Switchgear and Protection

Short notes for B.Tech EE · EEE · GATE EE

Uncodemy Handwritten Notes · free for students

I. Introduction

- **Switchgear** = devices for switching, controlling and protecting electric circuits: switches, isolators, fuses, circuit breakers, relays, CTs, PTs.
- A **protective system** = CT/PT (sense) → relay (decide) → circuit breaker (act), powered by a station battery (DC trip supply).

```
Line ---[CB]--------------------> to load
         ^        |
         |       CT
   trip coil      |
         ^        v
         +----- Relay <---- DC battery
```

➤ Faults

- **Shunt (short-circuit) faults**: L-G, L-L, L-L-G, L-L-L. **Series faults**: open conductor.
- Causes: insulation failure, lightning, tree contact, birds, mechanical damage, human error.
- Effects: heavy current (heating, mechanical force), voltage dip, loss of stability, fire risk.

➤ Requirements of protection

Quality	Meaning
Selectivity (discrimination)	Trip only the faulty section
Speed	Clear faults fast to limit damage and keep stability
Sensitivity	Detect even small fault currents
Reliability	Operate correctly every time it should
Stability	Do not trip for faults outside its zone (through faults)
Economy	Cost suitable for the equipment protected

- **Zones of protection** overlap around circuit breakers so that no part is left unprotected.
- **Primary protection**: first line. **Backup protection**: acts if primary fails, with a time delay (remote or local backup).

2. Fuses, Isolators and MCB

- **Fuse**: weakest link, melts on overcurrent. Simple and cheap, but must be replaced.
- **HRC fuse**: silver element in a ceramic body filled with quartz sand. Very high breaking capacity and current-limiting (cuts off before the first peak).

> **FORMULA** Fusing factor = minimum fusing current / current rating (always more than 1).

- Total operating time = pre-arcing (melting) time + arcing time.
- **Isolator**: off-load switch, opened only after the breaker has opened. Gives visible isolation for maintenance.
- **MCB**: thermal (bimetal) trip for overload + magnetic trip for short circuit. **MCCB** for higher currents.
- **RCCB / ELCB**: trips on earth leakage (imbalance between phase and neutral current).

Point	Fuse	Circuit breaker
Function	Detects and interrupts	Only interrupts (relay detects)
After operation	Replace	Reclose
Speed	Very fast (HRC)	Slower (few cycles)
Remote operation	Not possible	Possible

3. Arc Phenomena and Circuit Breaker Theory

- When CB contacts separate, an **arc** forms in the ionised medium. The arc keeps current flowing until it is extinguished.
- Factors keeping the arc: potential difference between contacts, ionised particles.

Methods of arc extinction

- **High resistance method**: increase arc resistance by lengthening, cooling, splitting the arc. Used in DC and low-power AC breakers.
- **Low resistance (current zero) method**: AC current passes through zero every half cycle; at that instant the dielectric strength of the gap is built up faster than the voltage rises. Used in all high-voltage AC breakers.
- Theories: **Slepian's** (race between dielectric strength and restriking voltage), **energy balance** (Cassie).

Important terms

- **Restriking voltage**: transient voltage across contacts just after current zero.
- **Recovery voltage**: normal-frequency voltage across contacts after the transient dies.
- **RRRV** (rate of rise of restriking voltage, kV/μs): if dielectric strength rises faster than RRRV, the arc does not restrike.
- Restriking transient frequency depends on system L and C.

FORMULA $f_n = 1 / (2\pi \sqrt{LC})$. Peak restriking voltage = $2 V_m$. Max RRRV = $V_m / \sqrt{LC}$. Average RRRV = $2 V_m / (\pi \sqrt{LC})$.

EXAMPLE V_m = 100 kV, L = 10 mH, C = 0.01 μF. $\sqrt{LC} = \sqrt{10^{-2} \times 10^{-8}} = 10^{-5}$ s. $f_n = 1/(2\pi \times 10^{-5}) = 15.9$ kHz. Peak restriking voltage = 200 kV, reached at $t = \pi \times 10^{-5} = 31.4$ μs. Average RRRV = 200/31.4 = 6.37 kV/μs. Max RRRV = 100 kV × 10^5 /s = 10 kV/μs.

- **Current chopping**: breaker cuts small inductive currents (transformer magnetising current) before natural zero → high overvoltage = $i\sqrt{L/C}$. Common in air-blast and vacuum breakers.
- **Capacitive current breaking** (opening unloaded lines) can cause restrikes and voltage build-up.
- **Resistance switching**: resistor across contacts damps the transient and reduces RRRV and overvoltage.

4. Types and Ratings of Circuit Breakers

Type	Arc medium	Voltage range	Features
Air break	Air at atmospheric pressure	Low voltage	Arc chutes, magnetic blowout
Bulk oil	Oil (hydrogen gas from arc cools it)	Medium (older)	Fire risk, large oil volume
Minimum oil	Small oil volume	Medium–high (older)	Less oil, tank live
Air blast	Compressed air	High	Fast, noisy, needs compressor
SF6	Sulphur hexafluoride gas	High and extra high	Electronegative, high dielectric strength, compact
Vacuum	Vacuum	Medium voltage (e.g. 11, 33 kV)	Long life, no maintenance, fast dielectric recovery

- **SF6**: electronegative gas (captures free electrons), dielectric strength about 2–3 times air. It is a strong greenhouse gas, so leaks must be avoided.
- **Vacuum**: arc is a metal vapour arc; very fast dielectric recovery. Best for frequent switching at medium voltage.

➤ Ratings

- **Breaking capacity**: RMS current it can interrupt. Symmetrical and asymmetrical (includes DC offset).
- Breaking capacity (MVA) = $\sqrt{3}$ x rated kV x breaking current (kA).
- **Making capacity**: peak current it can close on = 2.55 x symmetrical breaking current (RMS).
- **Short-time rating**: current it can carry for a short time (e.g. 1 s or 3 s) without damage.
- **Operating duty**: e.g. O - t - CO - t' - CO (open, close-open).
- **Auto-reclosing**: most overhead line faults are temporary, so the breaker recloses after a short dead time.

5. Protective Relays

- **Electromagnetic**: attracted armature (instantaneous), induction disc (time delayed, IDMT). **Static**: electronic circuits. **Numerical**: microprocessor based, many functions, self-checking, event recording, communication.
- **Pick-up value**: minimum value at which relay operates. **Reset value**: value at which it returns.

➤ Overcurrent relay

Type	Characteristic
Instantaneous	Operates with no intentional delay
Definite time	Fixed delay regardless of current
IDMT	Inverse at low multiples, definite minimum time at high multiples
Very / extremely inverse	Steeper curves, for better coordination with fuses

FORMULA PSM (plug setting multiplier) = fault current in relay coil / (CT secondary rating x plug setting). Standard IDMT: $t = 0.14 \times TMS / (PSM^{0.02} - 1)$.

EXAMPLE CT 400/5 A, plug setting 125%, TMS = 0.2, fault current 4000 A. Relay current = 4000 x 5/400 = 50 A. Setting = 1.25 x 5 = 6.25 A. PSM = 50/6.25 = 8. $t = 0.14 \times 0.2 / (8^{0.02} - 1) = 0.028 / 0.0425 =$ 0.66 s.

- **Directional relay**: operates only for power flow in a set direction; needs voltage as reference. Used in ring mains and parallel feeders.
- **Grading** of radial feeders: time grading, current grading, or both (IDMT). Relays nearer the source get longer time.

➤ Distance relays

- Measure impedance Z = V / I up to the fault. Fault nearer → smaller Z.

Relay	Characteristic on R-X plane	Use
Impedance	Circle centred at origin (non-directional)	Medium lines
Reactance	Straight line parallel to R axis	Short lines (not affected by arc resistance)
Mho (admittance)	Circle through origin (directional)	Long lines (least affected by power swings)

- **Zones**: Zone 1 = about 80–90% of the line, instantaneous. Zone 2 = rest of line + part of next line, small delay. Zone 3 = backup for next line, longer delay.

➤ Differential relay

- Compares current entering and leaving a zone. Trips when the difference exceeds a set value.
- **Percentage (biased) differential**: restraining coil stops wrong trips due to CT mismatch during heavy through faults.
- **Merz-Price circulating current** system is used for generators and transformers.

6. Protection of Generators and Transformers

➤ Alternator

- Stator: **differential (Merz-Price)** for phase faults, **stator earth fault** protection.
- Rotor: **rotor earth fault**, **loss of excitation** (field failure).
- Others: **negative sequence** (unbalanced load heats rotor), **reverse power** (prime mover failure → motoring), over-speed, over-voltage, overheating.

➤ Transformer

- **Buchholz relay**: gas-actuated relay between tank and conservator of oil-filled transformers. Upper float → alarm for slow (incipient) faults. Lower float → trip for severe faults.
- **Differential protection**: CT connections must correct the phase shift. CTs in delta on the star side, star on the delta side of the transformer.
- **Magnetising inrush current** on switching can look like an internal fault; relay uses **2nd harmonic restraint** to avoid tripping.

- **Restricted earth fault** protection for star winding, overcurrent and earth fault as backup, temperature (winding and oil) alarms.

> **EXAM POINT** Buchholz relay works only for internal faults below oil level; it cannot detect faults in external connections.

7. Protection of Lines and Busbars

- **Radial feeders**: time-graded overcurrent relays. **Ring mains / parallel feeders**: directional overcurrent relays.
- **Long transmission lines**: distance protection (3 zones), often with **carrier (pilot) aided** scheme for fast tripping of both ends.
- **Pilot wire / carrier current** protection = unit protection (compares conditions at both ends).
- **Busbar protection**: differential (high-impedance), frame leakage. Busbar faults are rare but serious, since all circuits are lost.
- **Auto-reclosing** for temporary faults on overhead lines.

8. Overvoltage Protection and Neutral Earthing

➤ Causes of overvoltage

- **External**: lightning (direct or induced strokes).
- **Internal**: switching surges, arcing ground, resonance, current chopping, insulation failure.

➤ Protective devices

- **Ground (earth) wire** above the line shields conductors from direct strokes.
- **Lightning arresters (surge arresters)**: conduct surge to earth and then stop conducting.
  - Rod gap, horn gap, expulsion type, valve type (non-linear SiC + gaps), **metal oxide (ZnO) gapless** (most used now).
- **Surge absorber**: reduces steepness of the surge wave (protects windings).

- **Insulation coordination**: arrange insulation levels so the arrester protects equipment. **BIL** (basic impulse insulation level) of equipment must be above the protective level of the arrester.
- Standard lightning impulse wave: 1.2/50 μs.

➤ Neutral earthing

Method	Feature
Ungrounded (isolated)	Arcing ground possible, healthy phase voltage rises to √3 times
Solid grounding	Neutral directly to earth, fault current high, voltage controlled
Resistance grounding	Limits earth fault current
Reactance grounding	Limits current with a reactor
Resonant (Peterson coil)	Reactor tuned with line capacitance, arc extinguishes itself

FORMULA Peterson coil (arc suppression coil): $L = 1 / (3\,\omega^2\,C)$, C = capacitance of each phase to earth.

EXAMPLE $C = 1\ \mu F$ per phase, 50 Hz. $\omega = 314.16$ rad/s, $\omega^2 = 98696$. $3\,\omega^2\,C = 3 \times 98696 \times 10^{-6} = 0.296$. $L = 1/0.296 = 3.38\ H$.

- **Earthing of equipment** (body) is for human safety; **neutral earthing** is for system protection. Do not confuse them.

9. Most Asked Questions (practice)

1. State the requirements of a protective system. What are zones of protection?
2. Explain arc interruption theories. Define restriking voltage, recovery voltage and RRRV.
3. Derive the expression for restriking voltage and RRRV. What is current chopping?
4. Compare SF6 and vacuum circuit breakers.
5. Define breaking, making and short-time ratings of a circuit breaker.
6. Find the operating time of an IDMT relay for given CT ratio, PSM and TMS.
7. Compare impedance, reactance and mho distance relays. Explain zones of protection.
8. Explain transformer differential protection and the problem of magnetising inrush.
9. Explain the Buchholz relay with a sketch. List alternator protection schemes.

10. Explain lightning arresters and the Peterson coil. What is insulation coordination?

> **TIP** GATE EE protection questions are mostly RRRV, IDMT relay time, PSM, distance relay characteristics, making current factor and Peterson coil. Learn the formulas and the R-X diagrams well.