EEE4227: POWER SYSTEM PROTECTION
TERM: MID-TERM

Lecture 02

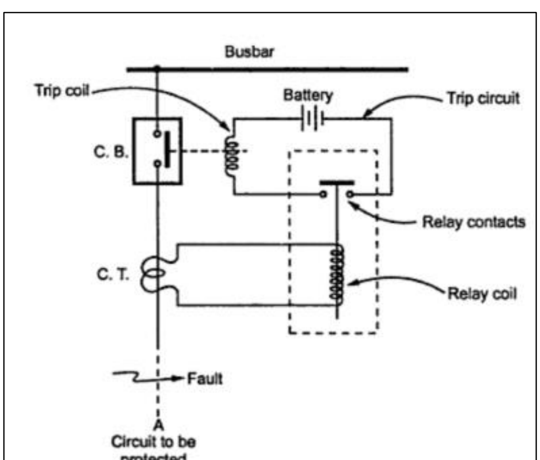
Part 01- High voltage circuit breaker (HVCB)

Part 02- Low voltage circuit breaker (LVCB)

Part 01-High voltage circuit breaker (HVCB)

- ❖ What is a circuit breaker(CB)??
  - ❖A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit.
- ❖ Depending on the voltage level CB can be classified into two categories
  - ❖High voltage CB
  - ❖Low voltage CB

Working principle of a HV CB (incorporated with relay):



When fault occurs in the protective circuit, relay connected to CT and PT actuate and close its contacts. Current flows from battery and closes the trip circuit. As the trip coil is energized, the circuit operating mechanism is actuated, and it operates for opening mechanism.

Sequence of fault clearing process using CB

Fault occurs

Relay senses the fault and closes the trip circuit

Energizes the trip coil and unlatch the spring

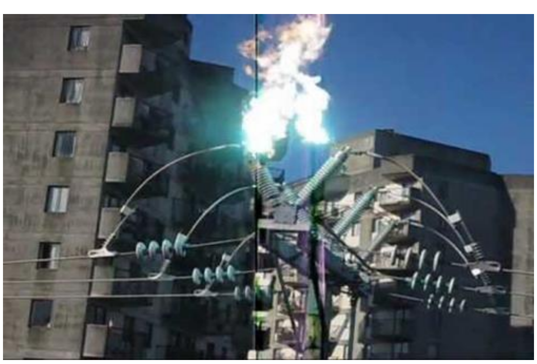
Contact starts to apart and arc is drawn between the contact of CB

Arc is extinguished at the instant when the fault AC current is zero

Fault interruption is completed i.e. fault is cleared

Arc flash in CB

❖ What is arc flash??



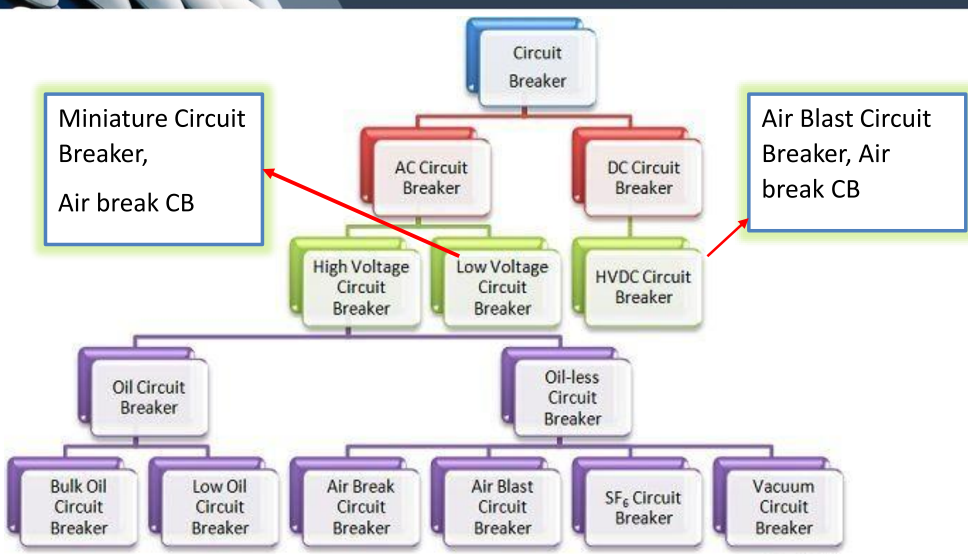
Arc flash in CB

- Available arc quenching methods: (i) **High resistance interruption (ii) Low resistance or zero point interruption:**
  - **High resistance interruption:**
    - The resistance of arc is increased by lengthening and cooling it to such an extent that the system can't maintain the arc and thus extinguishes

$$Rarc = \frac{Varc}{Iarc}$$

  - **Low resistance or zero point interruption:**
    - The arc gets extinguished at the natural current zero of the alternating current wave

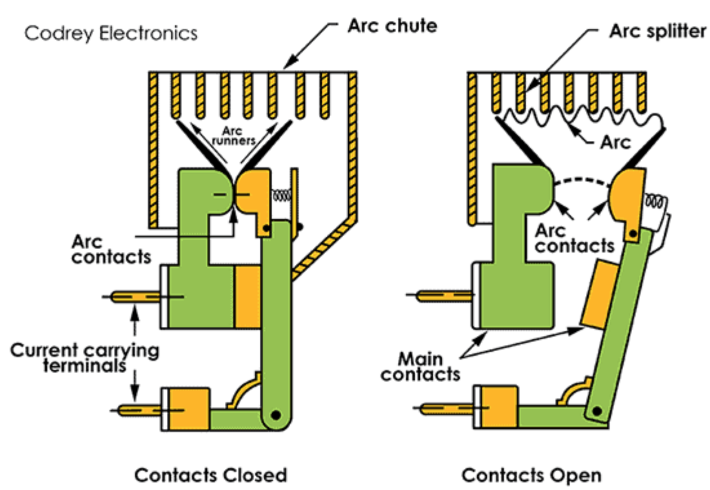
Classification of CB (based on voltage level and arc quenching method)



High voltage circuit breakers

- ❖Air break circuit breaker (ACB)
- ❖Air blast circuit breaker (ABCB)
- ❖Oil circuit breaker
  - ❖Minimum oil circuit breaker (MOCB)
  - ❖Bulk oil circuit breaker (BOCB)
- ❖SF6 circuit breaker
- ❖Vacuum circuit breaker

Air break circuit breaker (ACB)



Air break circuit breaker (ACB)

- **Working Principle of ACB**

When the breaker is in close condition, the current flows in the main contact. When the contacts are open, the main contact is separated first and the arcing contact remains closed.

Therefore, the current in the main contact moves to the arcing contact. Now the arcing contacts are separated and an arc is formed between them. **Here, the high resistance is used for arc interruption.**

> lengthening, splitting, and cooling the arc increases the resistance.
> The two chambers called arc runner (Arcing horns) and arc chutes increases the length of the arc. The arc moves along the arc runner and forced to move upwards into the arc chute. The arc is split in this way by arc splitters and thus it extinguishes.

Low and medium voltage systems use ACB in electric furnaces and in large motors. They are available in the range of 400V to 12kV.

Air break circuit breaker (ACB)

- **Classification of ACB**

There are three types of Air circuit breakers used in the low voltage switch gears and indoor medium voltage. They are:

- ✓ **Plain Break Type or Cross-Blast ACB**
- ✓ **Magnetic Blowout Type Circuit Breaker**
- ✓ **Air Chute Circuit Breaker**

>>> Plain break type is the simplest form of air break circuit breaker. It is made in the shape of two horns. In this, the circuit breaker is fitted with a chamber surrounding the contact. The chamber is known as “arc chute”. The arc is made to drive in it. **This type of circuit breaker is a good choice for low voltage applications.**

>>> Magnetic blowout air circuit breakers provide magnetic control over the arc moment to make arc extinction within the devices. The arc extinction is controlled using the magnetic field provided by the current in blowout coils connected in series with the circuit being interrupted. These coils are called “blow out the coil”. **These kinds of circuit breakers are used up to 11kV.**

>>> In the air chute circuit breaker, there are two types of contacts namely “main contact” and “auxiliary or arcing contacts”. The main contacts are made of copper and the silver plates having low resistance and conduct the current in a closed position. During the circuit breaker operation, the arcing or auxiliary contacts are closed before and open after the main contacts of the circuit breaker.

Air blast circuit breaker

The compressed air is stored in a tank. When a fault occurs, the contacts are opened in a flow of arc and it is established by opening of blast valve. The high-pressure air blast cools the arc and sweeps away the ionized particles along with it.

This rapidly increases the dielectric strength of the medium between the contacts and prevents from reestablishing the arc. The arc is extinguished now and the current is interrupted.

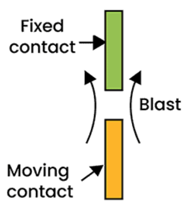


Fig: Axial type blast

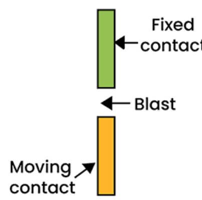


Fig: Cross type blast

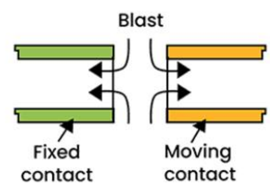
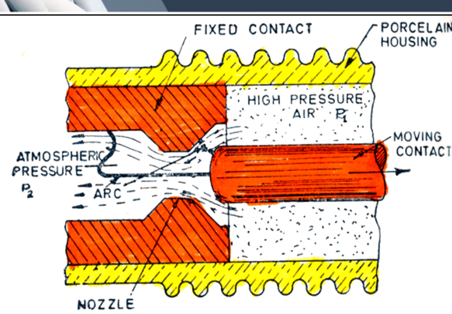


Fig: Radial type blast

Air blast circuit breaker

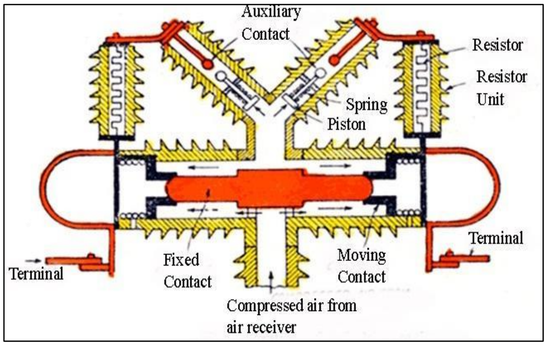


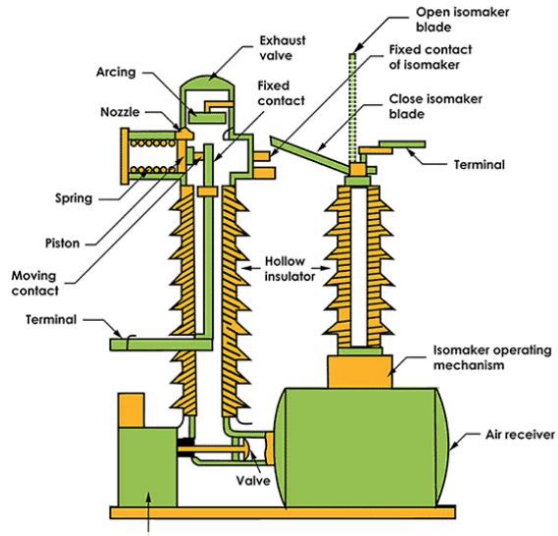
(a) Axial flow.

Under normal conditions, the contacts are closed by spring pressure. The air reservoir is connected to the arcing chamber through an air valve.

When a fault occurs, the air valve opens. The high-pressure air entering the arcing chamber pushes away the moving contact and an arc is formed between the contacts. The high-pressure air flows along with the arc and sweeps away the ionized particles. Now the arc is extinguished.

Air blast circuit breaker





Sample images of installed air blast circuit breaker at outdoor switchyard

Oil Circuit Breaker

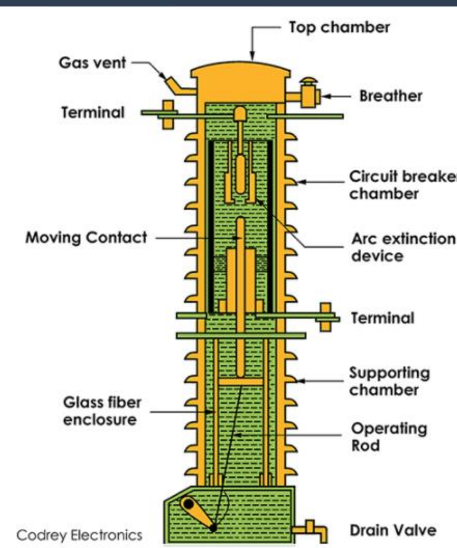
The working of the oil circuit breaker is, the contacts are opened when the fault occurs in the system and the arc is developed between the contacts. The heat of the arc evaporates the surrounding oil.

This creates a large bubble of hydrogen that surrounds the arc. The oil surrounding the bubble conducts the heat away from the arc and also contributes to deionization and extinction of the arc.

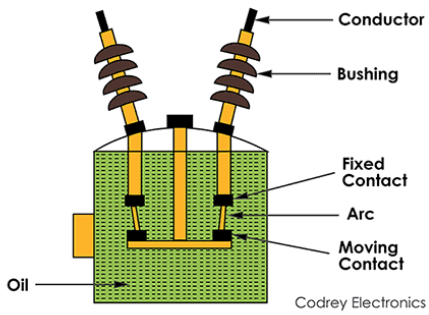
Minimum oil circuit breaker

This circuit breaker occupies less space, needs less oil, smaller tank size, and reduces the risk of fire. It consists of two chambers namely circuit breaker chamber (upper) and supporting chamber (lower) which are separated from each other and filled with oil.

The upper chamber is used for arc extinction and the lower is used for insulation purposes.



Bulk oil circuit breaker



Oil-Based Circuit Breaker

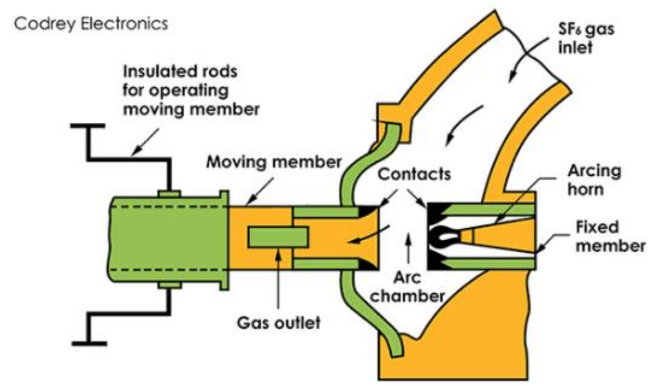
SF6 circuit breaker

SF6 circuit breaker uses SF6 (Sulfur Hexafluoride) gas as an air quenching medium. This gas is electro-negative and it has high dielectric strength to absorb free electrons. This is very effective for high voltage applications ranging from 33kV to 800kV

Properties of SF6

- No color, no odor, non-toxic and noninflammable gas
- Excellent heat transfer property
- Chemically inert
- Chemically stable at atmospheric pressure and temperature
- Non-corrosive on all metals at ambient temperatures
- High dielectric strength (2.5 times greater than air)
- Arc-interrupting capacity
- The dielectric constant is independent of the frequency of the applied voltage

SF6 circuit breaker



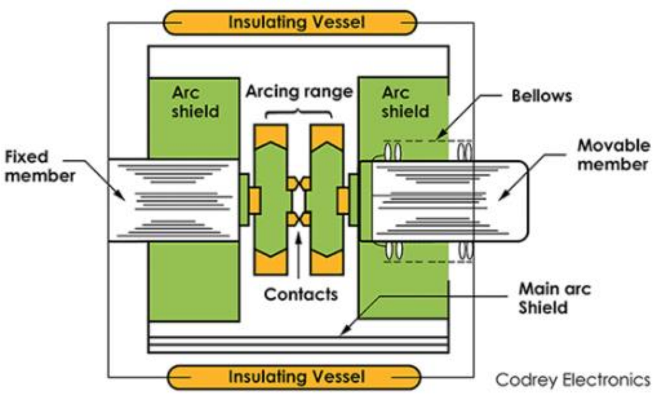
SF6 Circuit Breaker

Vacuum circuit breaker

The vacuum circuit breaker (also known as vacuum interrupter or VCB) uses the arc quenching process in the vacuum as a switching medium.

The vacuum has the highest insulating strength. So, it has far superior arc quenching properties than any other medium. The degree of vacuum is in the range of 10^-7 to 10^-5 torr. It is suitable for medium-voltage power distribution ranging from 22kV to 66 kV.

Vacuum circuit breaker



SF6 vs Vacuum CB

Parameter	SF6 Circuit Breaker	Vacuum Circuit breaker
Arc interruption	Uses self-blast interruption to extinguish arc at high and low currents	Forms charge carrier to extinguish short circuit currents.
Electrical Endurance	Maintenance free	Maintenance free
Switching over voltages	Capable by using soft interruption	Uses contact materials for switching
Capacitor	Uses to limit current	Synchronous control with voltages greater 27kV
Motor Switching	Protects over-voltage limit	For small motors (currents less than 600 Amperes)
Technique	Auto puffer	Auto puffer
Malfunction	Due to over-pressure values	Implosion effect
Usage	The SF6 circuit breaker is used in high-frequency applications	The vacuum Circuit breaker is used in low-frequency applications (16 Hz)

Summary

HV CB	Voltage level	VA level
Air break CB	up to 600 V	5-35 MVA
Vacuum CB	11 KV	500 MVA
Bulk Oil CB	up to 12 KV	500 MVA
Minimum oil CB	33-245 KV	30000 MVA
Air blast CB	245-400 KV	35000 MVA
SF6 CB	245-700 KV	35000-50000 MVA

Time and speed of circuit breaker

- **CB time :**
  - Fault clearing time= [Relay time] + [Circuit breaker time]
  - Relay time= [Instant to fault] to [Closure of trip circuit]
  - Circuit breaker time= [Closure of trip circuit] to [Final arc extinction] =[Opening time + Arcing time]
  - i.e. **Fault clearing time= [Instant to fault] to [Arcing time]**

- **Speed of CB and Relay:**
  - Before 1930: CB interrupting time: 15-30 cycles; Relay interrupting time: 6-120 cycles
  - 1930: CB interrupting time: 8 cycles
  - 1935: CB interrupting time: 3 cycles
  - Present days relay time becomes as small as 1-3 cycles

Review of short circuit fault

- ❖ Short circuit fault:
  - ❖ Whenever a fault occurs on a network such that a large current flows in one or more phases, a short-circuit is said to have occurred.
- ❖ Causes of short circuit fault:
  - ❖ Internal effects: Aging of insulation ,inadequate design or improper installation
  - ❖ External effect: Lighting surges, over loading of equipment causing excessive heating, mechanical damage by public
- ❖ Effects of short circuit fault:
  - ❖ Excessive heating due to heavy current that may damage equipment.
  - ❖ Low voltage created by fault has a very harmful effect on the service rendered by the power system.

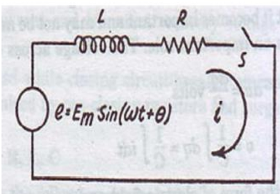
Review of short circuit fault

- ❖ Types of short circuit fault:
  - ❖ Symmetrical fault
    - ❖ L-L-L fault
    - ❖ L-L-L-G fault
  - ❖ Asymmetrical fault
    - ❖ Single L-G fault
    - ❖ L-L or double line fault
    - ❖ L-L-G or double line to ground fault

Review of short circuit fault

❖ Transients in RL circuits:

Consider the following R-L circuit

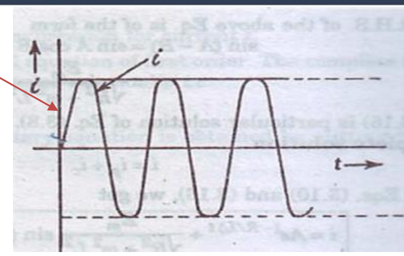


$V_m\sin(\omega t + \alpha) = Ri + L\,di/dt$

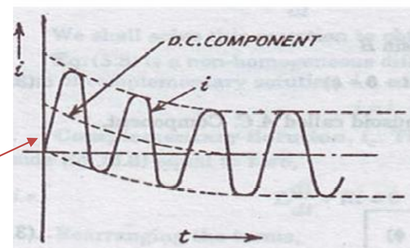
$$i(t) = \underbrace{\frac{V_m}{|Z|}\sin(\omega t + \alpha - \theta)}_{\text{ac component}} - \underbrace{\frac{V_m}{|Z|}e^{-\frac{R}{L}t}\sin(\alpha - \theta)}_{\text{dc component}}$$

Where $Z = \sqrt{R^2 + (\omega L)^2}$; $\theta = \tan^{-1}(\omega L/R)$

Symmetrical ac component

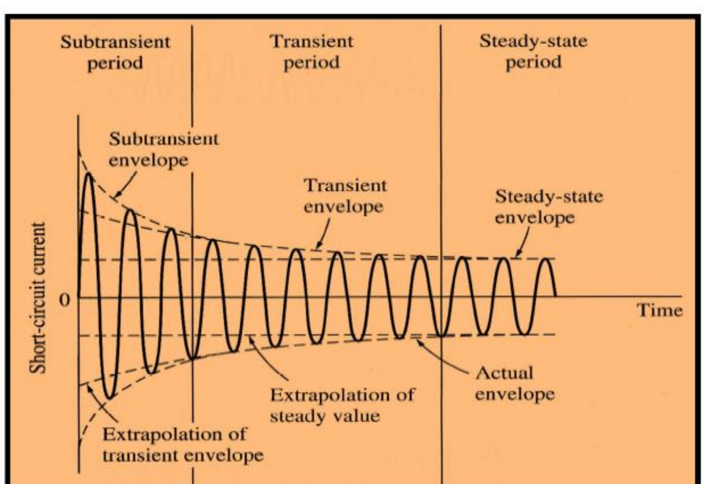


Summation of ac and dc component



Review of short circuit fault

❖ Transients of short circuit fault current if the fault is at the terminal of a synchronous generator



Ratings of a CB

- **Rated voltage:** corresponds to the higher system voltage for which the circuit breaker is intended.
- **Rated current:** r.m.s. value of the current which the circuit breaker can carry continuously.
- **Rated short circuit breaking current:** r.m.s value of the fault current under transient period.
  - **Rated symmetrical breaking current**= $\frac{\text{Rated short circuit breaking capacity}}{\sqrt{3} \text{ X kV (Rated Voltage)}}$
  - **Rated short circuit breaking capacity (Rupturing Capacity) of a CB**= √3 X kV (Rated Voltage) X kA (symmetrical breaking current)
- **Rated short circuit making current:** peak value of the fault current is called the making current of the CB.
  - **Rated short circuit making current**= 1.8 X √2 X rated short circuit breaking current (symmetrical)
    = 2.55 X rated short circuit breaking current (symmetrical)
  - **Making Capacity** = 2.55 X symmetrical breaking capacity
- **Rated duration of short circuit (rated short time current)(short time rating):** r.m.s value of current that the CB can carry in a fully closed position during a specified time under prescribed conditions of use and behavior.

Mathematical problem

- **Problem 1:** A three phase CB is rated 1250 A, 2000 MVA (breaking capacity), 33kV, 4 sec. Find the symmetrical breaking current, making current and short time rating.
- **Solution:**
  - Rated symmetrical rms breaking current =$\frac{2000}{\sqrt{3}\times 33}$=34.99 kA
  - Rated making current = 2.55 X 34.99kA = 89.23kA
  - Short time rating = 34.99kA for 4 sec.

Difference between CB and Fuse

	Fuse	Circuit breaker
Function	It performs both detection and interruption functions	It performs interruption function only. The detection of fault is made by relay system
Operation	Inherently completely automatic	Requires elaborate equipment (i.e. relays) for automatic action
Breaking capacity	Small	Very large
Operating time	Very small (0·002 sec or so)	Comparatively large (0·1 to 0·2 sec)
Replacement	Requires replacement after every operation	No replacement after operation

End of part 01

Part 02-Low voltage circuit breaker (LVCB)

- ❖ Low voltage circuit breaker can be of two categories-
  - ❖ Miniature circuit breaker (MCB)
  - ❖ Moulded case circuit breaker (MCCB)

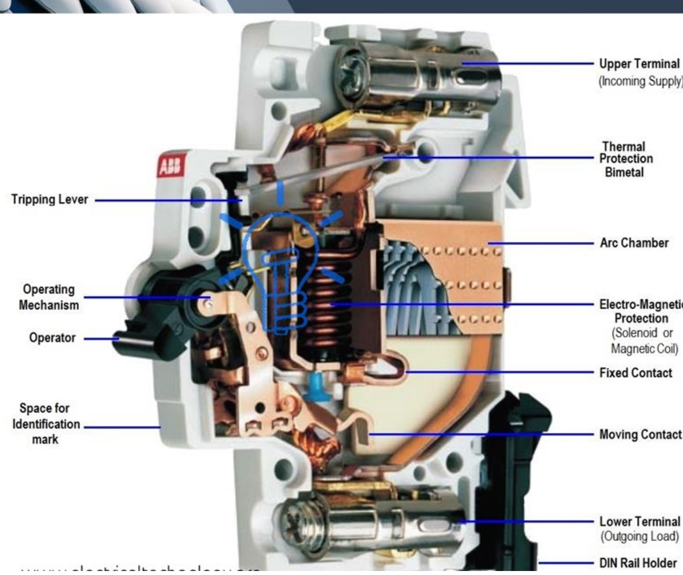
Features of LVCB

- ❖ In these circuit breakers arc extinction is carried under normal air.
- ❖ Rating of MCB is up to 100A.
- ❖ Rating of MCCB is up to 100A to 1000A.
- ❖ there are 1 pole/2 pole/3 pole MCB for single phase or three phase.
- ❖ But MCCB can only be 3 pole for 3 phase.
- ❖ In HVAC CB, there is a trip relay.
- ❖ In MCB and MCCB, there is trip release rather than trip relay.

Difference between trip relay and trip release

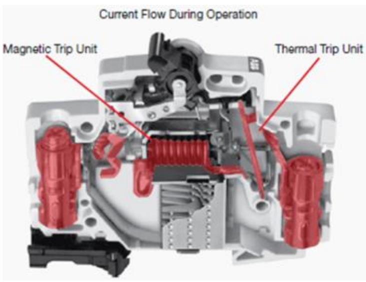
Trip relay	Trip release
Used in high voltage system	Used in low voltage system
A relay initiates the closure of the trip circuit for opening the contact of a CB under fault or abnormal operating condition.	No separate relay is required to open the contact of MCB/MCCB under abnormal operating condition. A bimetallic element for thermal overload sensing and a magnetic coil for fault current sensing are connected in series with the circuit. This trip release is a mechanism which directly helps to open the contacts of MCB/MCCB

Components of a MCB

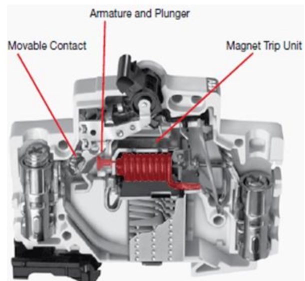


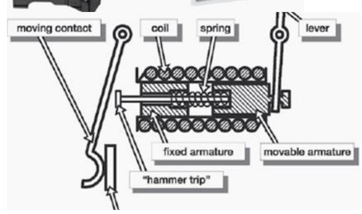
Components of a MCB

Direction of current flow during operation

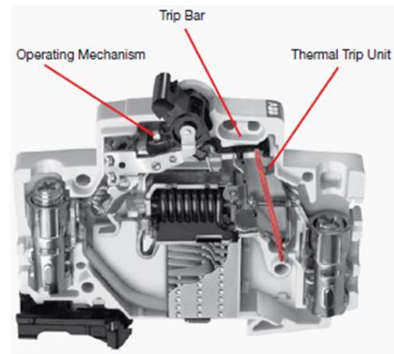


Internal construction of magnetic trip unit



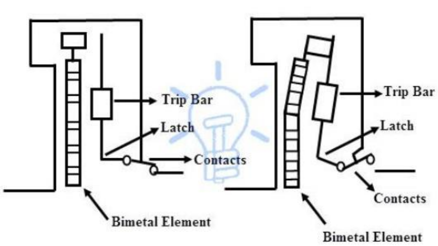


Internal construction of thermal trip unit

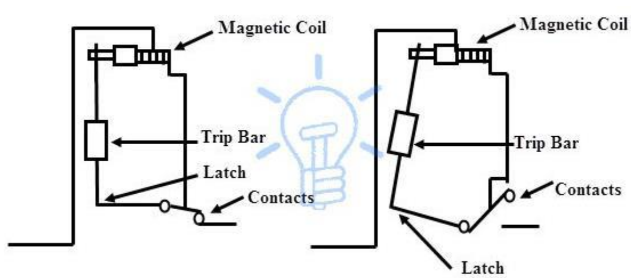


Working principle of MCB

Thermal trip unit operation



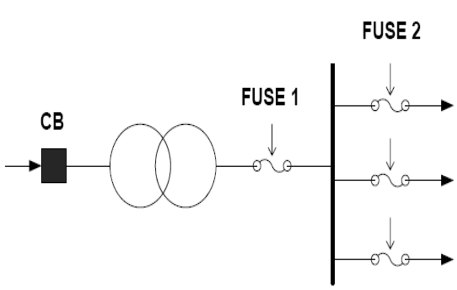
Magnetic trip unit operation



Difference between MCCB/MCB and CB

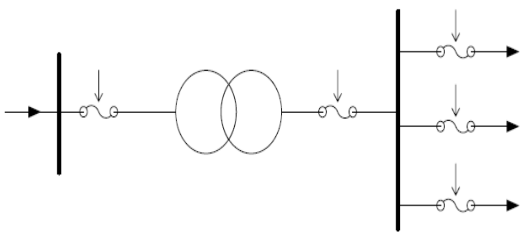
MCB/MCCB	CB
Used as switch under normal operating conditions	Used as switch under normal operating conditions
Tripping mechanism is actuated by trip release	Tripping mechanism is actuated by trip relay
Used in LV system	Used in HV system
Low rupturing capacity	High rupturing capacity

Coordination between CB and fuse



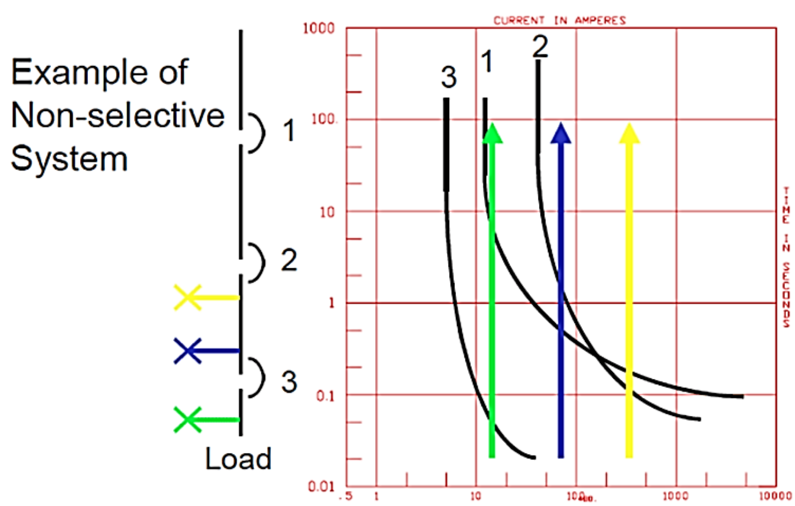
For faults on outgoing feeders, Fuse2 of that feeder should operate first.Fuse1 would provide backup. For any fault on LT bus, Fuse1 should operate first and HV circuit breaker should provide backup.

Coordination between CB and fuse



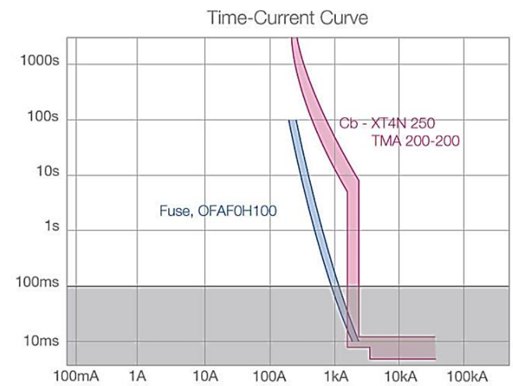
It is the normal practice not to use any CB on the HT side of the distribution transformer below 500kVA. In this case, fuses are used on the both sides of the transformer.

Problem with non-selective system



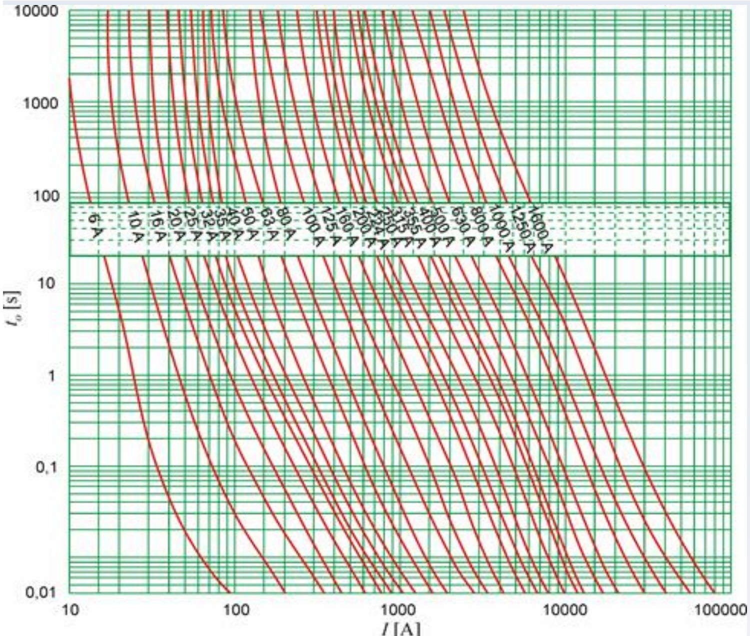
Selectivity in Overload Zone (Upstream-CB, Downstream-Fuse)

- ❖ Selectivity is obtained by comparing time-current characteristics
- ❖ It is advisable to maintain a safety margin between the maximum tripping time of the fuse characteristic and the minimum tripping time of the circuit-breaker characteristic.
- ❖ Generally, a delta time ≥ 1s is enough for thermal-magnetic breakers and 100 ms in case of electronic trip units.



Mathematical problem

❖ Suggest a guideline for the protection of HT and LT side of a transformer rated as 250 KVA, 450 V/11KV and Impedance 4.75%. The blow out time for the corresponding fault current is given in the following TCC curve. Also justify your answer on the selection of protective components.



Mathematical problem

Solution:

Transformer rating= 250 kVA

Transformer voltage ratio= 0.415/11 kV

Zpu= 4.75%= 0.0475 pu

Now,

$$IbaseLT = \frac{250 \times 10^3}{\sqrt{3} \times 415} Amp = 348\ Amp$$

$$IbaseHT = \frac{250 \times 10^3}{\sqrt{3} \times 11 \times 10^3} = Amp = 13.12\ Amp$$

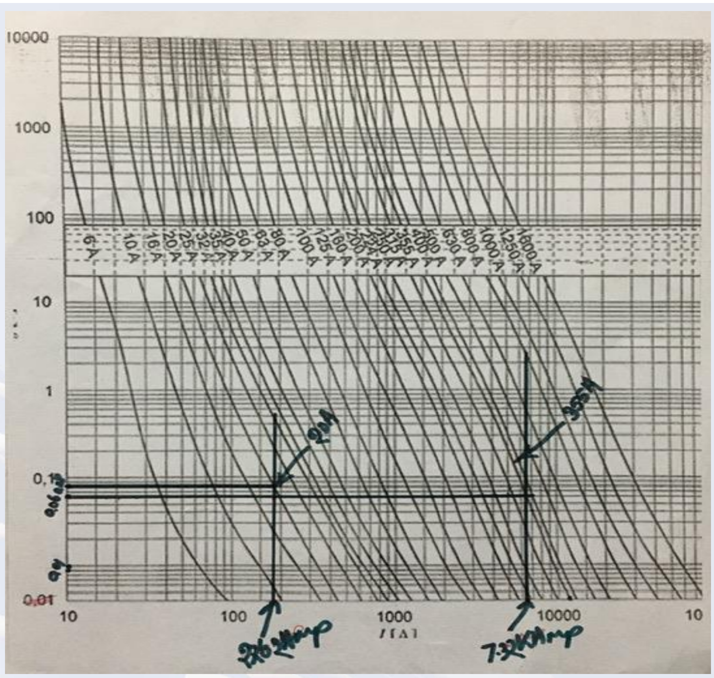
$$IpuLT = IpuHT = \frac{1}{Zpu} = \frac{1}{0.0475} = 21.05\ pu$$

Mathematical problem

$IfaultLT = 348 \times 21.05\ Amp = 7.32\ kAmp$

$IfaultHT = 13.12 \times 21.05\ Amp = 276.2\ Amp$

So, for LT side, fuse of 355 Amp should be chosen and for HT side fuse of 20 Amp should be chosen.



End of part 02

- Key References-
- Chapter 19/ Principles of power systems/ V.K.Mehta & Rohit Mehta.
- ABB Manuals
- Codrey.com

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