Fuses
Fuses

Many improvements have been made since the invention of first crude model. Now-a-days, several types of fuses are available which find extensive use in low to moderate voltage applications where frequent operations are not expected or where the use of circuit breaker is uneconomical.
200 A Industrial fuse. 80 kA breaking capacity.

Electronic symbols for a fuse. IEC (upper) and IEEE/ANSI American/Canadian (lower two) versions.
Advantages
(i) It is the cheapest form of protection available.
(ii) It requires no maintenance.
(iii) Its operation is inherently completely automatic unlike a circuit breaker which requires an elaborate equipment for automatic action.
(iv) It can break heavy short-circuit currents without noise or smoke.
(v) The smaller sizes of fuse element impose a current limiting effect under short-circuit conditions.
(vi) The inverse time-current characteristic of a fuse makes it suitable for overcurrent protection.
(vii) The minimum time of operation can be made much shorter than with the circuit breakers.
Disadvantages

(i) Considerable time is lost in rewiring or replacing a fuse after operation.
(ii) On heavy short-circuits, *discrimination between fuses in series cannot be obtained unless there is sufficient difference in the sizes of the fuses concerned.
(iii) The current-time characteristic of a fuse cannot always be co-related with that of the protected apparatus.
Desirable Characteristics of Fuse Element

The function of a fuse is to carry the normal current without overheating but when the current exceeds its normal value, it rapidly heats up to melting point and disconnects the circuit protected by it. In order that it may perform this function satisfactorily, the fuse element should have the following desirable characteristics:

(i) low melting point e.g., tin, lead.

(ii) high conductivity e.g., silver, copper.

(iii) free from deterioration due to oxidation e.g., silver.

(iv) low cost e.g., lead, tin, copper.

The above discussion reveals that no material possesses all the characteristics. For instance, lead has low melting point but it has high specific resistance and is liable to oxidation. Similarly, copper has high conductivity and low cost but oxidises rapidly. Therefore, a compromise is made in the selection of material for a fuse.
Important Terms

The following terms are much used in the analysis of fuses:

(i) **Current rating of fuse element.**
   It is the current which the fuse element can normally carry without overheating or melting. It depends upon the temperature rise of the contacts of the fuse holder, fuse material and the surroundings of the fuse.

(ii) **Fusing current.**
   It is the minimum current at which the fuse element melts and thus disconnects the circuit protected by it. Obviously, its value will be more than the current rating of the fuse element.

For a round wire, the approximate relationship between fusing current \( I \) and diameter \( d \) of the wire is

\[
I = k d^{3/2}
\]
where k is a constant, called the fuse constant. Its value depends upon the metal of which the fuse element is made. Sir W.H. Preece found the value of k for different materials as given in the table below:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Material</th>
<th>Value of k</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>d in cm</td>
</tr>
<tr>
<td>1</td>
<td>Copper</td>
<td>2530</td>
</tr>
<tr>
<td>2</td>
<td>Aluminium</td>
<td>1873</td>
</tr>
<tr>
<td>3</td>
<td>Tin</td>
<td>405.5</td>
</tr>
<tr>
<td>4</td>
<td>Lead</td>
<td>340.6</td>
</tr>
</tbody>
</table>

The fusing current depends upon the various factors such as:
(a) material of fuse element
(b) length – the smaller the length, the greater the current because a short fuse can easily conduct away all the heat
(c) diameter
(d) size and location of terminals
(e) previous history
(f) type of enclosure used
(iii) Fusing factor.
It is the ratio of minimum fusing current to the current rating of the fuse element i.e.
Fusing factor =

\[
\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{Current rating of fuse}}
\]

Its value is always more than one.
The smaller the fusing factor, the greater is the difficulty in avoiding deterioration due to overheating and oxidation at rated carrying current.
For a semi-enclosed or rewirable fuse which employs copper wire as the fuse element, the fusing factor is usually 2.
Lower values of fusing factor can be employed for enclosed type cartridge fuses using silver or bimetallic elements.
(iv) Prospective Current. Previous Fig. shows how a.c. current is cut off by a fuse. The fault current would normally have a very large first loop, but it actually generates sufficient energy to melt the fuseable element well before the peak of this first loop is reached. The r.m.s. value of the first loop of fault current is known as prospective current. Therefore, prospective current can be defined as under: It is the r.m.s. value of the first loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible resistance.

(v) Cut-off current. It is the maximum value of fault current actually reached before the fuse melts.
On the occurrence of a fault, the fault current has a very large first loop due to a fair degree of asymmetry. The heat generated is sufficient to melt the fuse element well before the peak of first loop is reached (point ‘a’ in previous fig.) The current corresponding to point ‘a’ is the cut off current. The cut off value depends upon:
(a) current rating of fuse
(b) value of prospective current
(c) asymmetry of short-circuit current
The outstanding feature of fuse action is the breaking of circuit before the fault current reaches its first peak. This gives the fuse a great advantage over a circuit breaker since the most severe thermal and electro-magnetic effects of short-circuit currents (which occur at the peak value of prospective current) are not experienced with fuses. Therefore, the circuits protected by fuses can be designed to withstand maximum current equal to the cut-off value. This consideration together with the relative cheapness of fuses allows much saving in cost.

(vi) Pre-arcing time. It is the time between the commencement of fault and the instant when cut off occurs. When a fault occurs, the fault current rises rapidly and generates heat in the fuse element. As the fault current reaches the cut off value, the fuse element melts and an arc is initiated. The time from the start of the fault to the instant the arc is initiated is known as pre-arcing time. The pre-arcing time is generally small: a typical value being 0.001 second.

(vii) Arcing time. This is the time between the end of pre-arcing time and the instant when the arc is extinguished.
(viii) **Total operating time.**
It is the sum of pre-arcing and arcing times. It may be noted that operating time of a fuse is generally quite low (say 0.002 sec.) as compared to a circuit breaker (say 0.2 sec or so).
This is an added advantage of a fuse over a circuit breaker. A fuse in series with a circuit breaker of low-breaking capacity is a useful and economical arrangement to provide adequate short-circuit protection. It is because the fuse will blow under fault conditions before the circuit breaker has the time to operate.

(ix) **Breaking capacity. (Important)**
It is the r.m.s. value of a.c. component of maximum prospective current that a fuse can deal with at rated service voltage.
Types of Fuses

- Since the invention of first fuse by Edison, several improvements have been made and now-a-days, a variety of fuses are available. Some fuses also incorporate means for extinguishing the arc that appears when the fuse element melts. In general, fuses may be classified into:

  - (i) Low voltages fuses
  - (ii) High voltage fuse
Low voltage fuses can be subdivided into two classes viz.,

(i) semi-enclosed rewirable fuse.
Semi-enclosed rewirable fuses are made up to 500 A rated current, but their breaking capacity is low e.g., on 400 V service, the breaking capacity is about 4000 A. Therefore, the use of this type of fuses is limited to domestic and lighting loads.
(ii) **High rupturing capacity (H.R.C.) cartridge fuse.**
The primary objection of low and uncertain breaking capacity of semi-enclosed rewirable fuses is overcome in H.R.C. cartridge fuse.

(III). **H.R.C. fuse with tripping device.** Sometime, H.R.C. cartridge fuse is provided with a tripping device. When the fuse blows out under fault conditions, the tripping device causes the circuit breaker to operate.
High Voltage Fuses

(i) Cartridge type.
High voltage cartridge fuses are used up to 33 kV with breaking capacity about 8700 A at that voltage. Rating of the order of 200 A at 66 kV and 11 kV and 50 A at 33 kV are also available.

(ii) Liquid type. They may be used for circuits up to about 100 A rated current on systems up to 132 kV and may have breaking capacities of the order of 6100 A.

(iii) Metal clad fuses.
Current Carrying Capacity of Fuse Element

The current carrying capacity of a fuse element mainly depends on the metal used and the cross sectional area but is affected also by the length, the state of surface and the surroundings of the fuse.

When the fuse element attains steady temperature,
Heat produced per sec = Heat lost per second by convection, radiation and conduction

\[
\begin{align*}
I^2R &= \text{Constant} \times \text{Effective surface area} \\
I^2 \left(\rho \frac{l}{a}\right) &= \text{constant} \times d \times l \\
\text{where} & \quad d = \text{diameter of fuse element} \\
& \quad l = \text{length of fuse element} \\
\therefore \quad I^2 \frac{\rho l}{(\pi/4) d^2} &= \text{constant} \times d \times l \\
\text{or} & \quad I^2 = \text{constant} \times d^3 \\
\text{or} & \quad I^2 \propto d^3 \\
\text{Expression (i) is known as ordinary fuse law.}
\end{align*}
\]
Example 20.1. A fuse wire of circular cross-section has a radius of 0.8 mm. The wire blows off at a current of 8A. Calculate the radius of the wire that will blow off at a current of 1A.

Solution.

\[ I^2 \propto r^3 \]

\[ \left( \frac{I_2}{I_1} \right)^2 = \left( \frac{r_2}{r_1} \right)^3 \]

\[ \therefore \quad \frac{I_2}{I_1} = \frac{r_2}{r_1} \]

or

\[ r_2 = r_1 \times \left( \frac{I_2}{I_1} \right)^{2/3} = 0.8 \times \left( \frac{1}{8} \right)^{2/3} = 0.2 \text{ mm} \]
## 20.9 Difference Between a Fuse and Circuit Breaker

It is worthwhile to indicate the salient differences between a fuse and a circuit breaker in the tabular form.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Particular</th>
<th>Fuse</th>
<th>Circuit breaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Function</td>
<td>It performs both detection and interruption functions.</td>
<td>It performs interruption function only. The detection of fault is made by relay system.</td>
</tr>
<tr>
<td>2.</td>
<td>Operation</td>
<td>Inherently completely automatic.</td>
<td>Requires elaborate equipment (i.e. relays) for automatic action.</td>
</tr>
<tr>
<td>3.</td>
<td>Breaking capacity</td>
<td>Small</td>
<td>Very large</td>
</tr>
<tr>
<td>4.</td>
<td>Operating time</td>
<td>Very small (0.002 sec or so)</td>
<td>Comparatively large (0.1 to 0.2 sec)</td>
</tr>
<tr>
<td>5.</td>
<td>Replacement</td>
<td>Requires replacement after every operation.</td>
<td>No replacement after operation.</td>
</tr>
</tbody>
</table>
1. What is a fuse? Discuss the advantages and disadvantages of a fuse.
2. Why do we prefer silver as a fuse element?
3. Define and explain the following terms:
   (i) fusing current (ii) cut off current (iii) operating time (iv) breaking capacity
4. Write short notes on the following:
   (i) Semi-enclosed rewireable fuse
   (ii) H.R.C. cartridge fuse
   (iii) Difference between a fuse and circuit breaker

**DISCUSSION QUESTIONS**

1. Why are circuit breakers preferred to fuses?
2. Why fuses cannot provide adequate discrimination on heavy short-circuit?
3. Why fuses can interrupt heavy short-circuit currents successfully?