

# Chapter 5

## Distribution Equipment

# Introduction

**A large variety of equipment is necessary to economically and efficiently distribute electrical power.**

The equipment includes:

1. Conductors
2. Insulators
3. Conductor support towers and poles
4. Transformers
5. Protection devices.

Practical, reliable, and safe distribution depends on protective devices to **sense fault conditions and disconnect malfunctioning equipment.**

Protective devices must protect people and equipment from malfunctions. Quickly disconnecting malfunctioning equipment minimizes the damage to the equipment and thereby shortens the time that the equipment is out of service.

The most important protective devices for distribution **are circuit breakers, reclosers, sectionalizers, fuses, relays to sense fault conditions, and lightning arresters.**

# Circuit Breakers

Circuit breakers for electrical power distribution include both medium (between 600 V and 34.5 kV) and high voltage (above 34.5 kV), **high current devices that must automatically disconnect faulted equipment** to protect people, prevent damage to upstream equipment, and minimize damage to downstream equipment in two to five cycles.

The circuit breaker should not damage itself when it operates.

Breakers are classified by:

- 1) Voltage
- 2) Continuous current
- 3) Interrupting capacity (maximum fault current the breaker can interrupt without becoming dangerous themselves), and methods of extinguishing the arc.

# The Arc

When current carrying contacts open, the initial electric field between the just parted contacts is very high.

**The high electric field causes any gas between the contacts to ionize and support current flow through it, or arc.**

The higher the voltage that the contacts are breaking the more severe the arcing.

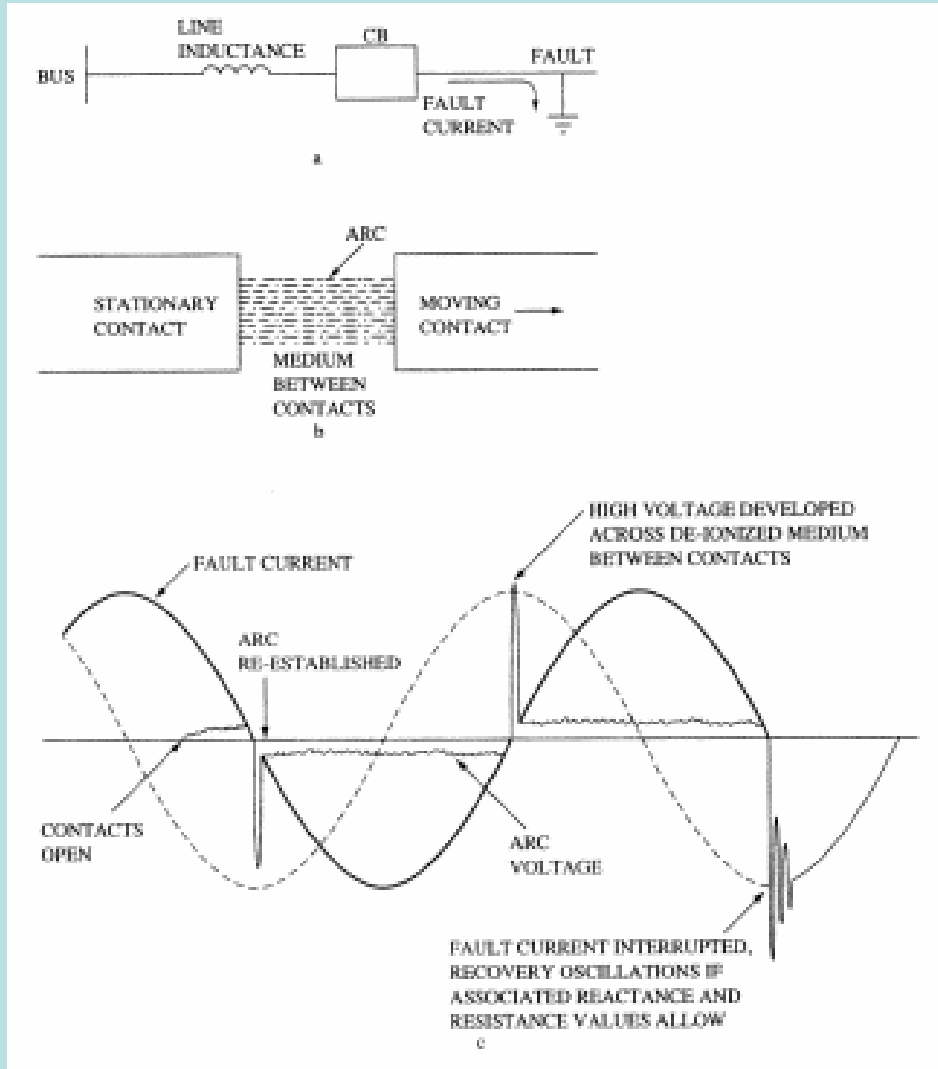
The arc must be extinguished to interrupt the current.

Many methods are used to **extinguish an arc**.

They use one or both of the following two principles:

1. **To lengthen the arc** until it is long and thin. This causes the arc resistance to rise, thus the arc current to drop, the arc temperature to decrease, and ultimately results in insufficient energy in the arc to keep it ionized.
2. **To open the arc** in a medium that absorbs energy from the arc causing it to cool and quench.  
Air, oil, and insulating gas are normally used as the medium.

# The Arc



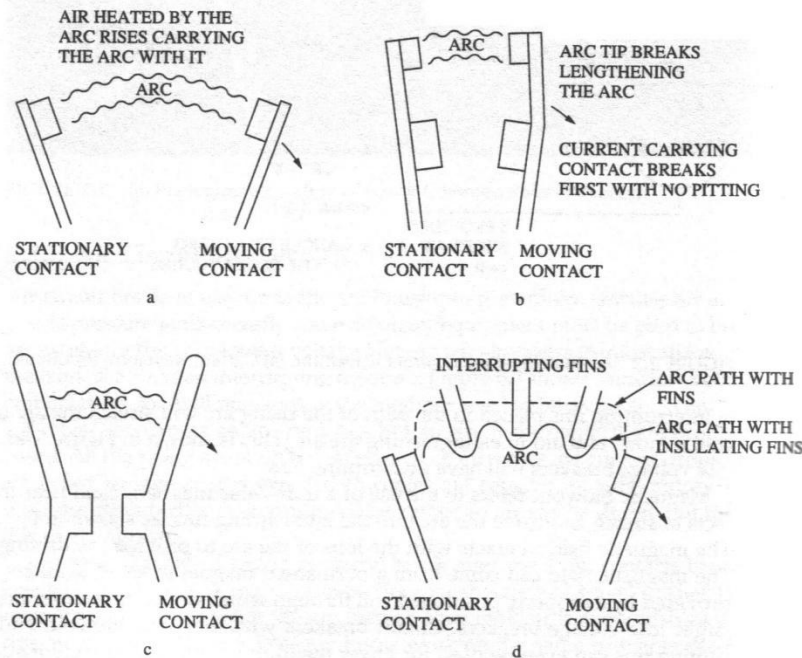
- a.) A faulted bus with circuit breaker
- b.) Established arc
- c.) Wave form across contacts

The inductance of the line or/and transformer is high and as a result there is a phase shift between the fault current and voltage developed across ionized air gap of the contacts.

Due to this phase shift, even when the fault current is low the voltage may be relatively high that result in arc re-ignition. This may occur several times until the distance between the contacts is sufficiently long. An ark re-established in the first  $\frac{1}{4}$  of a cycle is called **re-ignition** and in the second  $\frac{1}{4}$  of a cycle **re-strike**.

# Air Circuit Breakers

**Air circuit breakers use air as the arc interrupting medium.** Because air at atmospheric pressure ionizes easily some auxiliary equipment must be used to break the arc except for the very lowest voltage and capacity breakers.



Arc lengthening methods include: (a) Convection (b) Arc tip (c) Arc horn and (d) Interrupting fins.

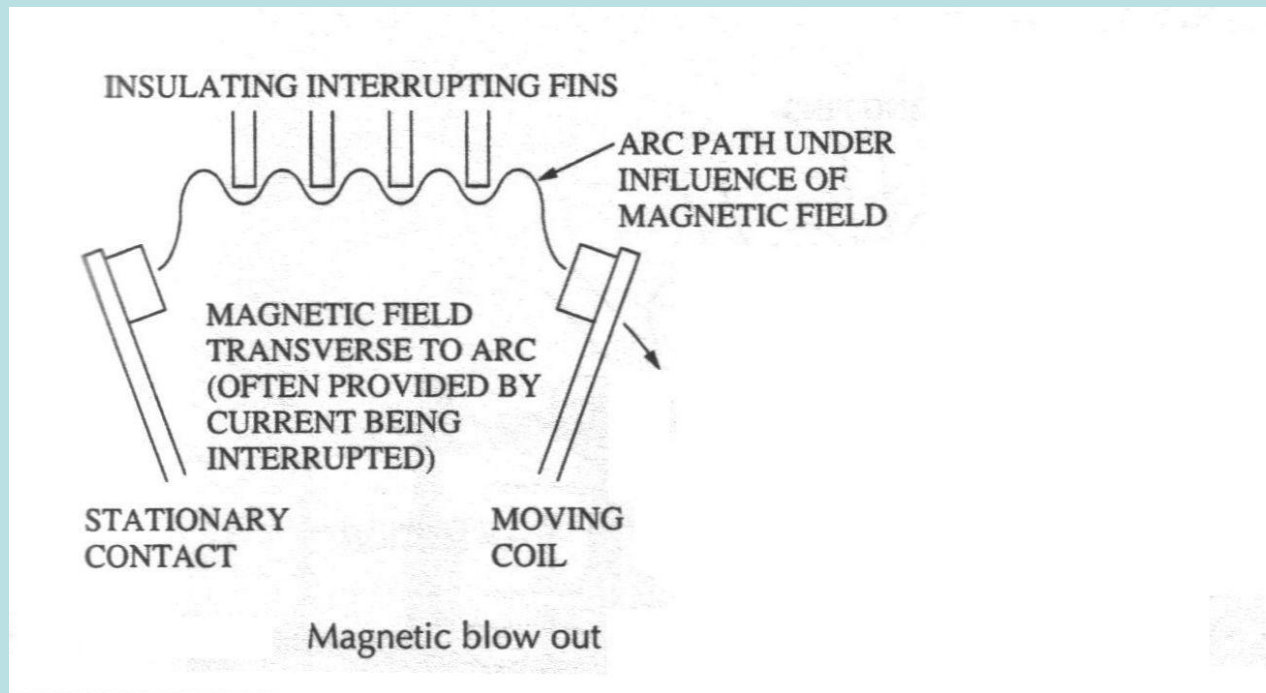
Convection causes an arc, which is hot, to rise if the contacts are properly oriented. As the rising arc stretches its resistance increases, its current drops, and its increased surface area is exposed to cooler air, causing its temperature to drop until the arc is finally extinguished. The longer an arc can be drawn out the easier it is to extinguish.

Arc tips break after the main contacts break

Arc horns work on the same principle except convection drives the arc up the spreading horns causing the arc to leave the load current carrying contacts and stretch.

Interrupting fins placed in the path of the rising arc will stretch the arc farther, cool it more, and aid in extinguishing the arc.

Large low voltage breakers will have interrupting fins.



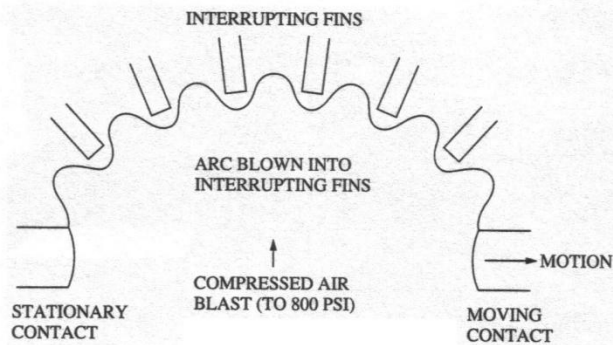
**Magnetic blowout** refers to the use of a transverse magnetic field near the contacts to stretch and drive the arc into the interrupting fins.

The magnetic field interacts with the ions of the arc to provide the driving force.

The magnetic field can come from a permanent magnet in small breakers, but is provided by a properly positioned coil through which the contact current flows in larger low voltage breakers.

**Circuit breakers with magnetic blowout and interrupting fins can even be used for medium voltages.**

# Air Blast Circuit Breakers

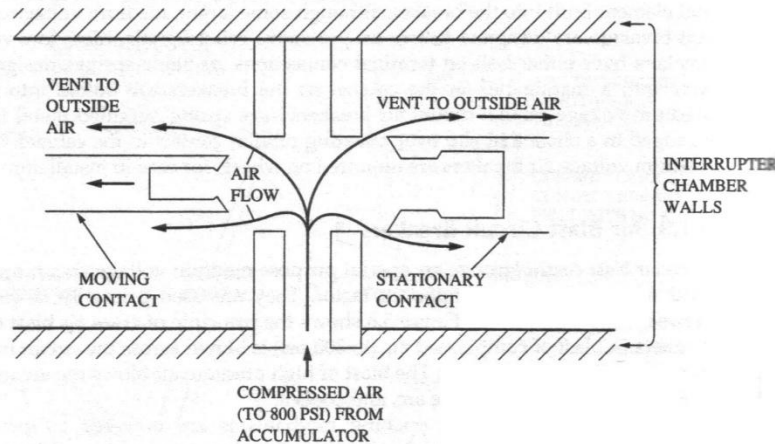


Cross air blast circuit breaker principle

**Cross air blast circuit breakers** are special purpose medium voltage circuit breakers used where noise is an important factor.

A blast of compressed air (to 800 psi) is blown across the circuit breaker contacts as the contacts open.

The blast of high pressure air blows the arc into the interrupting fins, stretches the arc, and cools it.



Axial air blast circuit breaker principle

**Axial air blast circuit breakers** blow high pressure air along the axis of the contacts to stretch and cool the arc.

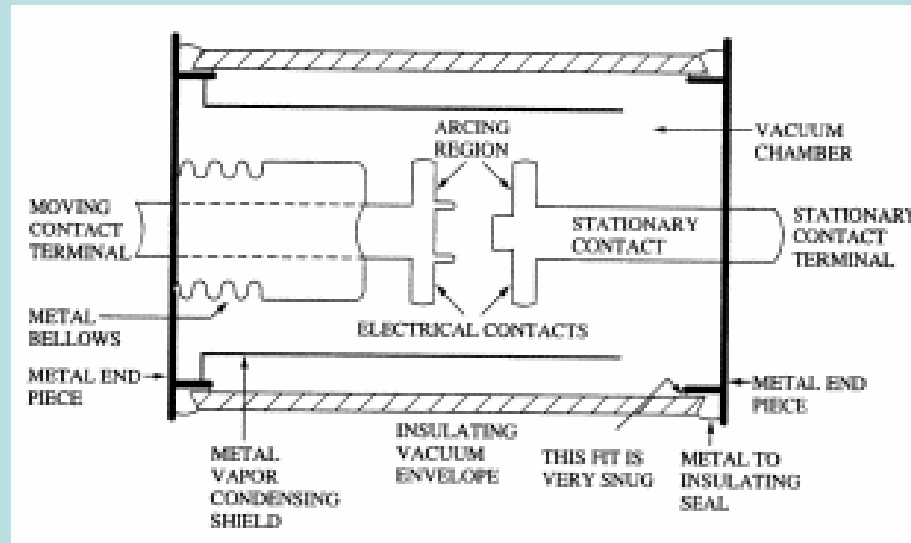
The air is blown from a port next to the stationary contact toward the moving contact.

Axial air blast breakers are usually high voltage breakers. They can be built to interrupt currents as high as 63 kA at 800 kV.



## **Vacuum Circuit Breakers**

Vacuum circuit break contacts are enclosed in a container with a high vacuum. No significant arcing can occur because there is no air between the contacts to ionize.



## **Vacuum Circuit Breaker:**

- ▶ Vacuum is used as an arc quenching medium.
- ▶ Have greatest insulating strength.
- ▶ Used in 11KV panel in control room of grid station.

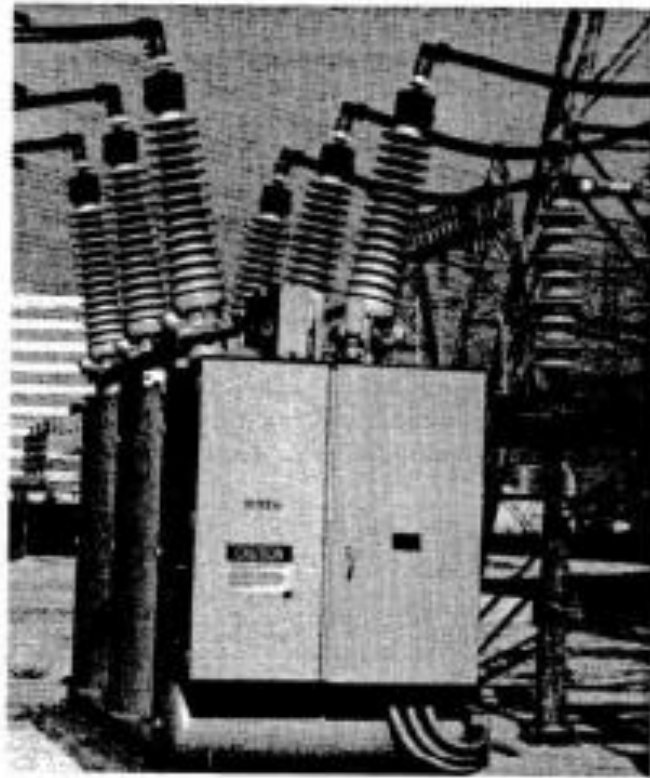
## **Advantages:**

Compact, reliable and have somewhat longer life.

- ▶ No fire hazards.
- ▶ No generation of gas during and after operation.
- ▶ Can interrupt any fault current.
- ▶ No noise is produced while operating.
- ▶ Require less power for control operation.

## **Oil Circuit Breakers**

Oil circuit breakers use oil as the arc interrupting medium. Oil has a dielectric strength far in excess of air. When contacts open in oil the arc causes the oil to disassociate which absorbs arc energy.



**FIGURE 5.10** 145 kV 2000 A Westinghouse oil circuit breaker (courtesy of Westinghouse) (a) Circuit breaker

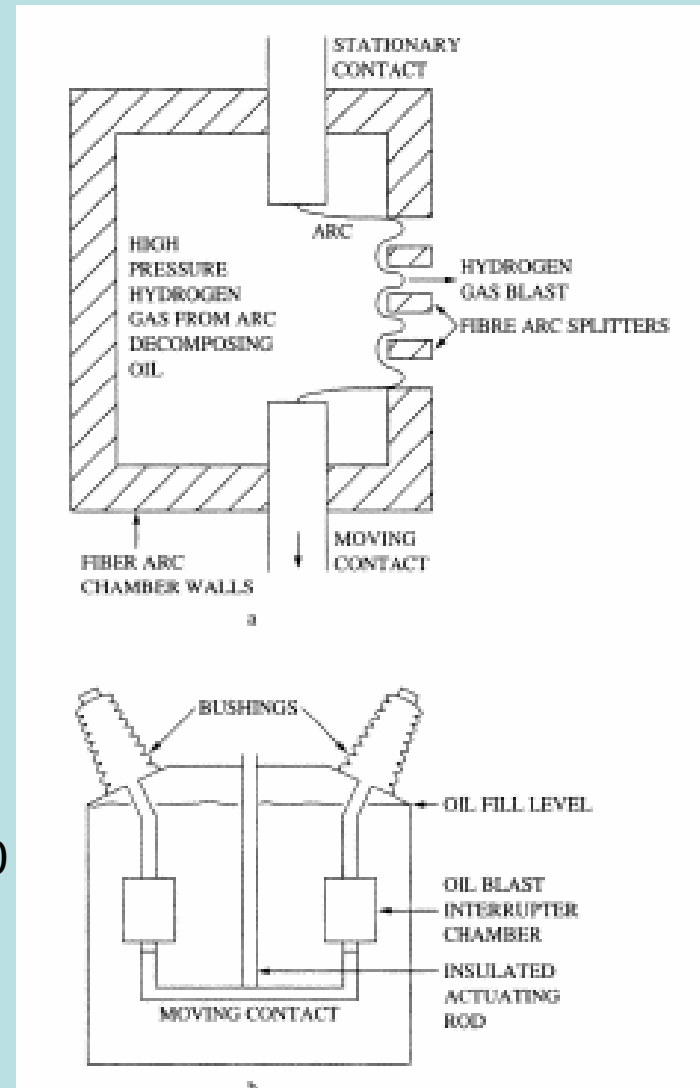
When contacts open in oil the arc causes the oil to disassociate which absorbs air.

One of the products of disassociation is hydrogen, which has heat capacity that air and is superior to air as a cooling medium.

Ionized hydrogen bubbles move more oil towards the arc.

The process continues till arc is quenched.

The use of arcing chamber increases the capacity of an oil breaker by a factor of 500



# Disadvantages Of Oil Circuit Breaker

- ▶ It is inflammable and there is a risk of fire.
- ▶ It may form an explosive mixture with air.
- ▶ It requires maintenance.
- ▶ Absorbs moisture, so dielectric strength reduces.
- ▶ Oil leakage problem.
- ▶ Oil has to be replaced after some operations because of the carbonization of oil.

## **Sulphur Hexafluoride Circuit Breakers**

Sulphur Hexafluoride gas is a popular interrupting medium for high voltage and extremely high voltage (EHV, above 345 kV) applications. Its voltage withstand rating is about three times that of air and it is extremely electronegative. That means its atoms bind for a considerable time to free electrons, thus becoming negative ions. When free electrons are removed from the arc it is difficult to sustain because no free electrons are available to accelerate and ionize atoms by collision.

1. SF<sub>6</sub> is an electro-negative gas.
2. It has strong tendency to absorb electrons.
3. When contact are opened in a high pressure flow of SF<sub>6</sub> gas, arc produced.
4. Free electron in the arc are captured by the gas, which build up enough insulation strength to extinguish arc.

It is much effective for high power and high voltages services

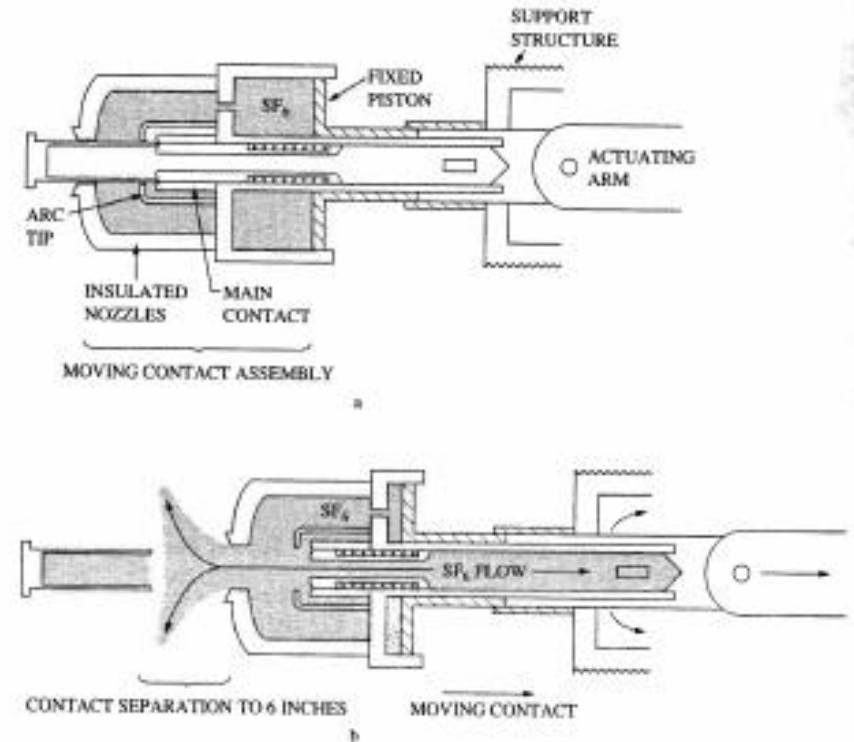


FIGURE 5.13 SF<sub>6</sub> puffer operation (a) Closed and (b) open

## **Advantages:**

- ▶ Simple construction, less cost.
- ▶ SF6 gas is non flammable, non toxic & chemical inert gas.
- ▶ Same gas is recirculated in the circuit.
- ▶ Maintenance free C.B.
- ▶ Ability to interrupt low and high fault current.
- ▶ Excellent Arc extinction.

## Advantages Of SF6 Over Oil Circuit Breakers:

- ▶ Short arcing time
- ▶ Can interrupt much larger currents
- ▶ Gives noiseless operation due to its closed gas circuit
- ▶ No moisture problem
- ▶ No risk of fire
- ▶ No carbon deposits. So no tracking and insulation problems
- ▶ Low maintenance cost



## **Circuit Breaker Ratings**

Users of circuit breakers must consider a number of ratings to select the right one. The **continuous voltage rating**, which may decrease at altitudes above 3300 ft, must be adequate.

The **rated impulse voltage** must be considered for insulation coordination, lightning, and surge protection.

The **continuous current rating** must be adequate for maximum loads and the interrupt capacity must be greater than the maximum fault current the breaker will have to interrupt.

The **interrupting time** must be fast enough to provide proper protection for the system, and if it is to be automatically reclosed, the reclose time must be known.

In addition to the electrical parameters there are a number of **mechanical considerations** such as size, foundation requirements, and space required.

## **Circuit Breaker Controls**

The controls must include **monitoring sensors** for the compressed air, and **equipment to start the compressor** when the pressure is too low, or send an alarm when the pressure is too high or zero.

The interrupting medium level and pressure must be monitored. Any auxiliary heating equipment must be monitored and controlled.

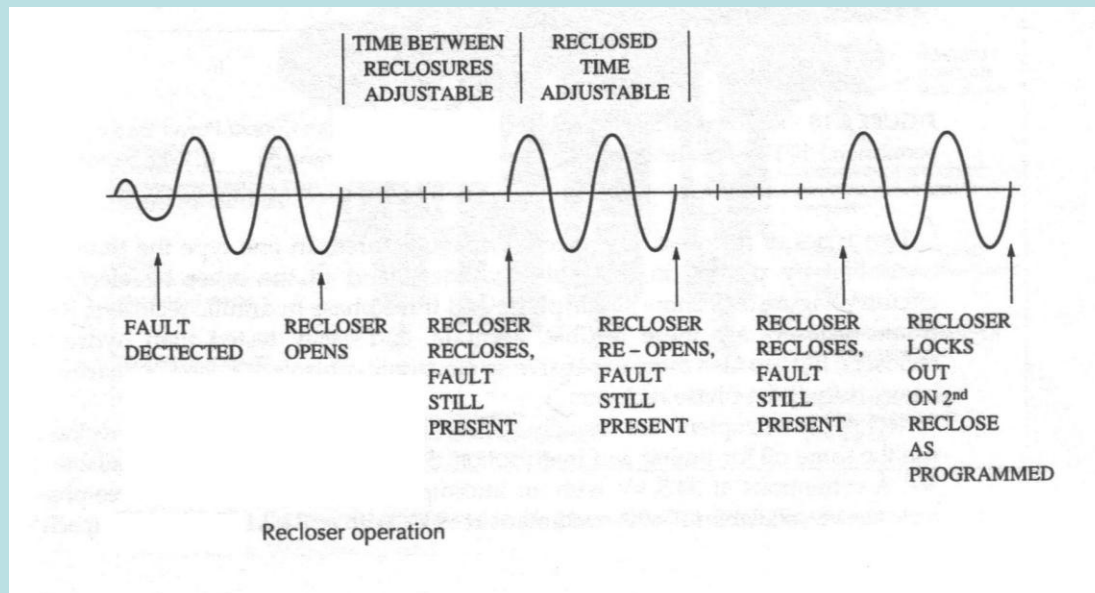
The trip signal from the protective relays must be monitored and acted upon, and the status of the breaker (open or closed) must be relayed to the appropriate.

# RECLOSERS

Most faults (80-95%) on distribution and transmission lines are temporary, lasting from a few cycles to a few seconds.

They are caused by such things as tree limbs falling or blowing across the lines and are removed when the limb burns off or is blown out of the line. **Reclosers allow temporary faults to clear and then restore service quickly, but disconnect a permanent fault.**

**Reclosers are essentially special purpose, light duty circuit breakers.** They can interrupt overloads but not severe faults. **Reclosers sense an overcurrent, open, then after a preprogrammed time, reclose.** They can be programmed to sense an overcurrent, open, and reclose several times (up to five times is typical) and after the preset number of operations remain open.



**Two types of reclosures** are currently manufactured. In one type the times are controlled **by pistons in hydraulic cylinders**, and in the other by **electronic circuitry**.

Electronic reclosers are more flexible, accurate, and easily tested than hydraulic closers, but are also more expensive so electronic controls are used primarily on heavy duty three-phase reclosers.

# SECTIONALIZERS

**A sectionalizer is a device that is used to automatically isolate faulted line segments from a distribution system.**

1. It senses any current above its actuating current followed by a line de-energization by a recloser.
2. It counts the number of overcurrent allowed by line de-energization sequences and after a preset number of times it opens and locks out.

**The sectionalizer must be manually reset after lock out.** If normal line conditions continue for a preset length of time after an overcurrent, de-energization sequence below the preset lock out number, the sectionalizer will reset itself to zero count. The delay before reset is usually set between 30 and 90 seconds:

**Two types of sectionalizers** are available:

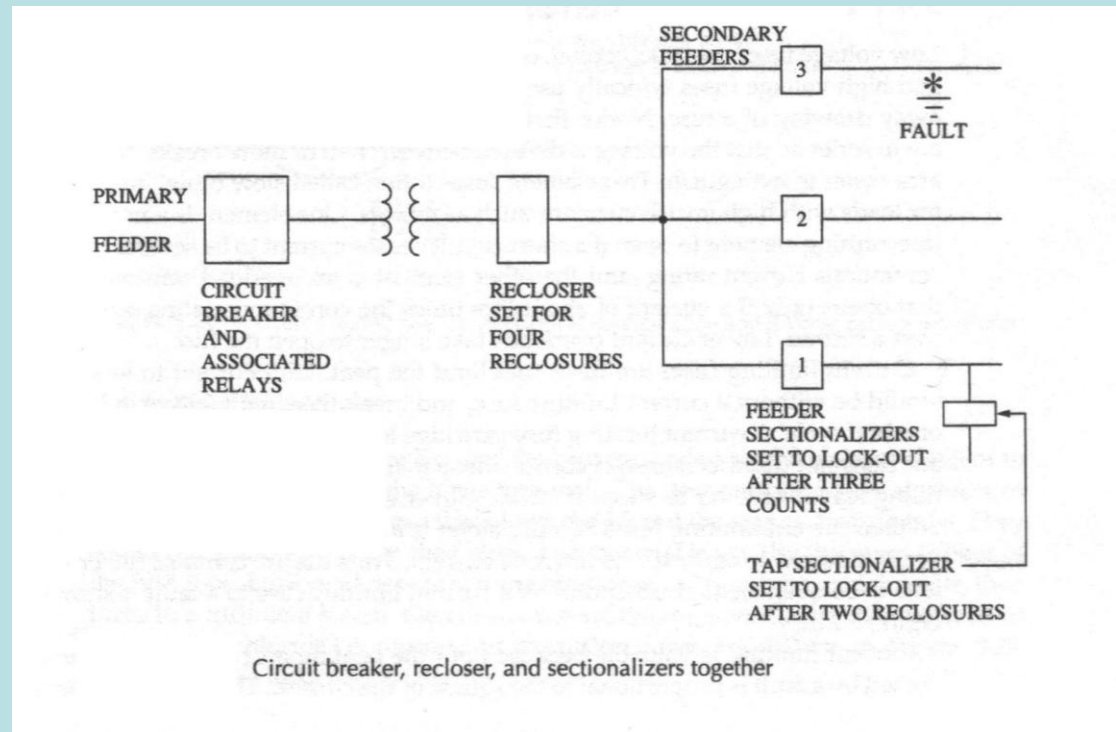
1. Smaller ones are hydraulically operated in a manner similar to reclosers
2. Higher capacity are electronically operated.

## Circuit breakers, reclosers, and sectionalizers are used together to provide better protection of lines.

One-line diagram with a circuit breaker, transformer, recloser, and the sectionalizers for three feeder circuits and a tap from one branch:

Assume a fault on feeder 3:

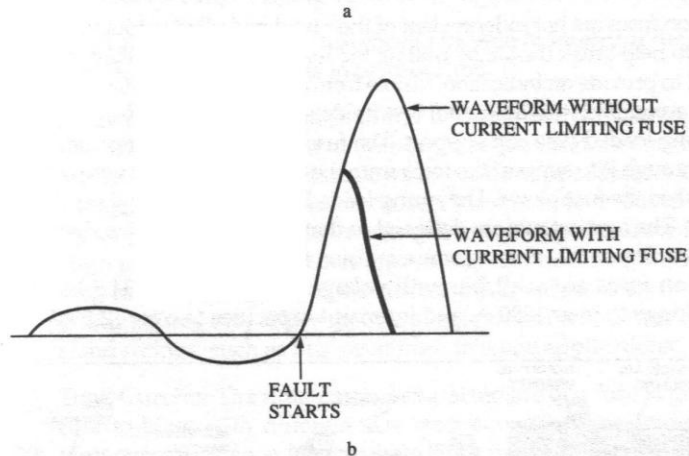
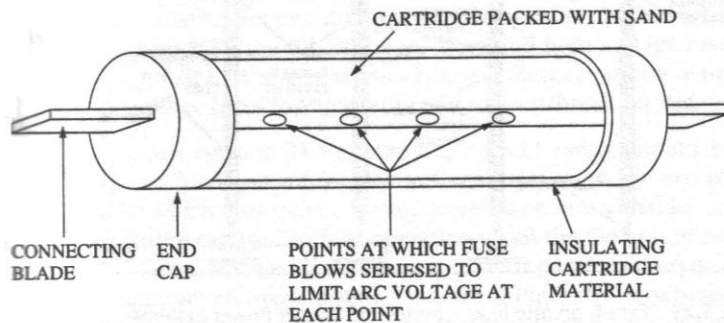
1. The recloser senses the overcurrent and opens.
2. After the preset time it recloses.
3. The sectionalizer senses each overcurrent and opening of the recloser.
4. After the third recloser reclose the sectionalizer locks out if the fault is still present and isolates feeder three.
5. It operates when the recloser opens for the fourth time.
6. If the recloser senses a fault after the fourth reclose it means the fault is between the sectionalizers and the recloser.
7. The recloser is set to lock out then.
8. If the circuit breaker opens that means the fault is between the breaker and the reclosers or that the recloser failed to operate.
9. If the fault had been on the tap circuit of feeder one, the tap recloser would have locked out upon the third opening of the recloser (after its second reclose). If the fault temporary in nature, such as a tree branch fallen across the line, the recloser and the associated sectionalizer would reset to count equal zero after a short time.



# FUSES

***Fuses are one-time devices that must be replaced each time they open a fault. They use a metallic element that melts when an overload current passes through it. The melted element separates breaking the circuit.***

## **1. Low voltage and current limiting fuses**



Current limiting fuse (a) Mechanical configuration and (b) fault current waveform

Low voltage fuses use zinc, copper, or silver as the metallic element, while medium and high voltage fuses typically use tin, cadmium, or silver.

Current limiting fuses are fuses that limit the peak fault current to less than it would be without a current limiting fuse, and break the circuit in less than one-half cycle.

A current limiting fuse cartridge is filled with sand. The sand melts but does not disassociate so it absorbs heat energy cooling the arc, plus the sand filling leaves little air to support an arc.

Current limiting is valuable because both the heating and mechanical damage caused by a fault is proportional to the square of the current.

## **2. Expulsion Fuses**

**Expulsion fuses, when blowing, use the heat generated by the melting element to decompose a material on the inner fuse wall.**

The decomposed material produces a high pressure, turbulent gas that blows the arc out the end of the fuse tube.

They sound like a shotgun when they blow.

The material is usually the interior fiber of the fuse tube, boric acid powder on the interior of the fuse tube, which melts, then turns to a turbulent steam, then blows the arc out, or a nonflammable gas such as carbon tetrachloride.

# Fuse Application Considerations .

## 1. Voltage.

The voltage rating of the fuse must be greater than the system voltage

## 2. Continuous current.

The continuous current rating should be 125% of the maximum load current for low voltage fuses, with the exception of bolt-on fuses in which they can be equal.

## 3. Interrupt capacity.

The fuse should be able to interrupt the highest fault current available in the zone to be protected.

## 4. Current limiting.

The desirability of using current limiting fuses should be considered. Often a current limiting fuse can limit the maximum current of a severe fault to a value that allows lower interrupt capacity devices to be used downstream for overload protection.

## 5. Time-Current.

The time-current characteristic of a fuse is the time it takes the fuse to blow with different size fault currents. Fuses blow more quickly at high currents than at low currents.

## 6. Fuse Coordination.

Coordination is accomplished by making sure the downstream fuse clears before the upstream fuse element melts.

Fuses can be coordinated with circuit breakers and reclosers.



# Lightning Protection

Lightning strikes power lines somewhere **between 59 and 232 times per 100 miles** each year on the average. The number varies greatly from year to year, and for different geographical locations.

## 1. Nature of lightning



A bolt of lightning can travel at a speed of 100,000 mph and can reach temperatures 50,000 °F, hot enough to fuse soil or sand into glass channels.

The first process in the generation of lightning is charge separation: The mechanism by which charge separation happens is still the subject of research, but one theory is the polarization mechanism, which has two components:

1. Falling droplets of ice and rain become electrically polarized as they fall through the atmosphere's natural electric field;
2. Colliding ice particles become charged by electrostatic induction.

When the electric field becomes strong enough, an electrical discharge (the bolt of lightning) occurs within clouds or between clouds and the ground.

During the strike, successive portions of air become a conductive discharge channel as the electrons and positive ions of air molecules are pulled away from each other and forced to flow in opposite directions. The electrical discharge rapidly superheats the discharge channel, causing the air to expand rapidly and produce a shock wave heard as thunder. The rolling and gradually dissipating rumble of thunder is caused by the time delay of sound coming from different portions of a long stroke.

## Lightning Arresters

The job of the lightning arresters **is to clip the induced voltage transient** caused by a lightning strike at a level below the BIL, but above the normal operating voltage, of the protected equipment.

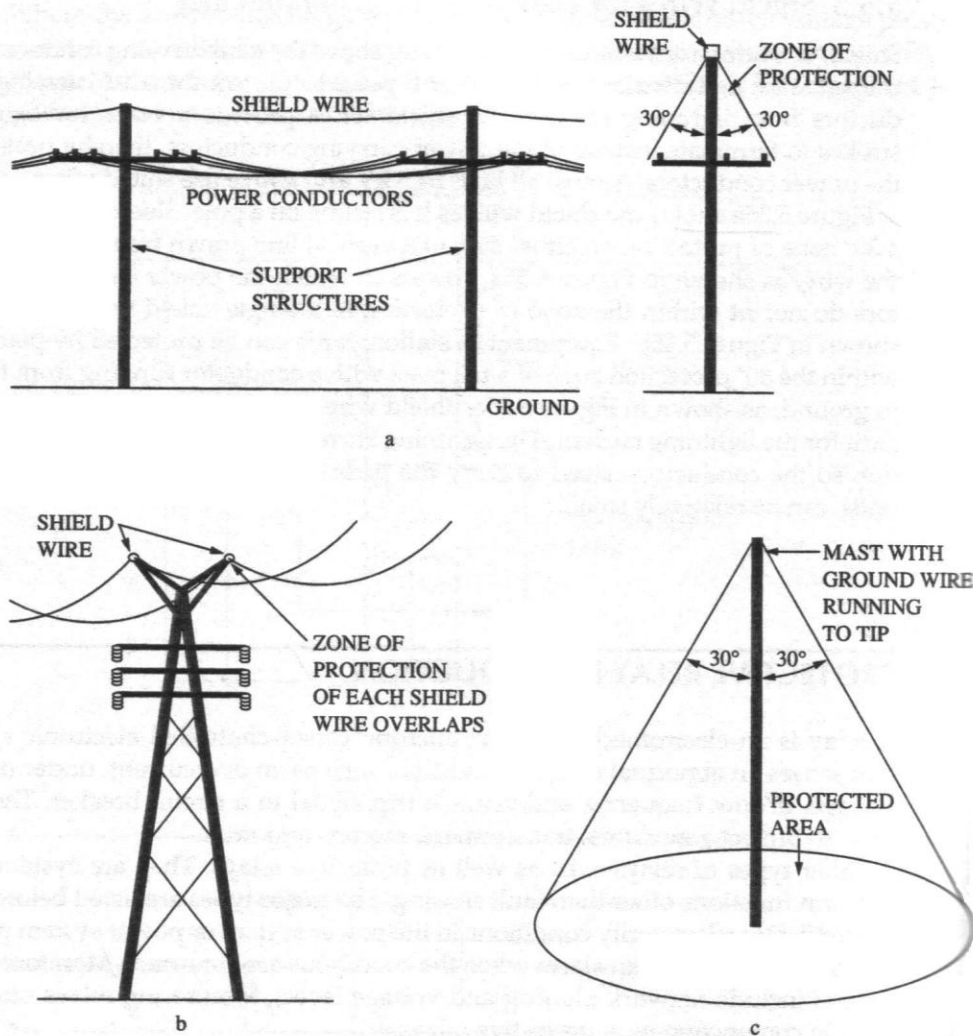
The lightning arrester should be an insulator at any , below the protected voltage, and a good conductor at any voltage above to pass the energy of the strike to ground.

## Shield wires for lightning protection of lines

Shield, or static wires, are conductors strung above the load carrying conductors on transmission and distribution towers and **poles to protect the load carrying conductors from lightning strikes.**

The shield wires provide a place for lightning strokes to terminate instead of the power carrying conductors, thereby protecting the power conductors.

Almost all lines 34.5 kV and above use shield wires.



Shield (static) wire (a) Narrow tower or pole (b) wide tower and (c) mast for substation yard protection

**Shield wires provide a 30° zone of protection on either side of a vertical line drawn from the ground to the wire.**

Towers in which the power carrying conductors do not fit within the zone of protection of a single shield wire use two.

Equipment in station yards can be protected by placing it within the 30° protection zone of a tall mast with a conductor running from the tip to ground.

**Shield wires must be grounded to provide a path for the lightning current.**

# PROTECTIVE RELAYS

**A relay is an electromechanical- or microprocessor-controlled electronic system** that senses an abnormal or fault condition, such as an overcurrent, under or over voltage, or low frequency, and sends a trip signal to a circuit breaker.

**They are used to protect generators, transformers, motors, and lines.**

**Monitoring relays** verify conditions in the power system or power system protection system and send an alarm when the conditions are abnormal.

Monitoring relays often are used in conjunction with protective relays.

**Programming relays** sequence events or detect sequences of events. They are used to control and monitor synchronization and reclosing sequences.

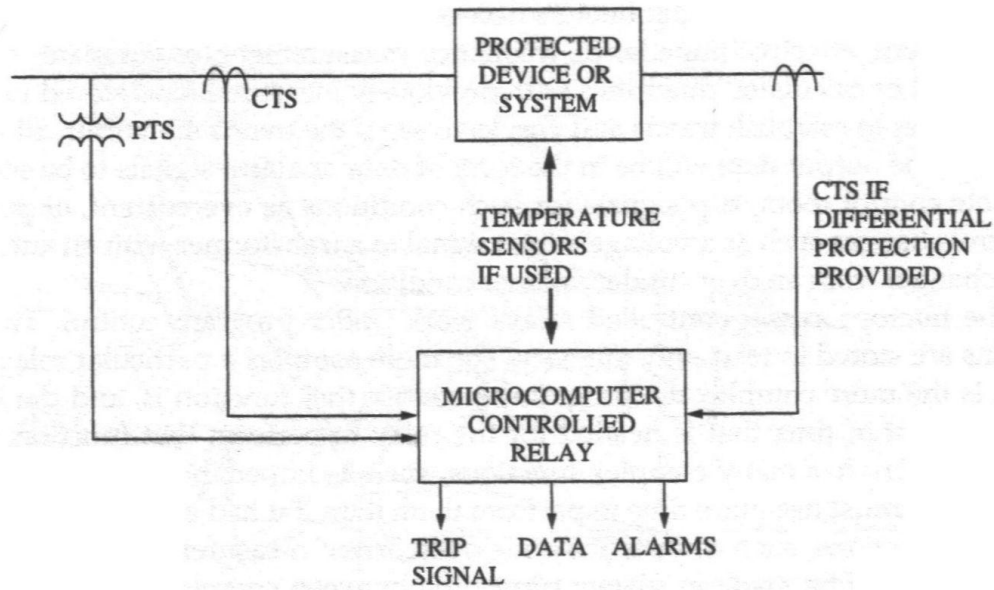
**Regulatory relays** are used to determine if a parameter, such as line voltage, is between programmed limits and send a control signal to force the parameter to return to within the limits

**Auxiliary relays** provide miscellaneous functions within other relaying systems. Timers are an example of an auxiliary relay function.

Relays must operate reliably, and quickly, be economical, and selective, operating only on the desired input

# Microcomputer Controlled Relays

The use of microprocessors in microcomputer relay systems has allowed relay systems to perform several relaying functions with a single central relaying package in a very economical manner. The multifunction capability of microprocessor controlled relay systems has resulted in a drop in the cost per function of such relays when compared to electromechanical relays.



Microprocessor controlled relay system (a) System

The current and potential transformers provide current and voltage information to the relay from which the relay microcomputer calculates any additional parameters needed, such as impedance, VAR and power quantity and flow direction, trends over a fixed time, and running averages of quantities.

The relay can also make use of other parameters, such as temperature and vibration sensor outputs, to monitor more conditions than electromechanical relays are able to monitor.

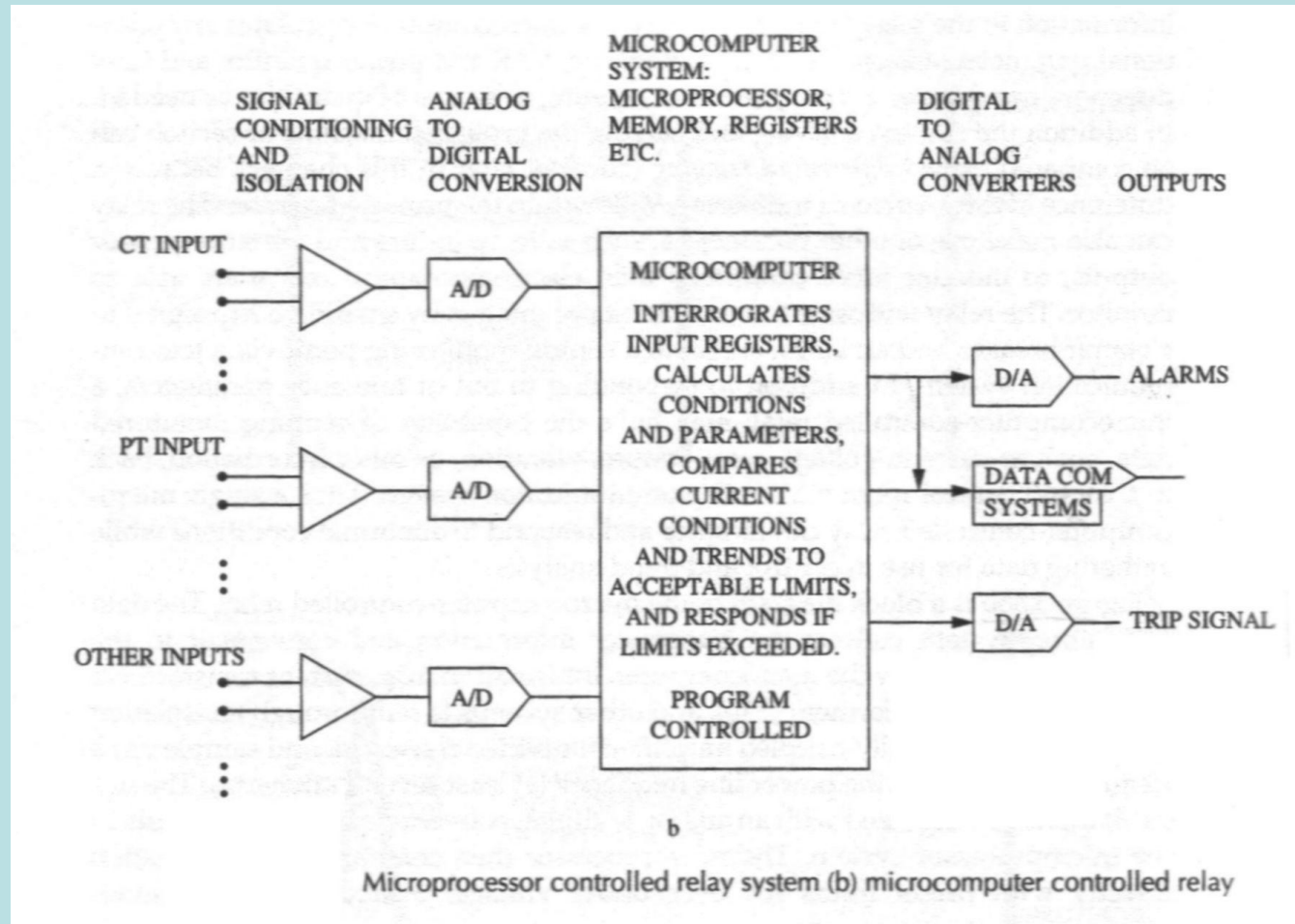
A single microcomputer-controlled relay can monitor and respond to abnormal conditions while gathering data for use in control and trend analysis.

The relay will react to out of limit parameters by sending a trip signal to a circuit breaker and an alarm signal to a central monitoring point via a telecommunication system.



## The microcomputer-controlled relay:

The data acquisition system collects the transducer information and converts it to the proper form for use by the microcomputer. Information from current transformers (CTs), potential transformers (PTs), and other systems is sent through an isolation transformer and sampled at a frequency well above the power line frequency. The signal samples are digitized with an analog to digital converter and fed to registers in the microprocessor system. The microprocessor then compares the information directly with preset limits for over/under voltage, overcurrent, over/under temperature.



Microcomputer-controlled relay systems are being designed into most new electrical systems and retrofitted into older systems as relay replacement is needed because of changes in the system or protection needs.

However, an enormous amount of electromechanical relaying equipment still exists, and it may be more than a decade, or maybe much more time, before it is all replaced by solid state microprocessor-controlled protective relays.

# DISCONNECT SWITCHES

Disconnect switches are designed to open and close a circuit at high voltages. The switches must have a large gap when open. An air gap of about 11 feet is required at 230 kV.

Disconnect switches cannot open a fault.

## Non-load Break Disconnect Switch:

High and medium voltage disconnect switches are designed to isolate a section of a circuit after the protective device has de-energized the circuit. Disconnect switches can be operated by motors, as most high voltage switches are, by an insulated lever connected to a actuating arm that moves the switch blade.



## Load Break Switches:

Load break disconnect switches can interrupt normal load currents, but not large fault currents. The wall switch is the most common load break switch.

Most load break switches use motors to open and close the switch blades but the interrupters are actuated by strong spring pressure.





## **METERING EQUIPMENT:**

Power metering equipment records the amount of power used in a particular area, sent down a particular line, and used in a particular structure.

Metering equipment provides power use information for planning for future needs from power use trends, and of course billing for revenue.