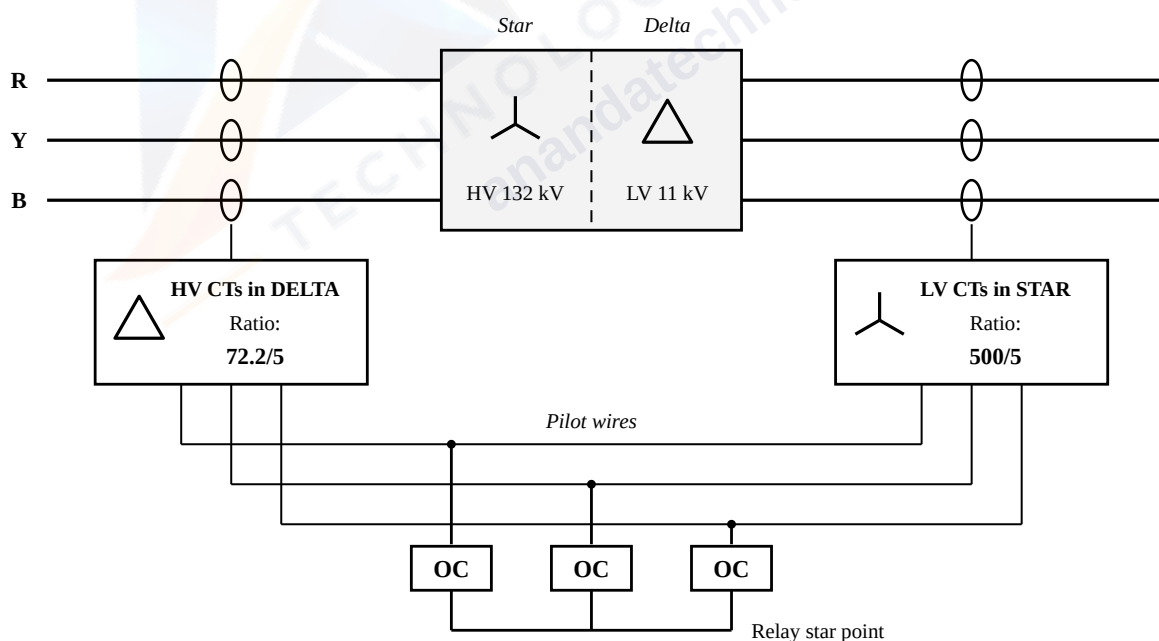
LV side (11 kV) is **delta** connected → LV CTs are connected in **star**. HV side (132 kV) is **star** connected → HV CTs are connected in **delta**.

Let the line current on LV side = 500 A (CT primary rating). LV CT secondary current = 5 A (CTs in star, so pilot current = 5 A).

Corresponding line current on HV side (power balance, $\sqrt{3} V_L I_L$ same): $I_{HV} = 500 \times 11/132 =$
41.667 A

HV CTs are in delta; the current leaving the delta (in pilot wire) must be 5 A, so the current in each HV CT secondary = $5/\sqrt{3} =$ **2.887 A**

HV CT ratio = $41.667 : 2.887 = 14.43 : 1$, i.e. $\approx 72.2 / 5$



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

Fig.: Merz-Price protection of 11/132 kV delta-star transformer (HV star side shown on left)

(Correct CT connections 1 M, HV current 1 M, CT secondary 1 M, ratio 1 M, diagram 2 M)

b) Time-graded protection of radial feeder.

6 M

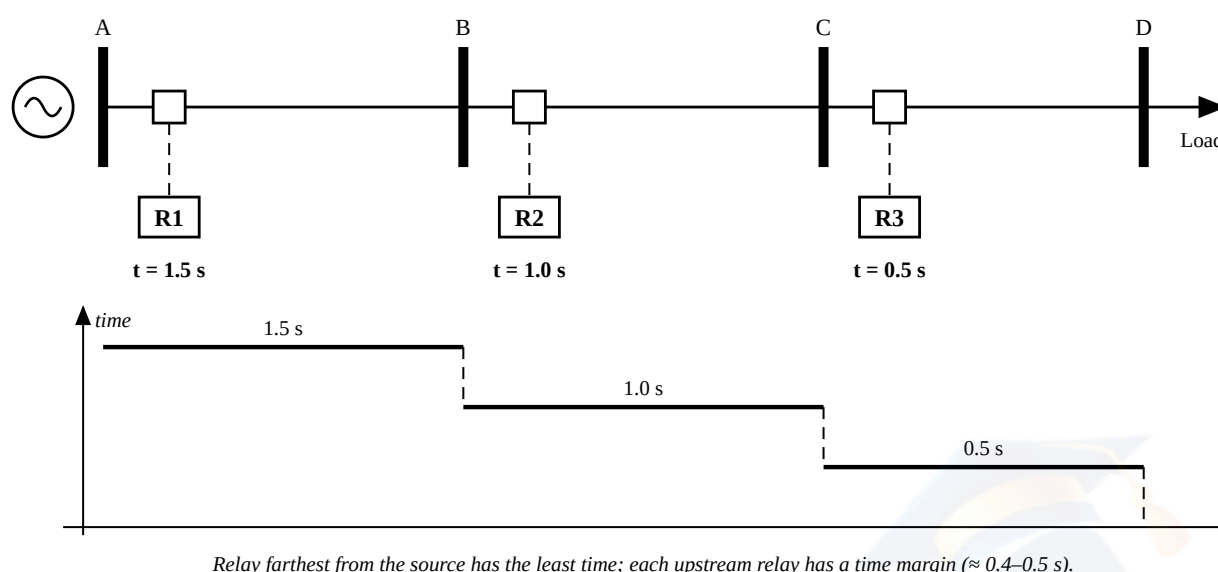


Fig.: Time-graded protection of a radial feeder

- In a radial feeder, relays R1, R2, R3 at stations A, B, C are set with **definite time delays** that increase towards the source (e.g. 0.5 s, 1.0 s, 1.5 s).
- For a fault beyond C, all relays may pick up; R3 has the least time (0.5 s), so CB at C trips first and isolates only the faulty section.
- R2 and R1 reset before their time elapses; if R3 / its CB fails, R2 trips after 1.0 s as back-up, and so on.
- The time margin between adjacent relays (about 0.4–0.5 s) covers CB operating time and relay overrun.

Drawbacks:

1. Faults near the source, where fault current is highest, are cleared after the **longest time** — more damage.
2. Number of sections in series is limited, because the time at the source end becomes too large.
3. Not suitable for ring mains / parallel feeders without directional relays.
4. Time delay does not depend on fault current (definite time); IDMT relays are used to reduce this drawback.

(Diagram 2 M, explanation 2 M, drawbacks 2 M)

c) Alternator faults; reverse power protection.

6 M

i) Faults in alternator:

1. Stator faults — phase-to-earth, phase-to-phase and inter-turn faults
2. Rotor (field) faults — earth fault in field winding, loss of excitation (field failure)
3. Unbalanced loading (negative sequence currents) and overloading / overheating
4. Failure of prime mover (motoring), over-speed and over-voltage

ii) Reverse power protection:

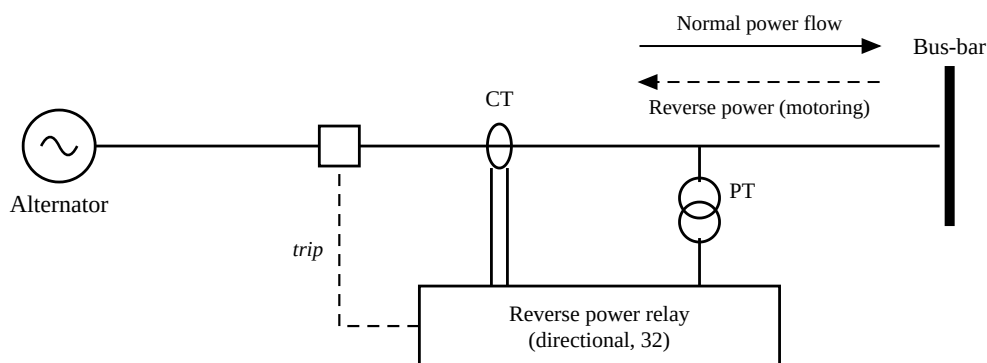


Fig.: Reverse power protection of alternator

- If the prime mover fails, the alternator running in parallel takes power **from** the bus-bars and runs as a synchronous motor (motoring).
- Motoring is harmful to the prime mover — overheating of steam-turbine blades, risk of fire / explosion in diesel engines.
- A **reverse power (directional power) relay** fed from CT and PT senses the direction of active power. When power flows from bus to alternator above the setting (a small % of rating), it trips the alternator CB after a short time delay (to avoid operation during synchronising or power swings).

(Faults 2 M, diagram 2 M, explanation 2 M)

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