POWER SYSTEMS PROTECTION COURSE

Dr. Audih al-ffaoury
Electrical Energy department
2018-2019

Department of Electrical Energy Engineering
Part 3
Protective Devices
Fuses & Circuit Breakers
**Introduction:**

- Fuse is advice used to protect the circuits and equipments against **overload** and **short circuits**.
- Fuse element materials having **low melting point, high conductivity**.
- Fuse operation **based on the heating effect** of the current when flows through element. In normal operation the heat dissipated rapidly into the surrounding air and element remains at below its melting point. When fault occurs in the electric circuit, the current exceeds the limiting value and cannot be dissipated heat fast enough and element melts and breaks the circuit.
- Its rating can start from few mA to several kA.
- Many forms and shapes depending on its application.
- Fuse has inverse time current characteristics.
Low voltage fuses
1- **Rewirable Fuse**
(made from porcelain or ceramic insulator).

**Advantage**
- Low cost
- Wire may be easy available.

**Disadvantage**
- wrong size of wire of to be fitted in fuse cause wrong operation at high current circuit which may be dangerous for the circuit protected and not adequate for electrical arc extinguish ..
2- Cartridge Fuse.

Advantage

- The wire is enclosed in a cartridge-type container.
- The wrong size of fuse cannot be fitted since it with different size for different current
- The fuse wire does not deteriorate and is more reliable in operation
3- High Rupturing Capacity (H.R.C)

It is a cartridge-type with silver element connected between two end-contacts of a ceramic tube filled with a special quartz powder.

- This type of fuse is very reliable in performance and does not deteriorate and has a high speed.
- When the fuse blows is a silver (which rapidly melt) produced with the filling powder high-resistance material are formed in of operation and the path of the arc, causing it to be extinguished.
- Ability to safely interrupt short circuit currents of much higher values (higher rupturing capacity).
Fusing factor

- Fusing factor is the **smallest current that will cause the fuse element to melt**.
- Fusing factor is the ratio of a fuse's **minimum fusing current**. This may vary between 1.25 and 2.5 times the current rating.
- The current rating is the nominal rated current in Amps marked on the fuse body that the fuse will carry continuously without deteriorating.

\[
Fusing \ factor = \frac{Rated \ minimum \ fusing \ current}{Current \ rating}
\]

\[Rated \ minimum \ fusing \ current = Fusing \ factor \times Current \ rating\]

Classification of LV fuses

There are four classes, depending on fusing factors:

1- **Class P** :- Having a **fusing factor of 1.25 or less**

This class is to protect **circuits with small overloads**
2- **Class Q fuses**: Used for circuits with small over-currents and higher values of overload. And its divided into two

- **Class Q1**—fusing factor between 1.25 and 1.5
- **Class Q2**—fusing factor between 1.5 and 1.75

3- **Class R fuses**: Used to protected a circuit against large over-currents only. (Mainly is back-up protection)

- **Class R**—Fusing factor between 1.75 and 2.5

Example: What is the minimum rated current of the 20A Q2 fuse that will be operated

\[
\text{Rated minimum fusing current} = \text{Fusing factor} \times \text{Current rating}
\]

\[
= 20A \times 1.5 = 30A \quad \text{or} \quad = 20A \times 1.75 = 35A
\]

Minimum fusing current rated to operate is between 30 and 35Amps
According to IEC standard, two classes of LV cartridge fuse are widely used:

1. For **domestic** (for lighting circuit) and **smaller installation** type gG is used.
2. For **industrial installations** (for motor protection) gM type is used.
3. For **industrial installations** (for short-circuit currents) aM type is used.

**Fuse symbols**
CURRENT MELTING FUSE ELEMENT AND CLEARING TIME

A curve to represent the total clearing time as a function of the current with main characteristics of a fuse the curve type may be:

1. • The minimum melting time curve
2. • The total clearing time curve
3. • The fuse minimum melting current
4. • The fuse rating (nominal current)

Note:- Don’t confuse with the minimum melting current.
**Short circuit Current**

The fuse installed to protect against such current must be able break this current as $I^2 t_1$. 

![Diagram of short circuit current]

- **Prospective fault current**
- **RMS value**
- **Cut-off point**
- **Fault current**
- **Pre-arcing time**
- **Arc being extinguished**

**Graphical Notes**
- Prospective fault-current peak
- RMS value of the AC component of the prospective fault current
- Current peak limited by the fuse

**Symbols**
- $T_f$: Fuse pre-arc fusing time
- $T_a$: Arcing time
- $T_{tc}$: Total fault-clearance time
**The \( I^2t \) factor of the fuse**

The operation time of the fuse at high levels of current is inversely proportional to the square of the current during the pre-arcing stage (operation).

For any conductor, its temperature rise depends on the \( I^2t \) factor. This factor can be calculated by:

- **For copper conductors**

  \[
  I^2 t = 11.5 \times 10^4 A^2 \log_{10} \frac{273 + \theta_m}{273 + \theta_o}
  \]

- **For Aluminum conductors**

  \[
  I^2 t = 5.2 \times 10^4 A^2 \log_{10} \frac{273 + \theta_m}{273 + \theta_o}
  \]

Where:

- \( I \) = Short circuit current (A)
- \( t \) = Duration of the short circuit (s)
- \( A \) = Cross-sectional area of the conductor (mm)
- \( \theta_o \) = Initial temperature of the conductor (°C)
- \( \theta_m \) = Final temperature of the conductor (°C).
Example:

It is proposed to use a No.30 AWG (American wire gauge) copper wire as a fuse element for Rewirable type. If its initial temperature is 50°C, taking in consideration that the copper melt at 1083°C calculate the following:

(a) The $I^2t$ needed to melt the wire.
(b) The time needed to melt the wire if the short circuit current is 30A.

**Solution**

\[ I^2t = 11.5 \times 10^4 A^2 \log_{10} \left( \frac{273 + \theta_m}{273 + \theta_o} \right) \]

\[ I^2t = 11.5 \times 10^4 \times 0.0503^2 \times \log_{10} \left( \frac{273 + 1083}{273 + 50} \right) = 181.3 A^2 \cdot s \text{ then;} \]

\[ t = \frac{181.3}{30^2} = 0.2s \]

The melt of the fuse is after 0.2 second but at what current of the load, this can be found from fuse curve.
From characteristic of the fuse for 0.2s and 30A normal rating the melting point at (copper melt at 1083 C⁰) short circuit is at around 270A.

Time/current characteristics of semi-enclosed fuses to BS 3036
High Voltage Fuses

Same characteristics and operation as LV fuse but differing in size and shape
The time current characteristics also may be represent as in Figure

$I^2.t$ rating of fuses
Circuit Breakers
Low Voltage Circuit breaker

A circuit breaker (CB) is an automatically switchable device to protect an electrical circuit from overload or short circuit.

- The main advantage is when operates can be reset.
- Its varying sizes and current rating.
Circuit Breaker Operation:-
There are many types of CB

1. **Magnetic circuit breakers:**

   - Based on a solenoid (electromagnet) whose pulling force increases with the current.
   - The contacts are held closed, in case of sc or overload the current in the solenoid increases beyond the rating of the CB, the solenoid's pull and releases the latch. This allows the contacts to open by spring action.
2. **Thermo-magnetic circuit breakers**

Thermal breakers use a **bimetallic strip**, which heats and bends with increased current, and release the latch. This type is commonly used with motor control circuits.
Types of circuit breaker

For applications at low voltage (less than 1000 V) the types are:-

a) **Miniature Circuit Breaker (MCB)**:

- **MCB rated current not more than 100 A.**
- MCB is used for 1-phase and 3-phase applications,

![Image of circuit breakers]

Rated current: International Standard IEC (at ambient air temperature of 30 °C) are:

(6, 10, 13, 16, 20, 25, 32, 40, 50, 63, 80 and 100) Amperes.

**Note**: The circuit breaker is labeled with the rated current in ampere, but without the unit symbol "A".
Instead, the ampere figure is preceded by a letter "B", "C", "D", "K" or "Z" that indicates the instantaneous tripping current (the minimum value of current that causes the circuit-breaker to trip) without intentional time delay (i.e., in less than 100 ms):

<table>
<thead>
<tr>
<th>Type</th>
<th>Instantaneous tripping current</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>above $3I_n$ up to and including $5I_n$</td>
</tr>
<tr>
<td>C</td>
<td>above $5I_n$ up to and including $10I_n$</td>
</tr>
<tr>
<td>D</td>
<td>above $10I_n$ up to and including $20I_n$</td>
</tr>
<tr>
<td>K</td>
<td>above $8I_n$ up to and including $12I_n$</td>
</tr>
<tr>
<td></td>
<td>For the protection of loads that cause frequent short duration (approximately 400 ms to 2 s) current peaks in normal operation.</td>
</tr>
<tr>
<td>Z</td>
<td>above $2I_n$ up to and including $3I_n$ for periods in the order of tens of seconds.</td>
</tr>
<tr>
<td></td>
<td>For the protection of loads such as semiconductor devices or measuring circuits using current transformers.</td>
</tr>
</tbody>
</table>

*Note: $I_n$=Nominal current*
b) Molded Case Circuit Breakers (MCCB)

- Thermal or thermal-magnetic operation.
- Tripping current may be adjustable.
- Mainly is used for 3-phase circuits and for currents larger than 100A and up to 1600A.
- Mainly is used in industrial applications to protect cables and equipment.
- Types of these C.Bs are shown below:
c) **Air Circuit Breaker (ACB)**

- Tripping current is adjustable
- This type of circuit breaker is **used for very large current applications** up to 6000A. Its construction is shown below:

  ![Air Circuit Breaker External Labels](image)

  1. OFF button (O)
  2. ON button (I)
  3. Main contact position indicator
  4. Energy storage mechanism status indicator
  5. Reset Button
  6. LED Indicators
  7. Controller
  8. “Connection”, “Test” and “isolated” position stopper (the three-position latching/locking mechanism)
  9. User-supplied padlock
  10. Connection “,” Test “and” separation “of the position indication
  11. Connection (CE) Separation, (CD) Test (CT) Position indication contacts
  12. Rated Name Plate
  13. Digital Displays
  14. Mechanical energy storage handle
  15. Shake (IN/OUT)
  16. Rocker repository
  17. Fault trip reset button
d) Other types of circuit breakers.

Breakers for protections against earth faults to trip an over-current device such as:

- **Residual Current Device (RCD)** or **Residual Current Circuit Breaker (RCCB)**:
  Disconnects a circuit when detects the electric current is not balanced between the phase conductor and the neutral conductor. Does NOT provide over-current protection. Sometimes caused by current leakage through the body of a person who is grounded and accidentally touching the energized part of the circuit.

- **Residual Current Breaker with Over-current protection (RCBO)**:
  Combines the functions of an RCD and an MCB in one package.

- **Earth leakage circuit breaker (ELCB)**:
  This detects earth current directly rather than detecting imbalance
High Voltage Circuit breakers

The most important types are:

a) Oil circuit breakers (OCBs)
b) Air-blast circuit breakers
c) SF6 circuit breakers
d) Vacuum circuit breakers

- The action that causes a circuit breaker to open is usually produced by means of an overload relay.
- The relay detect abnormal line conditions.
a) **Oil Circuit Breakers:**
There are two types of oil circuit breakers:

i. **Bulk oil circuit breakers**
- Composed of a steel tank filled with insulating oil (for electric arc).
- For three phase there are three movable contacts, actuated simultaneously by an insulated rod, open and close the circuit.
- When the circuit breaker is closed, the line current for each phase, flows through the fixed contact.
- If high current is detected the tripping coil releases a powerful spring that pulls on the insulated rod, causing the contacts to open.
ii. Minimum Oil Circuit breaker

These circuit breakers contain minimum quantity of oil. The three phases are separated into three chambers as shown in Figure.

**Advantages of OCB:**
- Oil has good dielectric strength.
- Low cost.
- Oil is easily available.
- It has wide range of breaking capability.

**Disadvantages:**
- Slower operation, takes about 20 cycles.
- It is highly risk of fire.
- High maintenance cost.
b) **Air-Blast Circuit Breakers:**

- These circuit breakers interrupt the circuit by **blowing compressed air** (about 435 psi) at supersonic speed across the opening contacts.
- The most powerful circuit breakers can typically open short-circuit currents of 40 kA at a line voltage of 750 kV in a matter of 3 to 6 cycles on a 50 Hz line.
- The noise air blast breaker is so loud then must considered when to be installed near residential areas.
c) **SF6 Circuit Breakers**

These totally enclosed circuit-breakers, insulated with SF6 (Sulfur hexafluoride) gas.

Several characteristics of SF6 circuit breakers:-

- Simply of the interrupting, does not need an auxiliary breaking chamber;
- Higher performance, up to 63 kA, with a reduced number of interrupting chambers.
- Possible compact solutions when used for GIS (gas insulation switchgear) or hybrid switchgear.
- Used in synchronized operations to reduce switching over-voltages.
Advantages:

- Very short arcing period due to superior arc.
- Much larger currents as compared to other breakers.
- No risk of fire.
- Low maintenance, less size.
- No over voltage problem.
- No carbon deposits.
- Reliability and availability.
- Low noise levels.

Disadvantages:

- Costly due to high cost of SF$_6$.
- SF$_6$ gas has to be reconditioned after every operation of the breaking.
- Additional equipment is required for this purpose.
d) **Vacuum Circuit Breakers.**

These circuit breakers operate on a different principle from other breakers because:

- There is no gas to ionize when the contacts open.
- They are silent and never become polluted.
- Several circuit breakers are connected in series.

Their interrupting capacity is limited to about 30 kV for higher voltages and is often used in underground distribution.

1. moving conductive shaft
2. oriented sleeve
3. bellow
4. moving cover plate
5. bellow shield
6. porcelain cover
7. shield cylinder
8. contact system
   (moving contact, fixed contact)
9. fixed conductive shaft
10. fixed cover plate
Advantages:

- Free from arc and fire hazards.
- Low cost for maintenance & simpler mechanism.
- Low arcing time & high contact life.
- Silent and less vibration operation.
- Due to vacuum contacts remain free from corrosion.

Disadvantages:

- High initial cost due to creation of vacuum.
- High cost & size required for high voltage breakers.