جامعة الإسكندرية

ALEXANDRIA UNIVERSITY

Safety of Electromechanical systems

Abstract

Protection of electrical circuits is very important in electrical systems as any fault current can cause huge losses for industries in terms of safety and productivity. Circuit protection devices are used to protect users and equipment from fault conditions in an electrical circuit by isolating the electrical supply. In this report, we will explain briefly the main two circuit protections devices: **Overcurrent protection devices** and **Residual Current devices,** and their types.

Overcurrent protection devices are used to protect against the potentially dangerous effects of overcurrents, which creates a fault current. When an overcurrent occurs, these devices break the circuit eliminating the current flow. Fuses and circuit breakers are the most common types of overcurrent protection devices. Fuses can be quicker for interrupting the flow of power, but when they melt they must be replaced; on the other hand circuit breakers just need to be reset.

Residual Current devices are designed to protect against the risks of electric shocks and fire caused by earth faults. There are various types of RCDs that can be used to offer high performance and protection. These devices offer a level of personal protection that ordinary fuses and circuit breakers cannot provide.

Safety devices

Introduction

An electrical system is built with great care to ensure that each separate electrical circuit is completely isolated from the others and that the current in a circuit will flow in its intended path. However, once the system is put into operation, many things can happen changing the original circuitry. Some of these changes can cause conditions that are dangerous to the circuit itself or to people living or working near the circuits. For this reason, circuit protection is required to avoid these potentially dangerous conditions. Although circuit protection devices cannot correct an abnormal current condition, they can indicate that an abnormal condition exists and protect people and circuits from that condition.

Circuit protective devices, as the name implies, all have a common purpose to protect users and equipment from fault conditions in an electrical circuit by isolating the electrical supply. As the technologies are getting improved, various devices are getting introduced, but the major two circuit protection devices are **Overcurrent protection devices** and **Residual Current devices**.

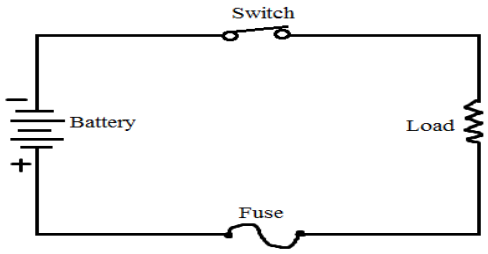
I. Overcurrent protection devices:

Overcurrent is an excess of current in an electrical circuit which occurs when the current exceeds the rated current capacity of that circuit or of the connected equipment. Overcurrent protection devices (OCPDs) are used to protect against the potentially dangerous impacts of overcurrents, such as an overload current or a short-circuit current, which creates a fault current.

There are many different types of OCPDs that are used to protect equipment and circuits from overcurrents. The most common types are **fuses** and **circuit breakers**. Both interrupt the flow of a current but in different ways from each other.

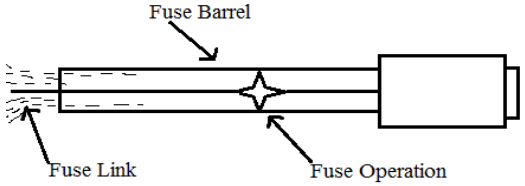
1. Fuses:

Fuses are safety devices, used to protect home appliances such as refrigerators, televisions, computers from damage by high voltage. It works as a circuit breaker or stabilizer which protects the device from damage. A fuse is made up of thin strip or strand of metal such as aluminum, copper, zinc. It is always connected in series with the electric circuit to protect it from overcurrent in the running cables, as shown in the circuit below.



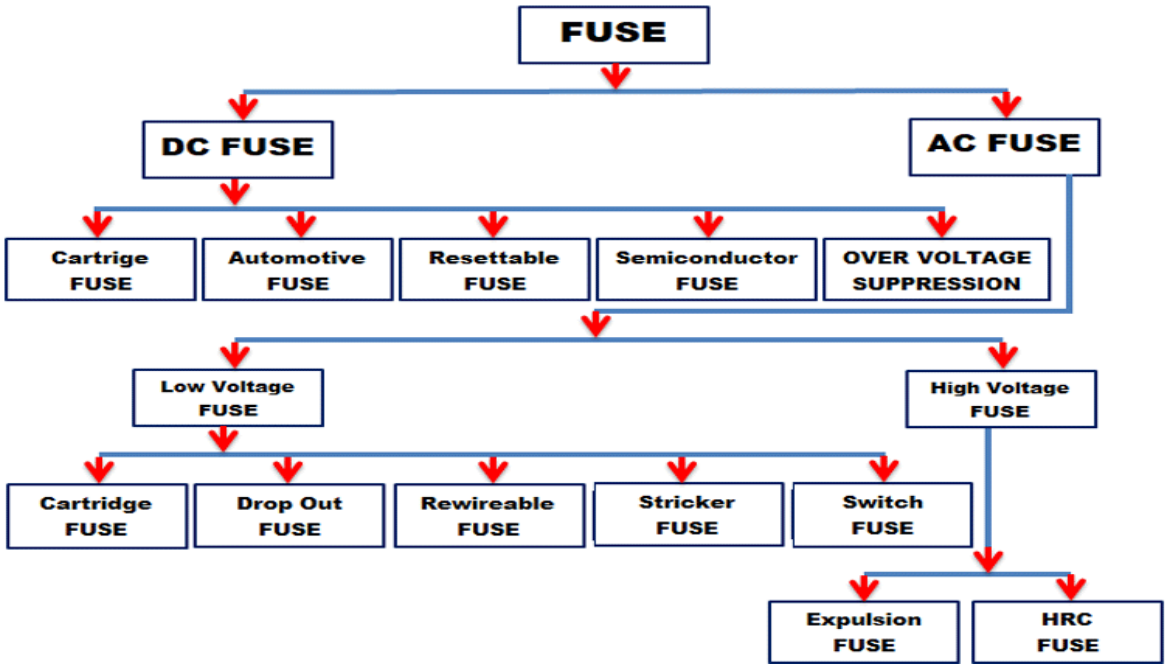
Theory of operation

The fuses work on the principle of the heating effect of the current. When an excessive current or heat is generated due to heavy current flows in the circuit, the fuse melts down due to the low melting point of the element and it opens the circuit. The excessive flow may lead to the breakdown of wire and stops the flow of current. The fuse can be replaced with the new one with suitable ratings.



Types of fuses

There are many types, features, and designs of fuses available in the market nowadays. They can be divided into two major categories: AC fuses, and DC fuses. The below block diagram illustrates the different types of the fuse under each category.

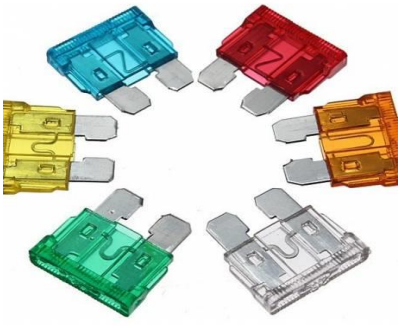


DC fuses

1. Cartridge fuses

This is the most common type of fuse. The fuse element is encased in a glass envelope that is terminated by metal caps. The fuse is placed in an appropriate holder. Since the glass envelope is clear, it is easy to visually determine if the fuse is blown.

2. **Automotive fuses:**



These fuses are specifically designed for automotive systems that run up to 32V and occasionally 42V. They come in ‘blade’ form (a transparent plastic envelope with flat contacts) and are colour coded according to rated current. Some of these types are also used in other high-power circuits.

3. **Resettable fuses/Polyfuses:**

These fuses are self-resetting. They contain carbon black particles embedded in organic polymers. Normally, the carbon black makes the mixture conductive. When a large current flows, heat is generated which expands the organic polymer. The carbon black particles are forced apart, and conductivity decreases to the point where no current flows.

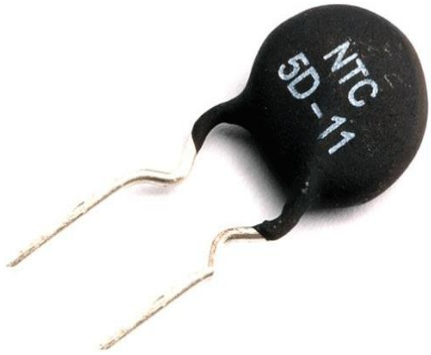
Conductivity is restored as temperature decreases. Thus, the fuse does not have to be physically replaced. This kind of fuse is also called “positive temperature coefficient PTC”, since resistance increases with temperature.

4. **Semiconductor fuses**

The power dissipated by a semiconductor increases exponentially with current flow, and hence semiconductors are used for ultrafast fuses. These fuses are usually used to protect semiconductor switching devices that are sensitive to even small current spikes.

5. **Overvoltage suppression**

Sometimes voltage spikes can be harmful to circuits too, and often an overvoltage protection device is used with a fuse to protect against both voltage and current spikes.



NTCs (negative temperature coefficient) are placed in parallel with the supply. When the supply voltage spikes, NTC Fuses decrease resistance due to higher current flow and 'absorb' spikes.

AC Fuses:

- **Low voltage fuses (LV)**

These fuses are used in the relatively low voltage distribution networks.

1. **Cartridge fuses**

They are very similar to cartridge DC fuses. They consist of a transparent envelope surrounding the fuse element. They can be plugged in (blade type) or screwed into a fixture (bolt type).

2. **Drop out fuses**

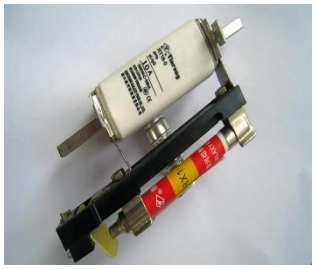
They contain a spring-loaded lever arm that retracts when a fault occurs and must be rewired and put back in place to resume normal operation. They are a type of expulsion fuse.

3. **Rewireable fuses**

They are a simple reusable fuse used in homes and offices. They consist of a carrier and a socket. When the fuse is blown, the carrier is taken out, rewired and put back in the socket to resume normal operation. They are somewhat less reliable than HRC fuses.

4. **Striker fuse:**

These fuses are provided with a spring-loaded striker that can act as a visual indicator that the fuse has blown and also activate other switchgear.



5. **Switch fuse**

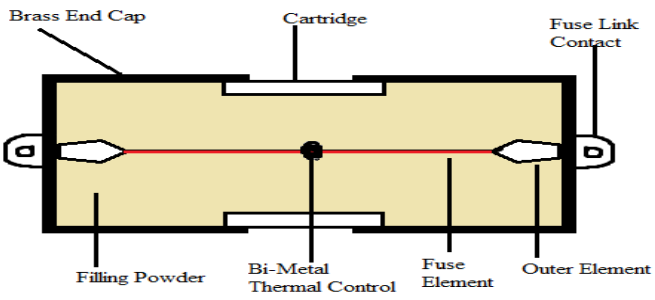
A handle that is manually operated can connect or disconnect high current fuses.

- **<u>High Voltage Fuses (HV)</u>**

These fuses are used in high voltage AC transmission lines where voltages can exceed several hundreds of kilovolts. All types of high voltage fuses are used upon the rated voltage up to 1.5 Kv to 138 Kv.

1. **HRC Fuses**

It is similar to low voltage type, only some designing features are different.



2. **Expulsion Type HRC Fuses:**

It is the escapable fuse, in which expulsion effect of gases produced by internal arcing. In this, the fuse link chamber is filled with boric acid for expulsion of gases.

Features of a Fuse

There are some important parameters that must be considered while selecting suitable fuses which are:

1. Current Rating
2. I^2T value
3. Voltage Rating
4. Operating Temperature

1. **Current Rating:**

This is the current carrying capacity of a fuse measured at normal conditions and temperature. Before adopting this technique, one must make sure that circuit components are able to withstand the overload of current before the fuse act its role. Therefore, whenever there is a sudden increase of current, only the fuse will blow out.

The circuit's current generally should be 75% of your fuse's current rating.

2. **I^2T Value of Fuse:**

This is also called as "melting current", when the current increases in the circuit, the melting time of the element decreases. This is because the power dissipation and the temperature increase rapidly. In short, the product of square of the current in the circuit should be less than I^2T value of the device.

$$I^2T_{Circuit} = I^2T_{Device}$$

3. **Voltage Rating:**

Voltage rating for the Fuses are mainly considered for safety reasons for the circuit as well as the environment. It is because an explosion may take place and might trigger fire if the open circuit voltage is higher than that of the device when fuses open up.

4. **Temperature:**

Temperature affects the capacity of Fuses. When the operating temperature is high, the current capacity will decrease and it melts early. Hence, the current capacity in the fuse is directly proportional to the operating temperature

Applications of Fuses

The applications of Fuses include nearly all electrical/ electronic devices such as:

- ✓ Electrical wiring at home.
- ✓ Appliances like AC, Refrigerator, TV, Washing machine etc.
- ✓ Laptops.
- ✓ Mobile chargers.
- ✓ Automobiles (Cars, Trucks, Buses, etc).

2. Circuit breakers:

The main duty of a Circuit Breaker is to switch ON and OFF the electrical circuits during normal or abnormal operating conditions, once or several times repeatedly.

Theory of operation

A typical circuit breaker consists of a fixed and a moving contact called Electrodes. These contacts are closed under normal conditions. If a fault occurs in the system, the contacts will open automatically and they can be opened manually. During fault conditions, a simple mechanism will pull the moving contacts away as a result of trip coil getting energized and essentially opening the circuit.

Types of circuit breakers

Circuit breakers are mainly categorized on the basis of application as per voltage:

Low Voltage Circuit Breakers

- Molded Case Circuit Breaker (MCCB)
- Air Circuit Breaker (ACB)
- Miniature Circuit Breaker (MCB)
- Motor Protection Circuit Breaker (MPCB)

Medium Voltage Circuit Breakers

- Vacuum Circuit Breaker (VCB)
- SF6 Circuit Breaker

High Voltage Circuit Breakers

- SF6/Vacuum Circuit Breaker
- Oil Circuit Breaker (OCB)

Low Voltage Circuit Breakers (operates up to 1KV)

1. Molded Case Circuit Breaker (MCCB):

MCCB is a kind of circuit breaker which is enclosed in the moulding or housing of a moulded material and that is the reason for its name. It is generally used for the current ratings up to 1600A and fault level up to 150KA. It offers protection against overload and short circuits through bimetal and solenoid, these days Microprocessor based MCCBs are being very popular due to the quick functioning of their electronic type release.

Applications:

These breakers are most commonly applied when very high fault levels are available and with applications where the current limiting capability is used upstream of the final load to limit current to the load. Typical loads include lighting and power distribution, and motor controller applications.

2. Miniature Circuit Breaker (MCB):

MCB is a circuit breaker which is used for protection where current ratings are lower. It can be used up to 125A circuits and like MCCBs it also offers protection against overload and short circuit through bimetal and solenoid. These days Class 3 MCBs are very popular due to their ability of tripping quickly and also minimum loss of let through energy.

3. Air Circuit Breaker (ACB):

ACB as the name suggests it's the circuit breaker where the medium of arc quenching is air. ACB is used for the high current applications, or we can say that ACB can offer protection against overload & short circuit upto 6300A. Tripping in ACB is achieved through release. The release is known as the mind of ACB as it only suggests the ACB to trip in case of fault.

4. Motor Protection Circuit Breaker (MPCB):

MPCBs are used specially for motor protections. MPCB as a standalone device offers protection against Overload, Short Circuit and Single Phasing, thus it is used specifically for motor applications.

Medium Voltage & High Voltage Circuit Breakers

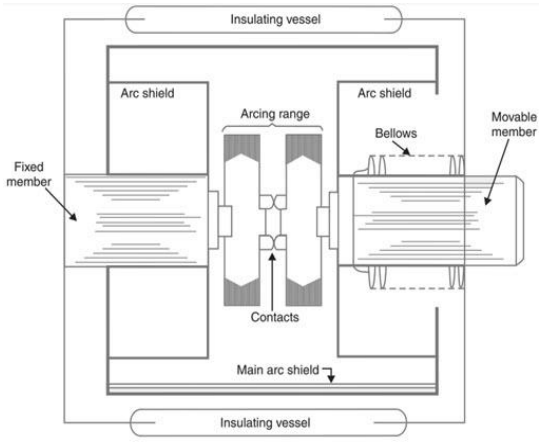
- ❖ Medium Voltage Circuit Breakers operates in a range from 1KV to 69KV
- ❖ High Voltage Circuit Breakers operates in a range from 69KV to 230KV

1. Vacuum Circuit Breaker (VCB)

VCB is used for Medium Voltage applications. In VCB the contacts operation & arc quenching takes place inside bottles where Vacuum is present.

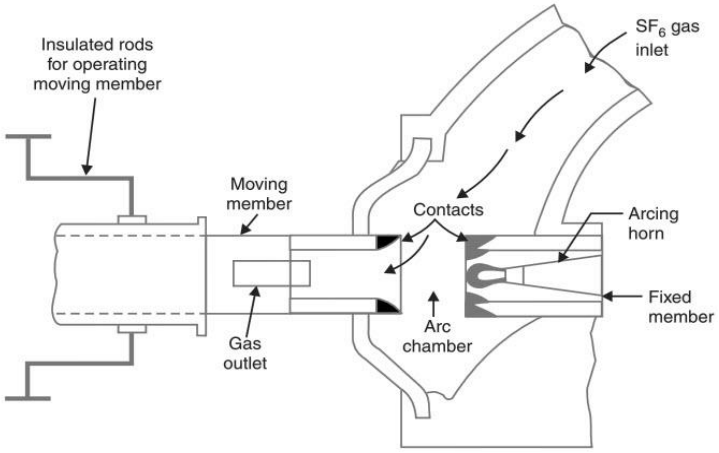
Advantages:

- No fire hazards.
- Compact, very reliable and have very long life.
- No gas is generated during or after operation.
- No or very little maintenance.
- VCB can interrupt any fault current.
- Can withstand lightning strikes.
- Low arc energy is released.



2. SF6 Circuit Breaker

SF6 circuit breakers are also used mainly in medium voltage applications. In this breaker SF6 gas is used for arc quenching due to its ability of quenching the arc very efficiently. SF6 Breakers being highly efficient in arc quenching are still not preferred much as SF6 being a poisonous gas, is dangerous to environment & humans.



Advantages:

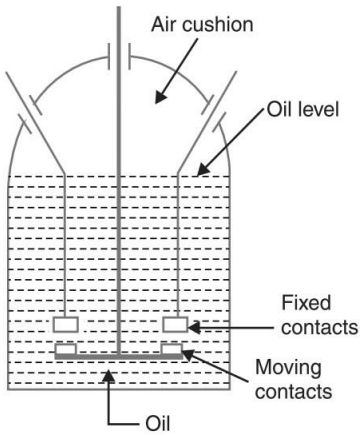
- Superior arc extinguishing property.
- Can interrupt larger currents as the dielectric strength of SF_6 gas is almost 3 times greater than air.
- Noise free operation and no exhaust into atmosphere.
- Moisture free operation as the gas filled chamber keeps in interior dry.
- Very low maintenance and requires minimum equipment.
- Suitable for hazardous and hostile conditions like coal mines as the breakers are enclosed and sealed.

Disadvantages:

- Sulfur hexafluoride gas is very costly.
- SF_6 has to be reconditioned after every operation.
- This high-pressure Sulfur hexafluoride gas will absorb all the conducting free electrons and as a result causes the extinction of the arc.

3. Oil Circuit Breaker

Oil Circuit Breakers were also used on high voltages & Oil was used as the arc quenching medium.



Advantages:

- Oil has excellent cooling property and the arc energy converts the oil into gas.
- Acts as insulator between live wires and earth.

Disadvantages:

- Oil is inflammable and is a fire hazard.
- Arcing products cannot escape and remain in the oil.

Applications of Circuit Breakers

- ✓ They are used for switching of loads in Industries, Buildings, Commercial complexes, Hotels etc.
- ✓ Air C/B is used for the protection of plants, electrical machines, transformers, capacitors and generators.
- ✓ Air Blast C/B is used in Indian Railways for electrification.
- ✓ Thermal and Magnetic Protection

Criteria in choosing the Circuit Breaker

- Electrical characteristics (AC or DC) of the installation for which the CB is intended
- Its environment: ambient temperature, in a kiosk or switchboard enclosure, climatic conditions, etc.
- Presumed short-circuit current at the point of installation
- Characteristics of the protected cables, busbars, busbar trunking system and application (distribution, motor...)
- Co-ordination with upstream and/or downstream device: selectivity, cascading, coordination with switch disconnector, contactor...
- Operational specifications: requirements (or not) for remote control and indication and related auxiliary contacts, auxiliary tripping coils, connection
- Installation regulations; in particular: protection against electric shock and thermal effect
- Load characteristics, such as motors, fluorescent lighting, LED lighting, LV/LV transformers

Calculating a safe circuit load

You first must add up the current of all the devices on the circuit that are on continuously, you just divide this number by the voltage at which it operates, which is either 120 volts or 240 volts.

Then, multiply this number by 125 percent. The rating of your circuit breaker must be larger than this total.

You want your circuit to be operating at 80 percent of capacity, which is called the safe load. You can calculate a safe load for a circuit breaker by multiplying its amperage by 0.8. A circuit can operate at a higher percentage, but not for long periods of time as this can compromise safety.

Selection Table

Element Wattage	Phases	Circuit Breaker Size (Amp)				Copper Wire Size in Gauge			
		208V	240V	277V	480V	208V	240V	277V	480V
3kW	1	20 A	20 A	15 A	15 A	12	12	14	14
	3	20 A	20 A	–	15 A	12	12	–	14
3.8kW	1	25 A	20 A	–	–	10	10	–	–
	–	–	–	–	–	–	–	–	–
4kW	1	25 A	25 A	20 A	15 A	10	10	12	14
	3	25 A	25 A	–	15 A	10	10	–	14
4.5kW	1	30 A	25 A	25 A	15 A	10	10	10	14
	3	30 A	25 A	–	15 A	10	10	–	14
5kW	1	30 A	30 A	25 A	15 A	10	10	10	14
	3	30 A	30 A	–	15 A	10	10	–	14
5.5kW	1	35 A	30 A	25 A	15 A	8	10	10	14
	3	35 A	30 A	–	15 A	8	10	–	14
6kW	1	40 A	35 A	30 A	20 A	8	8	10	12
	3	35 A	30 A	–	15 A	8	10	–	14
8kW	1	50 A	45 A	40 A	25 A	8	8	8	10
	3	45 A	40 A	–	20 A	8	8	–	12
9kW	1	–	50 A	45 A	25 A	–	8	8	10
	3	50 A	45 A	–	25 A	8	8	–	10
10kW	1	–	–	50 A	30 A	–	–	8	10
	3	–	50 A	–	25 A	–	8	–	10
11kW	1	–	–	50 A	30 A	–	–	8	10
	3	–	50 A	–	25 A	–	8	–	10
12kW	1	–	–	–	35 A	–	–	–	8
	3	–	–	–	30 A	–	–	–	10

Circuit Breaker Manufacturers

- General Electric – GE
- Westinghouse
- Cutler-Hammer
- Siemens – Allis Chalmers
- ABB – BBC – Gould – ITE
- Federal Pacific
- Square D
- PACS Industries

The Consumer Product Safety Commission (CPSC) estimates the life expectancy of a circuit breaker to be around 30 to 40 years, and it's the same for the GFCI, AFCI, and standard breakers. Because a breaker is a mechanical device, humid conditions or corrosive atmospheres will shorten the life span.

References:

https://www.electronicshub.org/

current-limiting-circuit-breaker-pa01213001e.pdf (eaton.com)

Circuit Breaker - How it Works, Types, Applications and Advantages (electricalfundablog.com)

Selection of a circuit-breaker - Electrical Installation Guide (electrical-installation.org)

How to Size a Circuit Breaker | Hunker

How to Find the Proper Size of Circuit Breaker? CB Calculator (electricaltechnology.org)

Understanding Your Breaker Box | White's Electrical

References:

https://electricalfundablog.com/fuse-features-types/#Features_of_a_Fuse

https://springltd.co/blog/70/the-importance-of-fuses#:~:text=A%20fuse(s)%20is%20needed,electrical%20overload%20or%20short%20circuit.

https://circuitdigest.com/tutorial/fuse-types-and-working

https://pdhonline.com/courses/e245/Mod03-Chapter-2%20Circuit%20Protection%20Devices.pdf

https://www.elprocus.com/what-is-a-protection-device-different-types-of-protection-devices/#:~:text=To%20ensure%20the%20highest%20security,tubes%2C%20thyristors%2C%20and%20more.