Chapter 1 - Switchgear Basics and Bus bar protection

Art & Science of Protection

A) Selection of protective relays requires compromises.
   - Maximum and Reliable protection at minimum equipment cost.
   - High Sensitivity to faults and insensitivity to maximum load currents.
   - High-speed fault clearance with correct selectivity.
   - Selectivity in isolating small faulty area.
   - Ability to operate correctly under all predictable power system conditions.

B) Cost of protective relays should be balanced against risks involved if protection is not sufficient and not enough redundancy.

C) Primary objectives is to have faulted zone's primary protection operate first, but if there are protective relays failures, some form of backup protection is provided.

D) Backup protection is local (if local primary protection fails to clear fault) and remote (if remote protection fails to operate to clear fault)

Primary Equipment & Components

A) **Transformers** - to step up or step down voltage level

B) **Breakers** - to energize equipment and interrupt fault current to isolate faulted equipment

C) **Insulators** - to insulate equipment from ground and other phases

D) **Isolators (switches)** - to create a visible and permanent isolation of primary equipment for maintenance purposes and route power flow over certain buses.

E) **Bus** - to allow multiple connections (feeders) to the same source of power (transformer).

F) **Grounding** - to operate and maintain equipment safely

G) **Arrester** - to protect primary equipment of sudden overvoltage (lightning strike).

H) **Switchgear** – integrated components to switch, protect, meter and control power flow

I) **Reactors** - to limit fault current (series) or compensate for charge current (shunt)

J) **VT and CT** - to measure primary current and voltage and supply scaled down values to P&C, metering, SCADA, etc.

K) **Regulators** - voltage, current, VAR, phase angle, etc.

Protection Zones

A) Generator or Generator-Transformer units.

B) Transformers.

C) Buses.

D) Lines (Transmission and Distribution).

E) Utilization equipment (Motors, Static loads, etc.)

F) Capacitor or Reactor (When separately protected).

Current Transformers

A) Current transformers are used to step primary system currents to values usable by relays, meters, SCADA, transducers, etc.

B) CT ratios are expressed as primary to secondary; 2000:5, 1200:5, 600:5, 300:5.

C) A 2000:5 CT has a "CTR" of 400.

1) **Description**:
    i. The arc extinction is facilitated mainly by two processes
        1. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts.
        2. Secondly, the gas sets up turbulence in the oil and forces it into the space between the contacts, thus eliminating the arcing products from the arc path.
    ii. The result is that arc is extinguished and the circuit interrupted.
2) **Types of oil circuit breakers:**
    i. Bulk oil circuit breakers (BOCB):
        1. This circuit breaker uses a large quantity of oil. The oil serves 2 purposes.
            a. It extinguishes the arc during the opening of contacts.
            b. It insulates the current conducting parts from one another and from the earthed tank.
                i. Plain break oil Circuit breaker
                ii. Arc control oil Circuit breaker
    ii. Low oil circuit breakers (LOCB):
        1. This circuit breaker uses minimum amount of oil.
        2. In such circuit breakers, oil is used only for arc extinction.
        3. The current conducting parts are insulated by air or porcelain or organic insulating material.
        4. **Advantages:**
            a. It requires smaller space for installation.
            b. Maintenance problems are reduced.
            c. Requires less quantity of oil is required.
            d. Risk of fire is reduced.
        5. **Disadvantages:**
            a. The degree of carbonization is increased due to less quantity of oil.
            b. Difficulty of removing the gases from the contact space in time.
            c. Possibility of explosion.
            d. The dielectric strength of the oil deteriorates rapidly due to high degree of carbonization.
3) **Arc extinction in oil circuit breaker:**
    i. In case of oil breaker the opening of contact which heats the oil surrounds the contact due to arc which causes hydrogen gas bubble to evolve and it removes the heat from the surface.
    ii. If the rate of heat removal is faster than its generation then the arc is extinguished.

B) Air Blast Circuit Breakers:

c. Hence, relays are also installed at the other end of line to detect fault and disconnect transmission line from other end as well.
d. Additional discrimination feature is to be provided to distinguish between fault that it should respond to and other's that it should not respond to.
e. The relay R_2 should operate if fault is at F_1 because it is on primary feeder but not behind i.e. at F_2

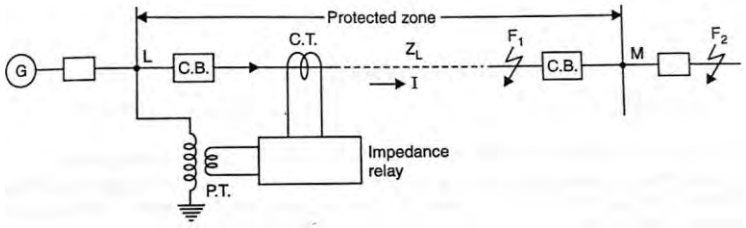
Distance Relays:

A) It is used widely for the protection of HV and EHV transmission lines.
B) It employs number of relays which measure the impedance of the line at relay location.
C) The measured impedance is proportional to the line length between the relay and fault.
D) The relay operates when the impedance is less than a predetermined value.
E) Types:

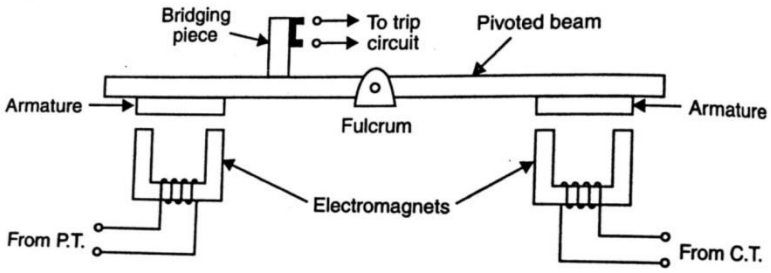
a. Impedance Relays:

i. Basic Principle:

1. The relays in which the operation is based on the ratio of applied voltage to the current in the protected circuit are called impedance relays.
2. This type of relay operates whenever the impedance (V/I) of the protected zone fails below a predetermined value.



ii. Relay:



iii. Torque produced by voltage element is proportional to $K_1.V^2$
iv. Torque produced by voltage element is proportional to $K_1.I^2$
v. The equation for the operating torque is given by,

$$T = K_1I^2 - K_2V^2 - K_3$$

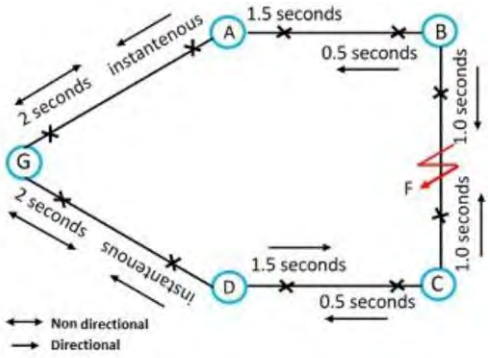
$$T = K_1I^2 - K_2V^2$$

vi. Hence, the relay will operate when

a. Both of the feeders have non directional over current relay at source end. Also, both of the feeders have directional relay or reverse power relay at their load end.
b. The reverse power relays used here should be instantaneous type. That means these relays should be operated as soon as flow of power in the feeder is reversed.
c. The normal direction of power is from source to load.
d. Now, suppose fault occurs at point F, say the fault current is I_f. This fault will get two parallel paths from source:
    i. One through CB-A.
    ii. Second via CB-B, feeder 2, CB-Q, load bus and CB-P.
e. As per Kirchhoff's law, $I_A + I_B = I_F$.
f. Now, I_A is flowing through CB-A, I_B is flowing through CB-P. As the direction of flow of CB-P is reversed it will trip instantly. But CB-Q will not trip as flow of current (power) in this circuit breaker is not reversed.
g. As soon as, CB-P is tripped, the fault current I_B stops flowing through feeder and hence there is no question of further operation of inverse time over current relay.
h. I_A still continues to flow even CB-P is tripped. Then because of over current I_A, CB-A will trip. In this way, the faulty feeder is isolated from system.

H) Protection of Ring Main system:

a. In the main ring system, the direction of power can be changed at will, particularly when the interconnection is used.
b. The elementary diagram of such a system is shown in the figure where G is the generation station. A, B, C and D are substations.



Protection of Ring System

c. At generating station, the power flow only in one direction and hence no time lag overload relays is used.
d. The time grade overload relay is placed at the end of the substation and it will trip only when overload flows away from the substation which they protect.
e. If the fault occurs at point F, the power from F is fed into the fault through two paths ABF and DCF. The relay to operate is that between substation B and fault point F and substation C and fault point F.
f. Thus the fault on any section will cause the relay on that section to operate, and the healthy section will be operating uninterruptedly.

I) Differential pilot wire protection (Merz Price):

a. The working principle of Merz Price Balance system is quite simple.
b. In this scheme of line protection, identical CT is connected to each of the both ends of the line.
c. The polarity of the CTs is same.
d. The secondary of these current transformer and operating coil of two instantaneous relays are formed a closed loop as shown in the figure.

v. The heated air around the arc and electro-magnetic action will rise up the horn and extinguish itself.

vi. **Advantages of Horn gap arrester:**

1. In case rod gap arrester, arc may continue even when then system attains normal frequency. But this arrester has no such problem.
2. Series resistance helps in limiting the flow of current to a small value.

vii. **Limitations:**

1. The gap can be bridged by some external agency such as birds.
2. At different frequencies, the gap breaks at different voltages.
3. The setting of horn gap is likely to change due to corrosion. This adversely affects the performance of the lightning arrester.
4. Breakdown voltage value is affected by atmospheric conditions.

c. Multi gap arrester

d. Expulsion type lightning arrester

e. Valve type lightning arrester

J) Surge Absorber:

a. A surge absorber is a protective device which reduces the steepness of wave front of a surge by absorbing surge energy.

b. The amount of damage caused not only depends upon the amplitude of the surge but also upon the steepness of its wave front.

c. **ERA Surge Filter:**

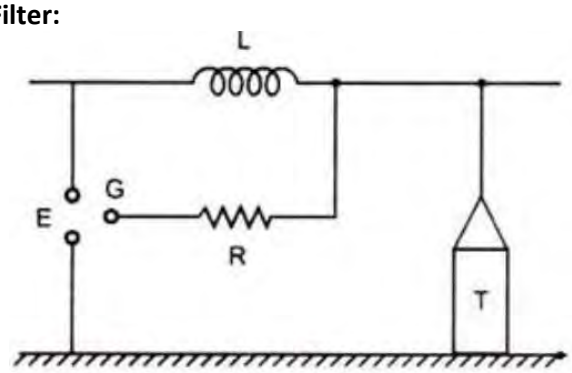


Fig. 9.37. *ERA Surge Filter*

i. A more recent form of the surge absorber is the ERA (Electrical Research Association, UK) surge filter incorporating a gap G and an expulsion gap E.

ii. When a high frequency wave reaches the inductor L, a high voltage is induced across it and causes the gap G to breakdown and so the resistor R and the expulsion gap E are included in the circuit.

iii. An incoming wave is thus flattened by the inductor L and resistor R and its amplitude is reduced by the expulsion gap E.