

Switchgear and Protection (315334)

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

Q.1

a) Effects of short-circuit faults.

2 M

1. Heavy fault current causes **overheating** and may burn insulation and equipment (fire).
2. Large **electromagnetic forces** damage bus-bars, windings and supports.
3. **Voltage dip** in the system — affects consumers and motors may stall.
4. Loss of **stability** (synchronism) of generators and interruption of supply; unbalanced currents for unsymmetrical faults.

(Any four, ½ M each)

b) Base kVA and percentage reactance.

2 M

i) Base kVA: a common (arbitrary) kVA value — usually the rating of the largest machine or a round figure — to which all percentage reactances of the system are referred for fault calculations.

$$\%X_{\text{new}} = \%X_{\text{old}} \times (\text{base kVA} / \text{rated kVA}).$$

ii) Percentage reactance: the percentage of the normal phase voltage dropped across the reactance when full-load (rated) current flows: $\%X = (I X / V) \times 100$.

(1 M each)

c) AIS vs GIS.

2 M

Sr.	Air insulated switchgear (AIS)	Gas insulated switchgear (GIS)
1	Air is the insulating medium between live parts.	SF ₆ gas in sealed metal enclosures is the insulating medium.
2	Needs large space (outdoor yard).	Very compact — about 10–25 % of the space of AIS; suitable for cities / indoor.
3	Affected by pollution, humidity and weather; more maintenance.	Sealed — not affected by atmosphere; very low maintenance.
4	Lower initial cost.	Higher initial cost.

(Any two, 1 M each)

d) Speed and sensitivity.

2 M

Speed: the relay should operate in the shortest possible time after the fault to reduce damage, avoid loss of synchronism and improve stability (modern relays: a few cycles).

Sensitivity: the ability of the relay to operate with the smallest possible value of fault (actuating) quantity, i.e. low pick-up value / low VA burden.

(1 M each)

e) Relay time and current setting.

2 M

i) Relay time: the time from the instant the actuating quantity exceeds the pick-up value to the instant the relay closes its trip contacts.

ii) Current setting: the pick-up current of the relay expressed as a percentage of its rated current; it is adjusted by the plug setting bridge (e.g. 50 %–200 %). Pick-up current = rated secondary current $\times$ current setting.

(1 M each)

f) Applications of MHO relay.

2 M

1. Protection of **long and EHV transmission lines** (directional distance relay).
2. Lines subjected to **power swings** — MHO relay is least affected by power swings among distance relays.
3. Used as the starting / third-zone (directional) element in three-zone distance schemes.

(Any two, 1 M each)

g) Type-1 vs Type-2 coordination.

2 M

Sr.	Type-1 coordination	Type-2 coordination
1	Under short circuit, contactor and overload relay may be damaged.	No damage to the starter except light welding of contacts that can be easily separated.
2	Starter needs repair / replacement before service is resumed.	Starter can be put back into service after the fault is cleared.
3	No danger to persons or installation; cheaper.	Higher reliability; costlier (higher rated components / suitable SCPD).

(Any two, 1 M each)

Q.2

a) Bus-bar fault MVA and feeder reactor.

4 M

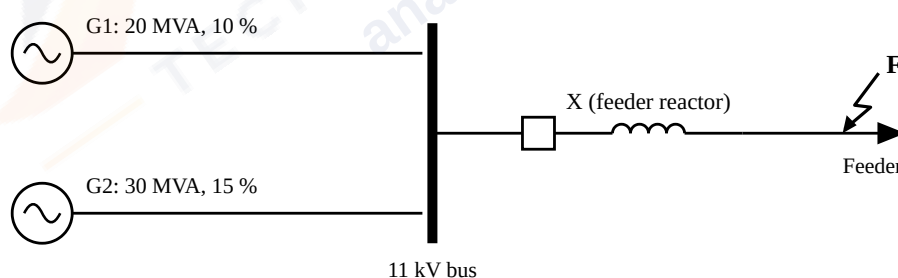


Fig.: Single-line diagram

Base = **30 MVA**. %X of G1 = $10 \times 30/20 = 15.00\%$; %X of G2 = $15 \times 30/30 = 15.00\%$

Parallel combination: $X_p = 15.00 \times 15.00 / (15.00 + 15.00) = 7.50\%$

i) Short-circuit MVA at bus-bar = $30 \times 100 / 7.50 = 400.00$ MVA (fault current = 20,995 A at 11 kV)

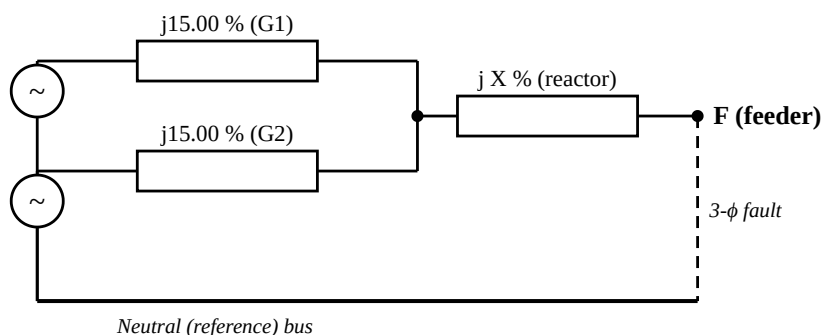


Fig.: Reactance diagram (per-unit on common base)

ii) For fault MVA = 250 MVA, total %X required = $30 \times 100 / 250 = 12.00 \%$

%X of reactor = $12.00 - 7.50 = 4.50 \%$ on 30 MVA base

Ohmic value: $X = \%X \times kV^2 \times 10 / kVA = 4.50 \times 11^2 \times 10 / 30,000 = 0.1815 \Omega$ per phase (base impedance = $11^2/30 = 4.033 \Omega$)

(Feeder fault current is then limited to 13,122 A.)

(Base conversion 1 M, bus fault MVA 1 M, reactor % 1 M, ohmic value 1 M)

b) Low resistance (current-zero) method; recovery rate theory.

4 M

In this method the arc resistance is kept low until the natural **current zero** of the a.c. wave; the arc is then prevented from restriking by rapidly building up the dielectric strength of the contact gap, i.e. by de-ionising the gap — lengthening the gap, high pressure, cooling and gas / oil blast. Used in almost all a.c. HV breakers (oil, air-blast, SF_6 , vacuum).

Recovery rate theory (Slepian): after current zero there is a race between the rate at which the **dielectric strength** of the gap recovers and the rate at which the **restriking voltage** rises (RRRV). If the dielectric strength always stays above the restriking voltage, the arc is extinguished; otherwise it restrikes.

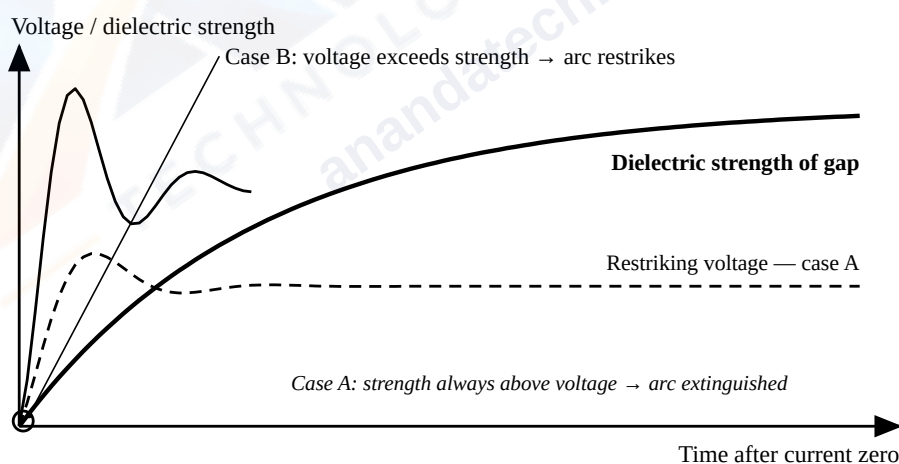


Fig.: Race between dielectric strength and restriking voltage (Slepian's theory)

(Method 2 M, theory with sketch 2 M)

c) Components of protective system and functions.

4 M

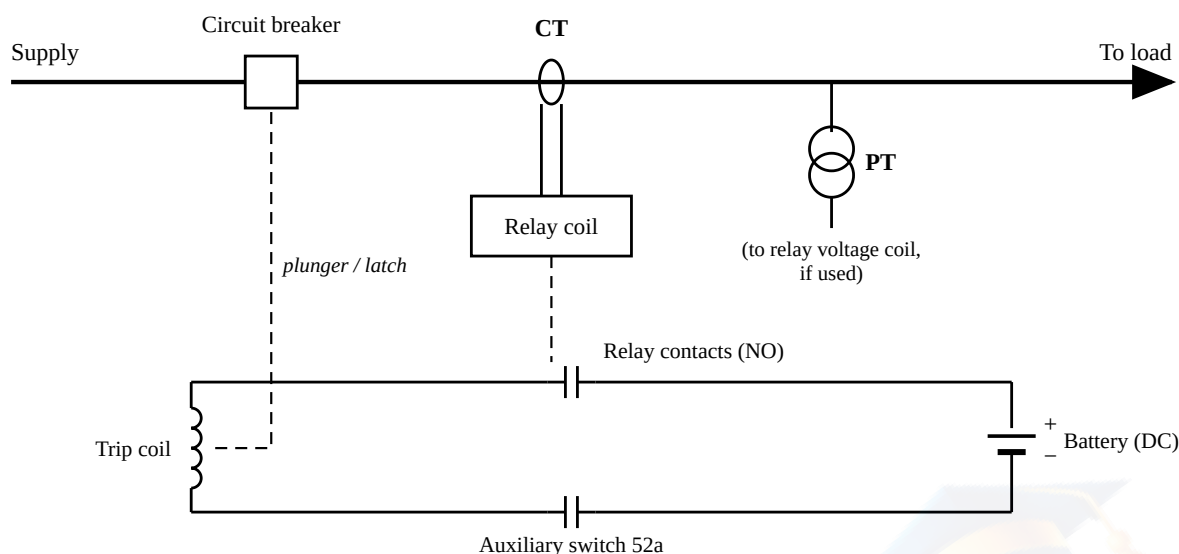


Fig.: Components of a protective system (CT, PT, relay, CB and trip circuit)

- **CT and PT:** reduce line current and voltage to safe standard values (1 A / 5 A, 110 V) for relays and isolate relays from HV.
- **Protective relay:** senses abnormal conditions and closes its contacts in the trip circuit.
- **Trip circuit with battery:** relay contacts energise the trip coil from a reliable DC supply; auxiliary switch 52a opens the coil after tripping.
- **Circuit breaker:** its contacts open on energising the trip coil, interrupting the fault current and isolating the faulty section.

(Diagram 2 M, functions 2 M)

d) Time–current characteristic of fuse and terms.

4 M

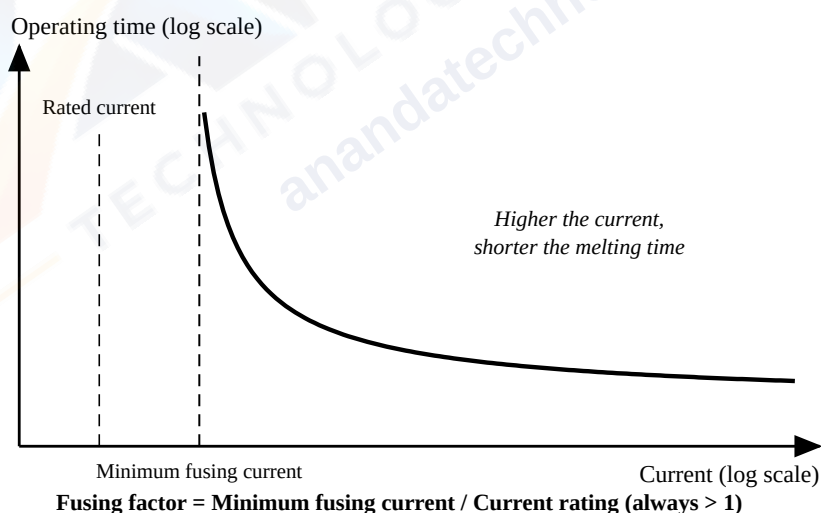


Fig.: Inverse time–current characteristic of a fuse

The time taken by a fuse to blow is **inversely** related to the current: a small overload takes a long time and a heavy short circuit melts the element very quickly. The curve becomes asymptotic to the **minimum fusing current**; below it the fuse never blows.

- **Prospective current:** the RMS (or peak) value of current that would flow in the circuit on short circuit if the fuse were replaced by a link of negligible impedance.
- **Cut-off current:** the maximum instantaneous current actually reached before the element melts (less than the prospective peak in HRC fuses).
- **Arcing time:** the time from the instant of melting (arc initiation) to the final extinction of the arc.

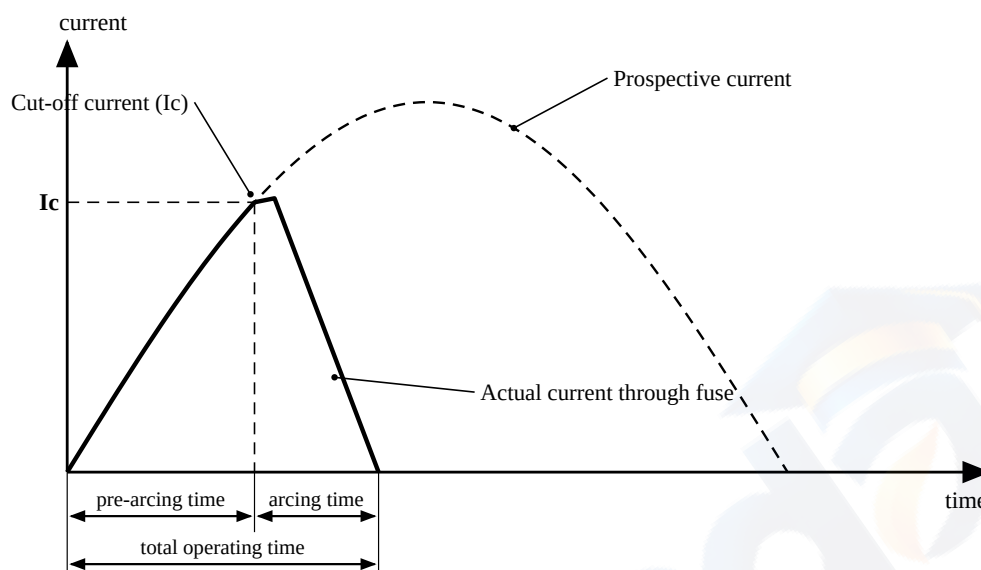


Fig.: Cut-off action of HRC fuse — terms related to fuse operation

(Characteristic 1 M, explanation 1 M, three terms 2 M)

Q.3

a) Isolator vs circuit breaker.

4 M

Sr.	Isolator	Circuit breaker
1	Off-load switching device.	On-load switching device; also interrupts fault current.
2	No arc-quenching arrangement.	Has arc-quenching medium (air, oil, SF ₆ , vacuum).
3	Operated manually (or by motor) after the CB has opened.	Operated manually or automatically through relay.
4	Used to isolate equipment for safe maintenance; gives visible break.	Used for protection and normal switching.
5	Simple and cheap.	Complex and costly.

Why not on load: an isolator has no arc-quenching arrangement; opening it on load draws a heavy arc between its contacts which damages the contacts and is dangerous to the operator. Sequence: open the CB first, then the isolator; while closing, close the isolator first and then the CB.

(Four points 3 M, reason 1 M)

b) Air break circuit breaker (ACB).

4 M

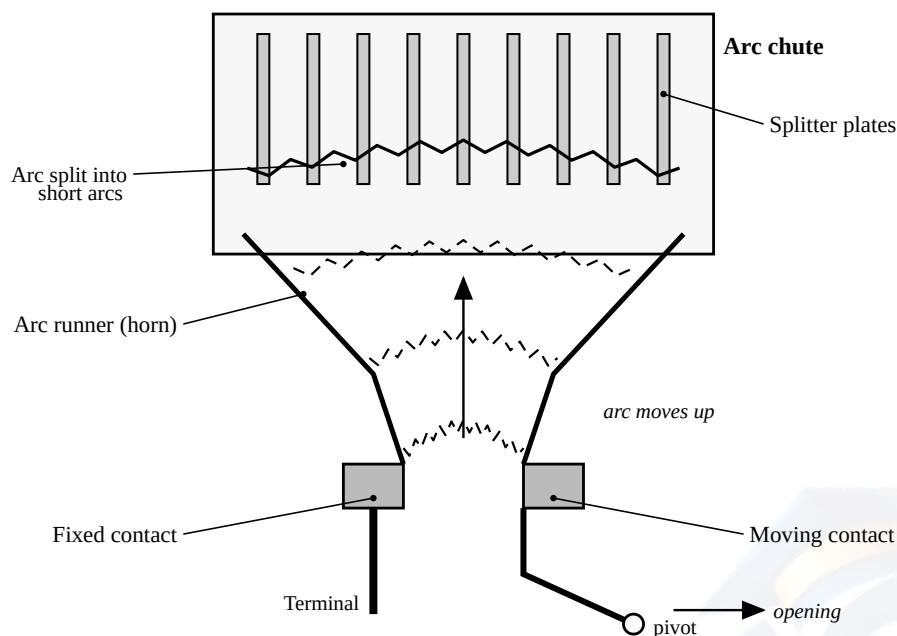


Fig.: Air break circuit breaker — contacts, arc runners and arc chute

- It has **main contacts** (carry normal current) and **arcing contacts** which open last, so the arc forms on the arcing contacts only.
- The arc is pushed upward by thermal convection and the magnetic field of the current (blow-out coil) and travels along the diverging **arc runners**.
- In the **arc chute** the arc is lengthened, cooled and split by **splitter plates**; its resistance increases (high resistance method) until the system voltage cannot maintain it — the arc is extinguished.
- Used on LT systems (415 V) as incomers and bus-coupler breakers, ratings up to several thousand amperes.

(Sketch 2 M, working 2 M)

c) Time grading of two IDMT relays.

4 M

Relay R2: pick-up = $125 \% \times 5 = 6.25 \text{ A}$; relay current = $2000 \times 5/200 = 50.00 \text{ A}$; PSM = $50.00/6.25 = 8$

Time from curve = 3.3 s; operating time of R2 = $0.2 \times 3.3 = 0.660 \text{ s}$

Relay R1: pick-up = $100 \% \times 5 = 5.00 \text{ A}$; relay current = $2000 \times 5/400 = 25.00 \text{ A}$; PSM = 5; time from curve = 4.28 s

Required time of R1 = $0.660 + 0.5 = 1.160 \text{ s}$; TMS of R1 = $1.160 / 4.28 = 0.271$

Nearest higher available setting (steps of 0.025) = **0.275**, giving $t_{R1} = 0.275 \times 4.28 = 1.177 \text{ s}$.

(R2 time 2 M, R1 PSM 1 M, TMS 1 M)

d) Static over-current relay; advantages.

4 M

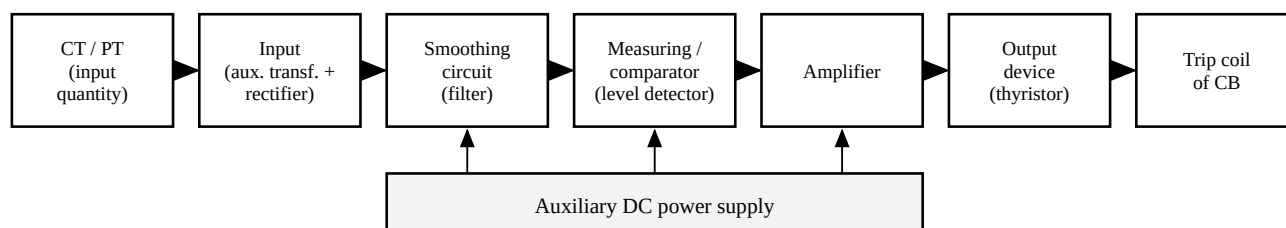


Fig.: Block diagram of static over-current relay

Advantages over electromagnetic relays:

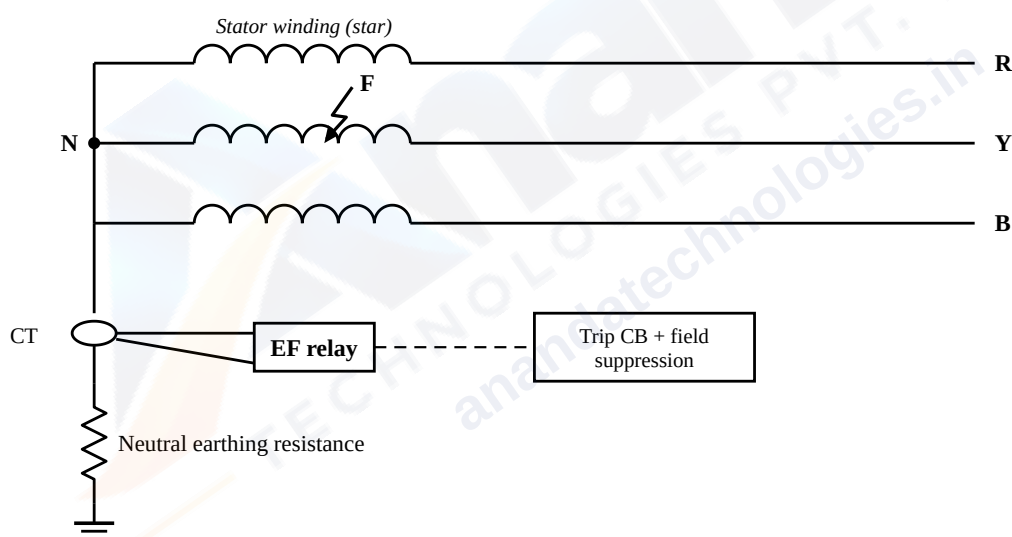
1. Very **low burden** on CTs and PTs.
2. No moving parts — no friction, wear or contact bounce; less maintenance.
3. Fast operation and quick reset (no overshoot).
4. Compact; many characteristics easily obtained; high sensitivity; not affected by vibration or gravity.

(Block diagram 2 M, four advantages 2 M)

Q.4

a) Stator earth-fault protection of alternator.

4 M



Earth fault current returns through the neutral → CT → EF relay operates (limited by resistance).

Fig.: Earth-fault protection of alternator (resistance earthed neutral)

- The neutral of the star-connected stator is earthed through a **resistance** (or earthing transformer) which limits the earth-fault current.
- A CT in the neutral-to-earth connection feeds an **earth-fault relay**.
- For an earth fault in the stator winding, fault current returns through the neutral connection; the relay operates and trips the main CB and the field (suppresses excitation).
- If the relay is set at x % of the maximum earth-fault current, about $(100 - x)$ % of the winding from the line end is protected; a small part near the neutral remains unprotected because the

fault voltage there is low.

(Diagram 2 M, explanation 2 M)

b) Buchholz relay — sketch, advantages, limitations.

4 M

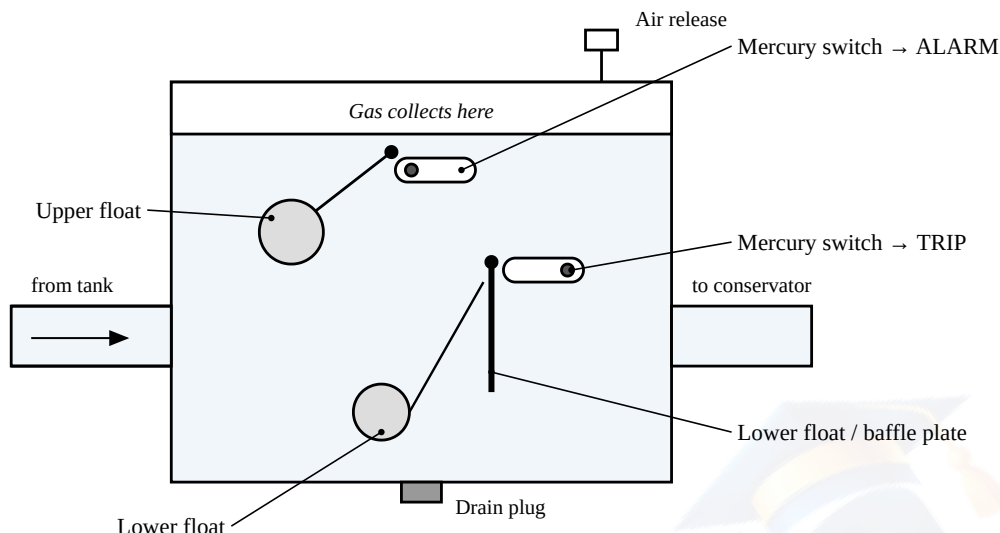


Fig.: Buchholz relay (fitted in the pipe between tank and conservator)

Advantages: gives early warning of incipient faults (alarm) before they become serious; the gas collected can be analysed to know the nature of the fault; simple and cheap.

Limitations: usable only for oil-immersed transformers with conservator; responds only to faults below oil level; comparatively slow (minimum about 0.1 s), so differential protection is also needed; may mal-operate due to oil surges (earthquake, mechanical shock) or air left after oil filling.

(Labelled sketch 2 M, advantages 1 M, limitations 1 M)

c) Single phasing preventer — importance and working.

4 M

Importance: loss of one phase (blown fuse, broken conductor) makes a running motor draw excessive current in the remaining phases; negative-sequence currents overheat the rotor and the winding may burn out before an ordinary overload relay acts. The SPP disconnects the motor quickly and saves the costly winding.

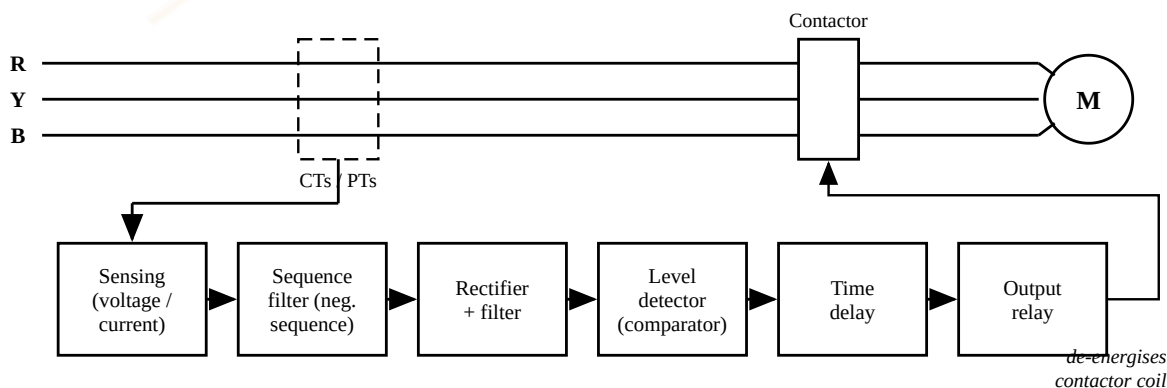


Fig.: Block diagram of a single phasing preventer

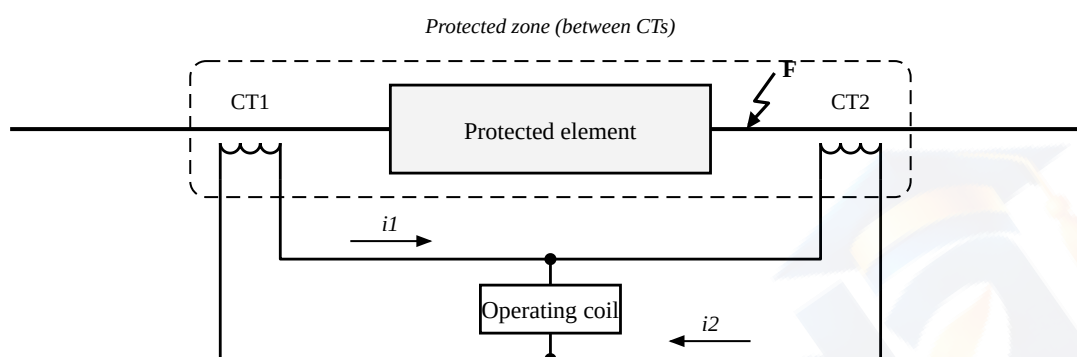
Working: the sensing unit monitors the three phase voltages / currents; a negative-sequence filter gives output only under unbalance; this is rectified and compared with a set level; after a short time delay the output relay de-energises the contactor coil and the motor is switched off.

(Importance 1 M, sketch 2 M, working 1 M)

d) Differential relay; current differential operation.

4 M

Differential relay: a relay which operates when the **vector difference** of two or more similar electrical quantities (currents or voltages) at the two ends of the protected element exceeds a pre-set value.



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

Fig.: Merz-Price circulating current differential protection

- Identical CTs at both ends of the protected element; secondaries joined by pilot wires so that current circulates; relay operating coil across the equipotential points of the pilots.
- Normal load / external fault: $i_1 = i_2$, the relay carries no current.
- Internal fault: $i_1 \neq i_2$; the difference $(i_1 - i_2)$ flows through the operating coil and the relay trips the CBs.

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

e) Bus-bar faults; fault bus protection.

4 M

Causes of bus-bar faults: failure of support insulators, flash-over due to dust / pollution or lightning, breakdown of CB / CT / PT, falling of foreign objects or animals, and human error (earth left connected, wrong switching).

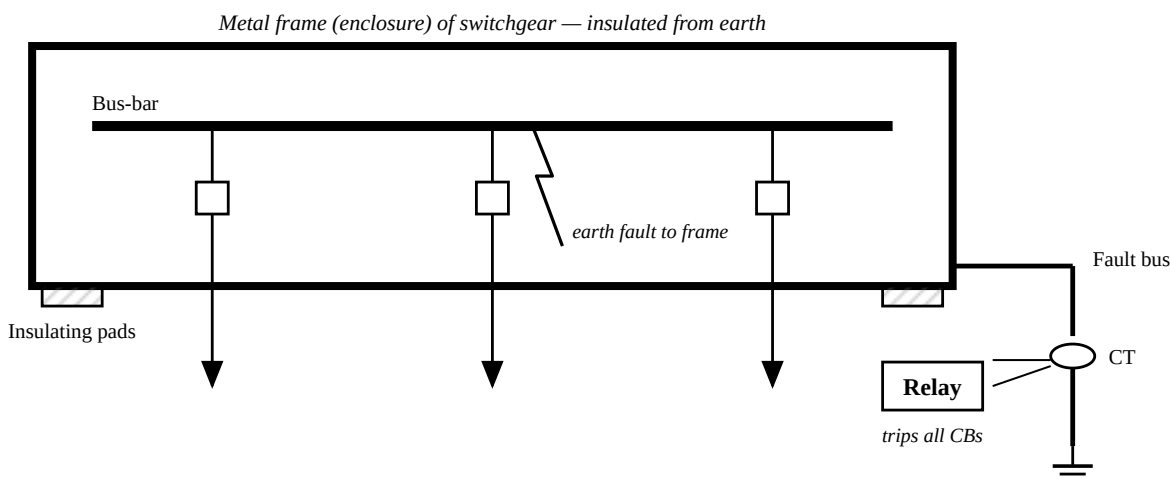


Fig.: Fault bus (frame leakage) protection of bus-bars / switchgear

- All metal frames of the switchgear are insulated from earth and interconnected by a **fault bus**, which is earthed through a single **CT**.
- Any flash-over to the frame (earth fault) sends current through the fault bus and CT to earth; the relay operates and trips all breakers on the bus.
- Simple and economical; protects against earth faults only.

(Causes 1 M, diagram 2 M, explanation 1 M)

Q.5

a) VCB working; VCB vs SF6 CB.

6 M

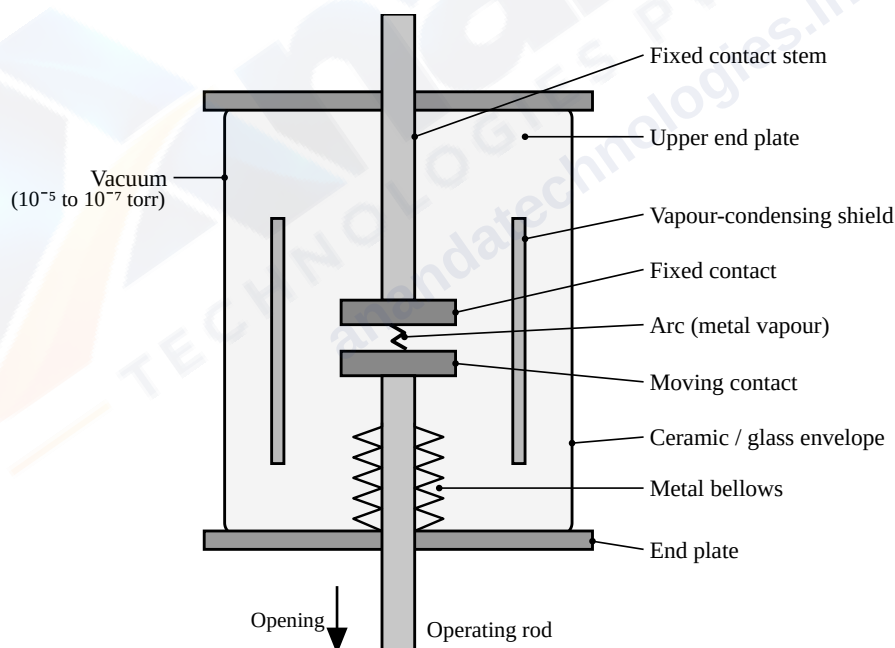


Fig.: Vacuum interrupter of a VCB (contacts open)

Working: On separation of the contacts in vacuum, the arc is sustained only by metal vapour from the contact surfaces. At current zero the vapour condenses rapidly on the contacts and the vapour shield, so the gap recovers its dielectric strength within microseconds and the arc does not restrike. The bellows permit contact movement while keeping the vacuum sealed.

Sr.	Vacuum circuit breaker	SF ₆ circuit breaker
1	Arc quenched in vacuum (10^{-5} to 10^{-7} torr).	Arc quenched by SF ₆ gas at about 5 bar.
2	Mostly used from 3.3 kV to 33 kV (medium voltage).	Used from 33 kV up to 765 kV (high and extra-high voltage).
3	Sealed interrupter, almost no maintenance; no gas handling.	Needs gas handling, pressure monitoring and leak checking.
4	Current chopping may cause over-voltages (surge suppressors used).	Little current chopping; smooth interruption.
5	No environmental problem.	SF ₆ is a strong greenhouse gas; leakage must be avoided.

(Sketch 2 M, working 2 M, comparison 2 M)

b) Digital relay block diagram; numerical relay.

6 M

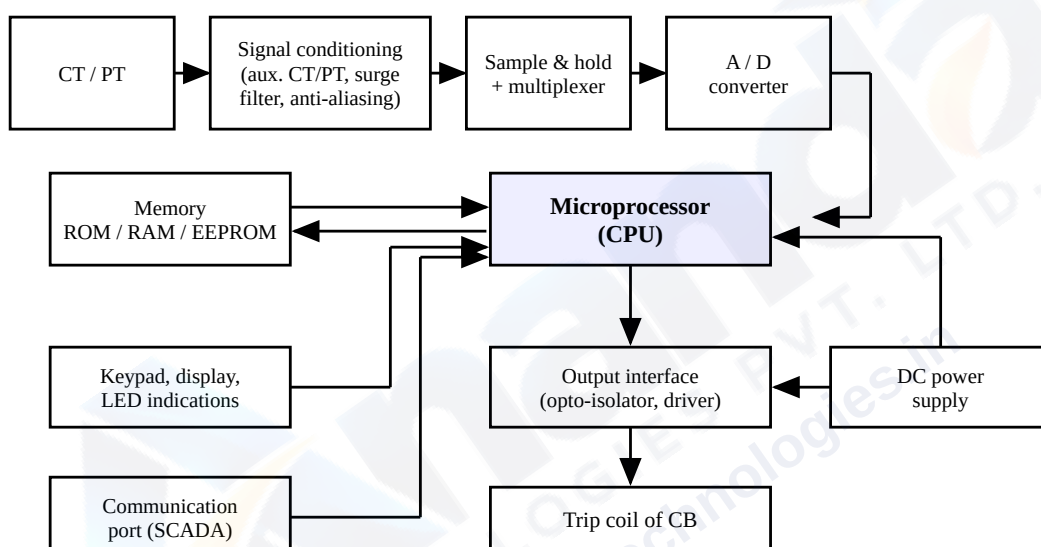


Fig.: Block diagram of a microprocessor based (digital) relay

- **Signal conditioning:** auxiliary CTs/PTs, surge protection and anti-aliasing filters.
- **Sample & hold + multiplexer:** sample the analog inputs and pass them in turn to the ADC.
- **A/D converter:** converts the samples to digital numbers.
- **Microprocessor:** runs the relay algorithm — computes magnitudes, compares with settings, applies time characteristics and decides tripping.
- **Memory:** ROM/EPROM (program), RAM (data), EEPROM (settings, event records).
- **Output interface:** opto-coupled drivers operate trip and alarm contacts; **HMI** (keypad, display) and **communication port**.

Numerical relay: an advanced digital relay in which the sampled values are processed by numerical algorithms (e.g. Fourier filtering) on a microprocessor / DSP. One unit provides many protection functions (over-current, earth-fault, distance, differential), metering, disturbance recording, self-supervision and communication with SCADA.

(Block diagram 2 M, explanation 2 M, numerical relay 2 M)

c) REF protection; overheating protection of transformer.

i) Restricted earth-fault (REF) protection:

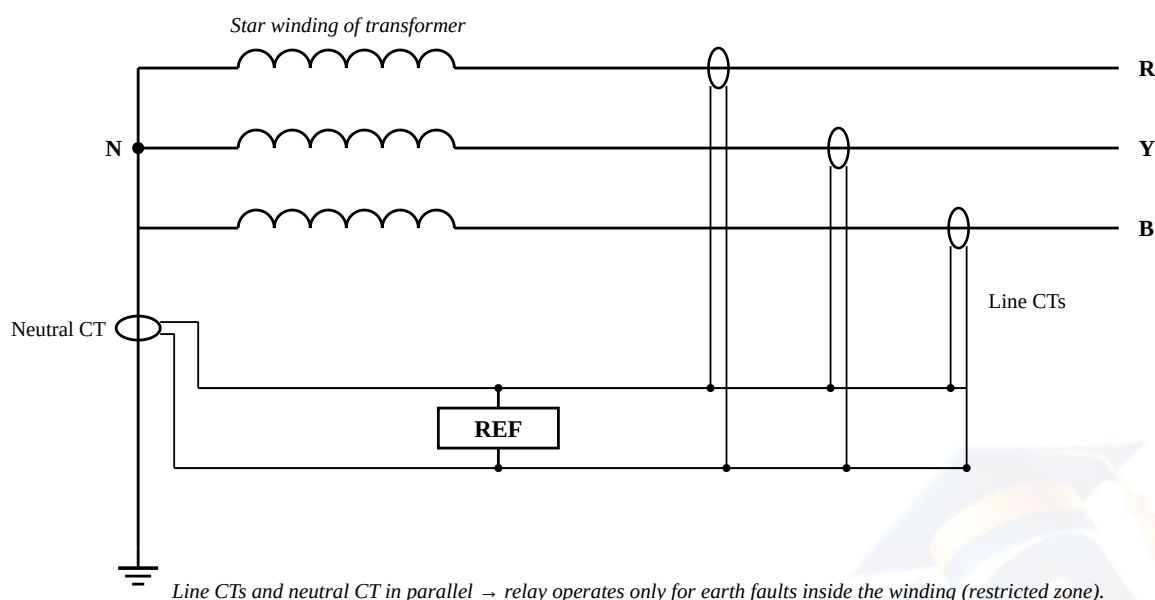


Fig.: Restricted earth-fault protection of star winding of transformer

- CTs are placed in each line of the star winding and one CT in the neutral-to-earth connection; all have the same ratio and their secondaries are connected in parallel with the relay.
- For external (through) earth faults and normal load, the sum of line CT currents equals the neutral CT current — no relay current.
- For an earth fault **inside** the winding (protected zone between the CTs), the balance is upset and the relay operates. It is very sensitive and covers a larger portion of the winding than ordinary differential protection.

ii) Overheating protection:

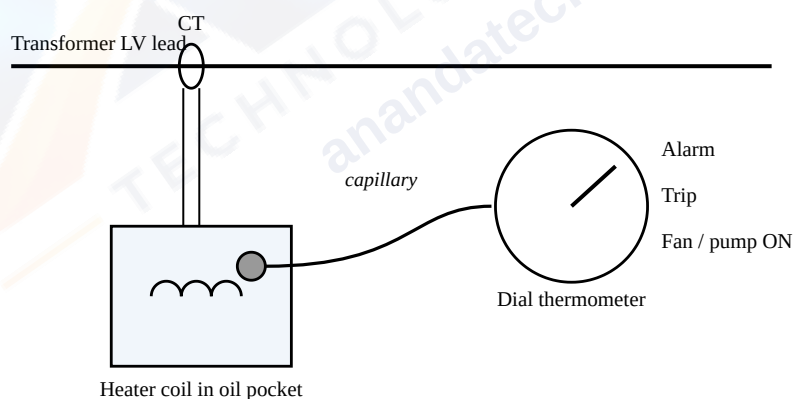


Fig.: Winding temperature indicator (overheating protection)

- Overheating results from sustained overload or failure of cooling. Oil temperature indicator (OTI) measures top-oil temperature.
- **Winding temperature indicator (WTI):** a CT in the LV lead feeds a heater coil in the oil pocket around the thermometer bulb, so the indication = oil temperature + winding gradient (hot spot).

- Contacts on the dial give stage-wise **fan / pump start, alarm and trip**.

(REF diagram and working 3 M, overheating protection 3 M)

Q.6

a) Three-zone distance protection; R–X characteristics.

6 M

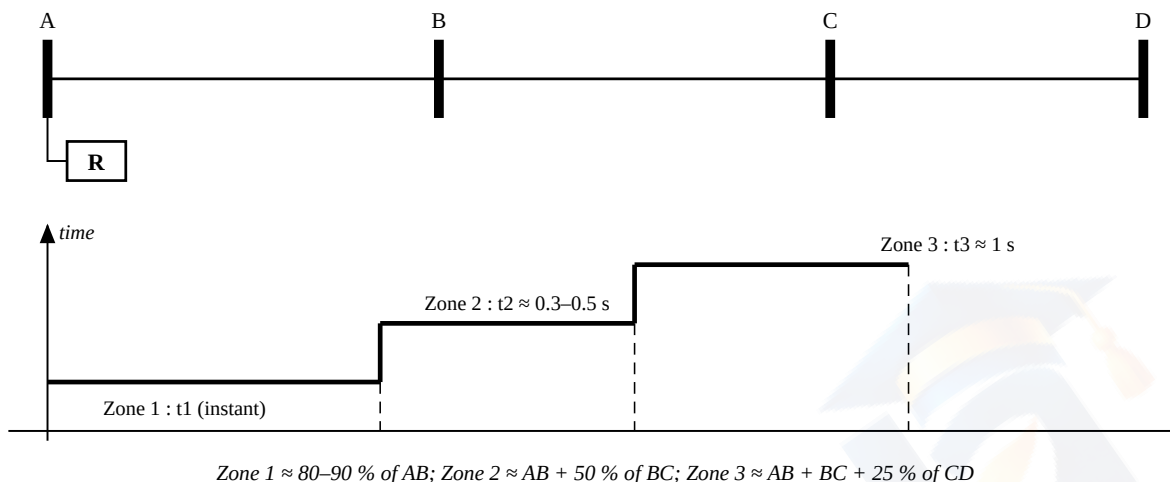


Fig.: Three-zone stepped time–distance characteristic of distance protection

- **Zone 1:** set to 80–90 % of the protected line AB; trips instantaneously (no intentional delay). Not set to 100 % to avoid over-reach due to CT/PT and relay errors.
- **Zone 2:** covers the rest of AB plus about 50 % of the next line BC; time delay $t_2 \approx 0.3\text{--}0.5$ s. Protects the end part of AB and backs up the next relay.
- **Zone 3:** covers AB, BC and about 25 % of CD; time delay $t_3 \approx 0.8\text{--}1$ s; gives remote back-up.
- The relay measures impedance V/I to the fault, which is proportional to distance; hence the zones are set in ohms.

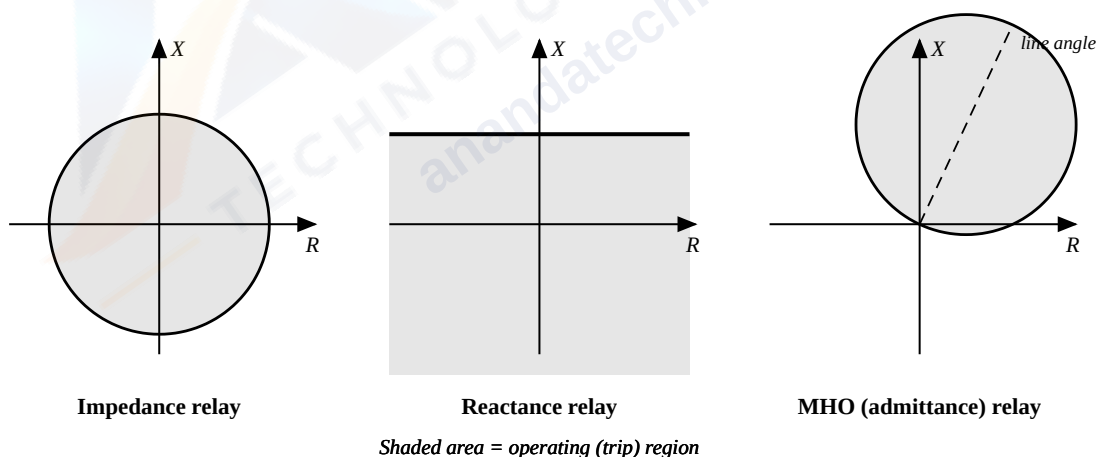


Fig.: Operating characteristics of distance relays on R–X diagram

- **Impedance relay:** circle with centre at origin — non-directional; operates when $Z < Z_{\text{set}}$.
- **Reactance relay:** straight line parallel to R-axis — operates when $X < X_{\text{set}}$; not affected by arc resistance.

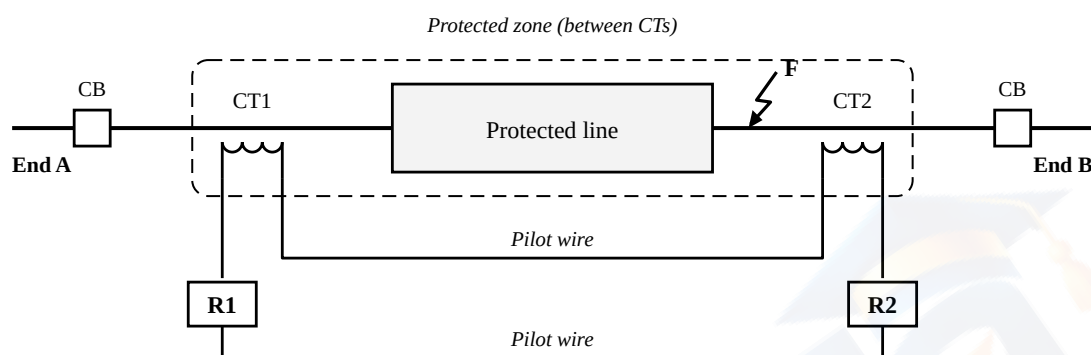
- **MHO relay:** circle passing through the origin — inherently directional; least affected by power swings; used for long lines.

(Zones with diagram 3 M, R-X characteristics 3 M)

b) Pilot-wire protection: applications, voltage balance, comparison.

6 M

Applications: protection of short transmission lines and feeders (up to about 15–25 km), interconnectors and cables where fast, selective clearance of the whole line is required; also used as unit protection of parallel feeders.



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

Fig.: Voltage balance (Merz-Price) pilot-wire system

Working: CT secondaries at the two ends are connected in opposition through pilot wires with relays in series. Normally the voltages balance and no current flows; an internal fault upsets the balance and current through the relays trips both CBs.

Sr.	Circulating current system	Voltage balance system
1	CT secondary currents circulate continuously in the pilot loop.	No current flows in pilots under normal conditions.
2	Relay connected across pilots at equipotential points (shunt).	Relays connected in series with pilots at both ends.
3	Ordinary (iron-cored) CTs can be used.	Air-gap / special CTs needed (secondary on open circuit).
4	Pilot capacitance has less effect, but relay location (mid-point) is critical.	Pilot capacitance causes charging current — may cause mal-operation on long pilots.

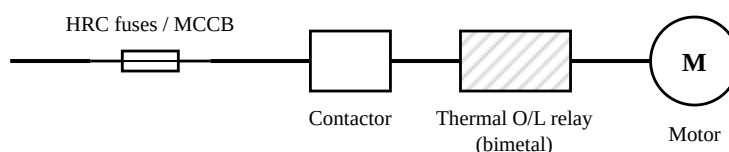
(Applications 1 M, diagram and working 2 M, comparison 3 M)

c) Induction motor faults and protection.

6 M

i) Faults: overload; single phasing; stator winding faults (phase-to-phase, phase-to-earth, inter-turn); unbalanced supply / phase reversal; under-voltage; rotor locking / stalling; bearing failure.

(a) Small LT motor (DOL starter)



Fuses: short circuit; O/L relay: overload; no-volt coil: under-voltage; SPP: single phasing

(b) Large HT motor (circuit breaker + relays)

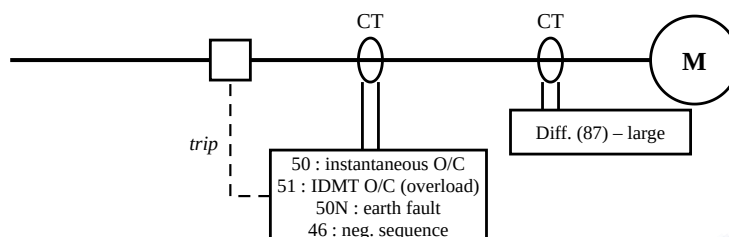


Fig.: Protection of induction motors — (a) small motor, (b) large HT motor

ii) (a) Small LT motors:

- HRC fuses or MCCB for short-circuit protection.
- Contactor with thermal (bimetallic) overload relay for overload; no-volt coil for under-voltage.
- Single phasing preventer and earth-leakage protection.

(b) Large HT motors:

- Circuit breaker operated by CT-fed relays: instantaneous over-current (50) for short circuits, IDMT / thermal (51, 49) for overload.
- Sensitive earth-fault relay (50N) and negative-sequence / unbalance relay (46) for single phasing.
- Differential protection (87) for very large motors; under-voltage relay (27) and locked-rotor protection.

(Faults 2 M, small motor 2 M, large motor 2 M)

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