UNIT – I: FUNDAMENTALS OF PROTECTION

Introduction:

The importance of electric supply in everyday life has reached such a stage that it is desirable to protect the power system from harm during fault conditions and to ensure maximum continuity of supply. For this purpose, means must be provided to switch on or off generators, transmission lines, distributors and other equipment under both normal and abnormal conditions. This is achieved by an apparatus called switchgear. Switchgear essentially consists of switching and protecting devices such as switches, fuses, circuit breakers, relay etc.

Sources of fault power:

When short circuit faults occur in the power system. Some machines in the power system will act as source to the short circuit current and delivers the short circuit current to the fault location.

Mainly there are three sources which can feed into the short circuit and they are:

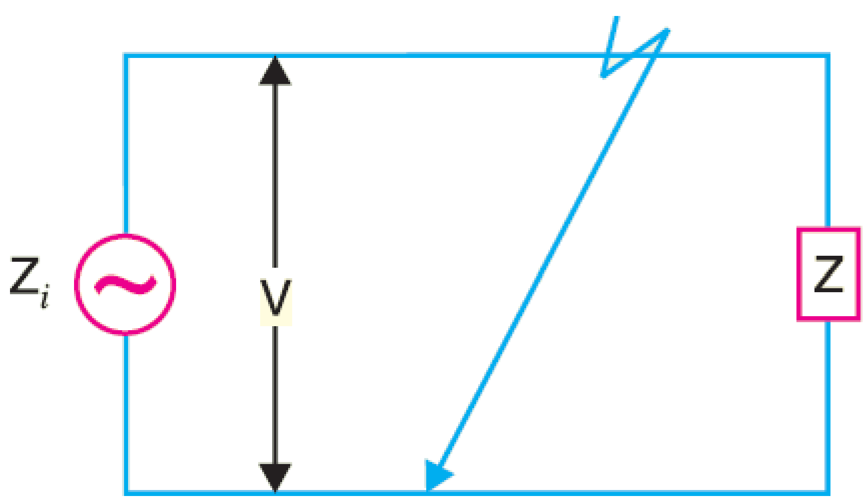
1. Generators
2. Synchronous motors
3. Induction motors

SHORT-CIRCUIT:

Whenever a fault occurs on a network such that a large current flows in one or more phases, a **short circuit** is said to have occurred.

PHENOMENA OF SHORT CIRCUIT:

When a short circuit occurs, a heavy current called short circuit current flows through the circuit. This can be beautifully illustrated by referring to Fig. where a single phase generator of voltage *V* and internal impedance *Zi* is supplying to a load *Z*. Under normal conditions, the current in the circuit is limited by *load impedance *Z*. However, if the load terminals get shorted due to any reason, the circuit impedance is reduced to a very low value ; being *Zi* in this case. As *Zi* is very small, therefore, a large current flows through the circuit. This is called short-circuit current. It is worthwhile to make a distinction between a ***short-circuit* and an *overload*. When a short-circuit occurs, the voltage at fault point is reduced to zero and current of abnormally high magnitude flows through the network to the point of fault. On the other hand, an overload means that loads greater than the designed values have been imposed on the system. Under such conditions, the voltage at the overload point may be low, but not zero. The under voltage conditions may extend for some distance beyond the overload point into the remainder of the system.



CAUSES OF SHORT CIRCUIT:

A short circuit in the power system is the result of some kind of abnormal Conditions in the system. It may be caused due to internal and/or external effects.

(I) INTERNAL EFFECTS: are caused by breakdown of equipment or transmission lines, from deterioration of insulation in a generator, transformer *etc*. Such troubles may be due to ageing of insulation, inadequate design or improper installation.

(II) EXTERNAL EFFECTS: causing short circuit include insulation failure due to lightning surges, overloading of equipment causing excessive heating; mechanical damage by public *etc*.

EFFECTS OF SHORT-CIRCUIT:

When a short-circuit occurs, the current in the system increases to an abnormally high value while the system voltage decreases to a low value.

(*i*) The heavy current due to short-circuit causes excessive heating which may result in fire or explosion. Sometimes short-circuit takes the form of an arc and causes considerable damage to the system. For example, an arc on a transmission line not cleared quickly will burn the conductor severely causing it to break, resulting in a long time interruption of the line.

(*ii*) The low voltage created by the fault has a very harmful effect on the service rendered by the power system. If the voltage remains low for even a few seconds, the consumers' motors may be shut down and generators on the power system may become unstable.

Due to above detrimental effects of short-circuit, it is desirable and necessary to disconnect the faulty section and restore normal voltage and current conditions as quickly as possible.

IMPORTANCE OF CALCULATIONS OF SHORT-CIRCUITS CURRENTS:

Most of the failures on the power system lead to short-circuit fault and cause heavy current to flow in the system. The calculations of these short-circuit currents are important for the following reasons:

(*i*) A short-circuit on the power system is cleared by a circuit breaker or a fuse. It is necessary, therefore, to know the maximum possible values of short-circuit current so that switchgear of suitable rating may be installed to interrupt them.

(*ii*) The magnitude of short-circuit current determines the setting and sometimes the types and location of protective system.

(*iii*) The magnitude of short-circuit current determines the size of the protective reactors which must be inserted in the system so that the circuit breaker is able to withstand the fault current.

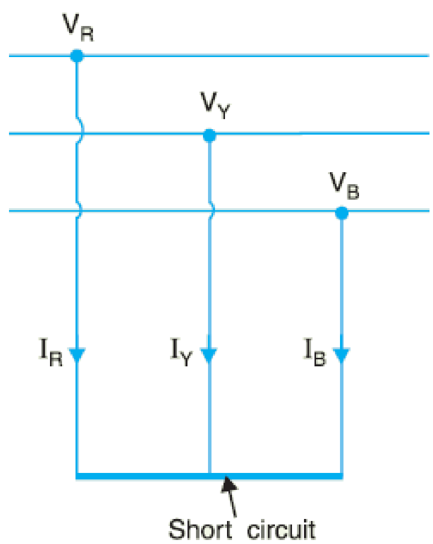
(*iv*) The calculation of short-circuit currents enables us to make proper selection of the associated apparatus (*e.g.* bus-bars, current transformers etc.) so that they can withstand the forces that arise due to the occurrence of short circuits.

FAULTS IN A POWER SYSTEM:

A fault occurs when two or more conductors that normally operate with a potential difference come in contact with each other. These faults may be caused by sudden failure of a piece of equipment, accidental damage or short-circuit to overhead lines or by insulation failure resulting from lightning surges. Irrespective of the causes, the faults in a 3-phase system can be classified into two main categories *viz*.

(*i*) Symmetrical faults **(*ii*)** Unsymmetrical faults

(*i*) Symmetrical faults. That fault which gives rise to symmetrical fault currents (*i.e*. equal faults currents with 120° displacement) is called a symmetrical fault. The most common example of symmetrical fault is when all the three conductors of a 3-phase line are brought together simultaneously into a short-circuit condition. The method of calculating fault currents for symmetrical faults.

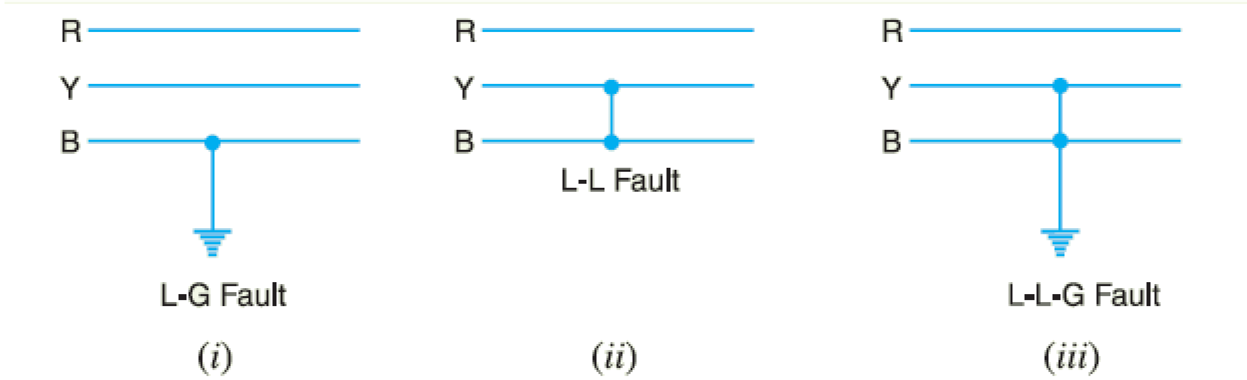


(*ii*) Unsymmetrical faults. Those faults which give rise to unsymmetrical currents (*i.e*. unequal line currents with unequal displacement) are called unsymmetrical faults. The unsymmetrical faults may take one of the following forms.

(*a*) Single line-to-ground fault

(*b*) Line-to-line fault

(*c*) Double line-to-ground fault



REACTOR:

In order to limit the short-circuit currents to a value which the circuit breakers can handle, additional reactances known as *reactors* are connected in series with the system at suitable points.

A reactor is a coil of number of turns designed to have a large inductance as compared to its ohmic resistance.

USES OF CURRENT LIMITING REACTORS:

(*i*) Reactors limit the flow of short-circuits current and thus protect the equipment from overheating as well as from failure due to destructive mechanical forces.

(*ii*) Troubles are localized or isolated at the point where they originate without communicating their disturbing effects to other parts of the power system. This increases the chances of continuity of supply.

(*iii*) They permit the installation of circuit breakers of lower rating.

ARRANGEMENT OF REACTORS:

Short circuit current limiting reactors may be connected

(*i*) In series with each generator

(*ii*) In series with each feeder and

(*iii*) In bus-bars.

Percentage Reactance:

It is the percentage of the total phase-voltage dropped in the circuit when full-load current is flowing i.e.

$$\%X = \frac{I\,X}{V} \times 100$$

Where, I = full-load current

V = phase voltage

X = reactance in ohms per phase

Base KVA:

The various equipments used in the power system have different KVA ratings. Therefore, it is necessary to find the percentage reactances of all the elements on a common KVA rating. This common KVA rating is known as base KVA.

$$\%\text{ age reactance at base kVA } = \frac{\text{Base kVA}}{\text{Rated kVA}} \times \%\text{ age reactance at rated kVA}$$

STEPS FOR SYMMETRICAL FAULT CALCULATIONS:

The procedure for the solution of such faults involves the following steps:

(*i*) Draw a single line diagram of the complete network indicating the rating, voltage and percentage reactance of each element of the network.

(*ii*) Choose a numerically convenient value of base KVA and convert all percentage reactance to this base value.

(*iii*) Corresponding to the single line diagram of the network, draw the reactance diagram showing one phase of the system and the neutral. Indicate the % reactances on the base KVA in the reactance diagram. The transformer in the system should be represented by a reactance in series.

(*iv*) Find the total % reactance of the network up to the point of fault. Let it be $X\%$.

(*v*) Find the full-load current corresponding to the selected base KVA and the normal system voltage at the fault point. Let it be I

(*vi*) Then various short-circuit calculations are:

$$\text{Short-circuit current, } I_{SC} = I \times \frac{100}{\%X}$$

$$\text{Short-circuit kVA} = \text{Base kVA} \times \frac{100}{\%X}$$

Protection against Lightning:

Transients or surges on the power system may originate from switching and from other causes but the most important and dangerous surges are those caused by lightning. The lightning surges may cause serious damage to the expensive equipment in the power system (*e.g.* generators, transformers etc.) The most commonly used devices for protection against lightning surges are:

(*i*) Earthing screen

(*ii*) Overhead ground wires

(*iii*) Lightning arresters or surge diverters

Lightning Arresters:

A **lightning arrester** or a **surge diverter** is a protective device which conducts the high voltage surges on the power system to the ground.

Types of Lightning Arresters:

We have the following types of lightning arresters:

1. Rod gap arrester

2. Horn gap arrester

3. Multigap arrester

4. Expulsion type or oxide film type lightning arrester

5. Valve type lightning arrester

1. Rod Gap Arrester:

It is a very simple type of diverter and consists of two 1·5 cm rods which are bent at right angles with a gap in between as shown in Fig.One rod is connected to the line circuit and the other rod is connected to earth. The distance between gap and insulator (*i.e.* distance *P*) must not be less than one-third of the gap length so that the arc may not reach the insulator and damage it. Generally, the gap length is so adjusted that breakdown should occur at 80% of spark-over voltage in order to avoid cascading of very steep wave fronts across the insulators. The string of insulators for an overhead line on the bushing of transformer has frequently a rod gap across it. Fig shows the rod gap across the bushing of a transformer. Under normal operating conditions, the gap remains non-conducting. On the occurrence of a high voltage surge on the line, the gap sparks over and the surge current is conducted to earth. In this way, excess charge on the line due to the surge is harmlessly conducted to earth.

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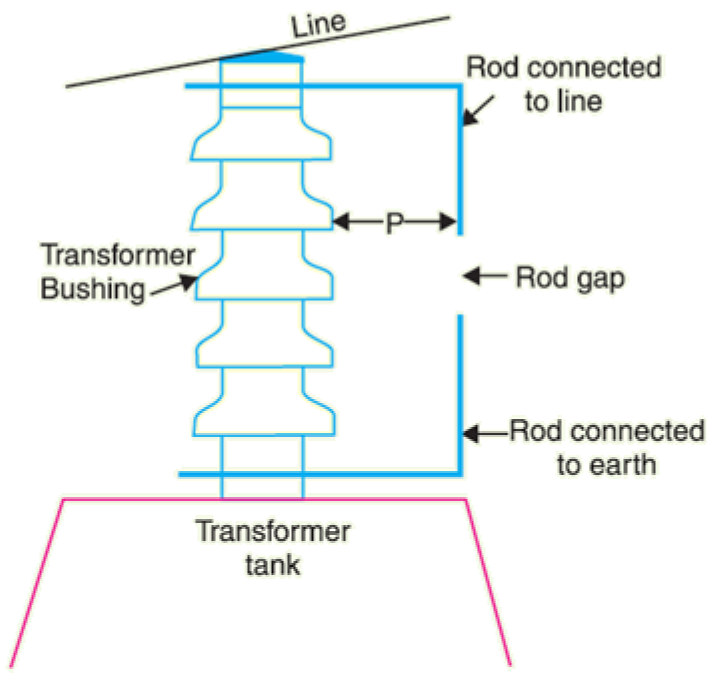
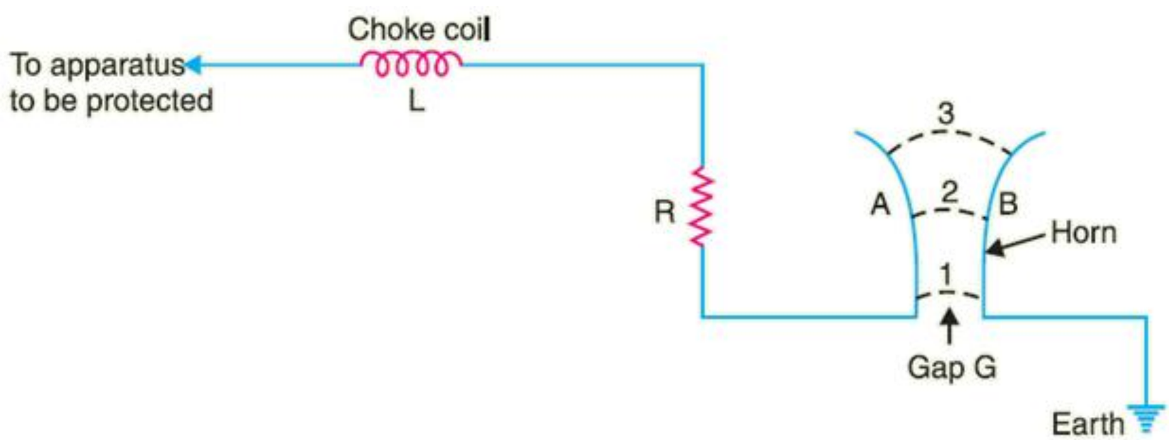


Fig.

2. Horn Gap Arrester:

Fig shows the horn gap arrester. It consists of two horn shaped metal rods *A* and *B* separated by a small air gap. The horns are so constructed that distance between them gradually increases towards the top as shown. The horns are mounted on porcelain insulators. One end of horn is connected to the line through a resistance *R* and choke coil *L* while the other end is effectively grounded. The resistance *R* helps in limiting the follow current to a small value. The choke coil is so designed that it offers small reactance at normal power frequency but a very high reactance at transient frequency. Thus the choke does not allow the transients to enter the apparatus to be protected. The gap between the horns is so adjusted that normal supply voltage is not enough to cause an arc across the gap.

Under normal conditions, the gap is non-conducting i.e. normal supply voltage is insufficient to initiate the arc between the gap. On the occurrence of an overvoltage, spark-over takes place across the *small gap *G*. The heated air around the arc and the magnetic effect of the arc cause the arc to travel up the gap. The arc moves progressively into positions 1, 2 and 3. At some position of the arc (perhaps position 3), the distance may be too great for the voltage to maintain the arc. Consequently, the arc is extinguished. The excess charge on the line is thus conducted through the arrester to the ground.



3. Expulsion type or oxide film type arrester:

This type of arrester is also called 'protector tube' and is commonly used on system operating at voltages upto 33 kV. Fig. (*i*) Shows the essential parts of an expulsion type lightning arrester. It essentially consists of a rod gap $A\ A'$ in series with a second gap enclosed within the fibre tube. The gap in the fibre tube is formed by two electrodes. The upper electrode is connected to rod gap and the lower electrode to the earth. One expulsion arrester is placed under each line conductor. Fig. (*ii*) Shows the installation of expulsion arrester on an overhead line.

On the occurrence of an overvoltage on the line, the series gap $A\ A'$ is spanned and an arc is struck between the electrodes in the tube. The heat of the arc vaporises some of the fibre of tube walls, resulting in the production of a neutral gas*. In an extremely short time, the gas builds up high pressure and is expelled through the lower electrode which is hollow. As the gas leaves the tube violently, it carries away ionised air around the arc. This de-ionising effect is generally so strong that arc goes out at a current zero and will not be re-established.

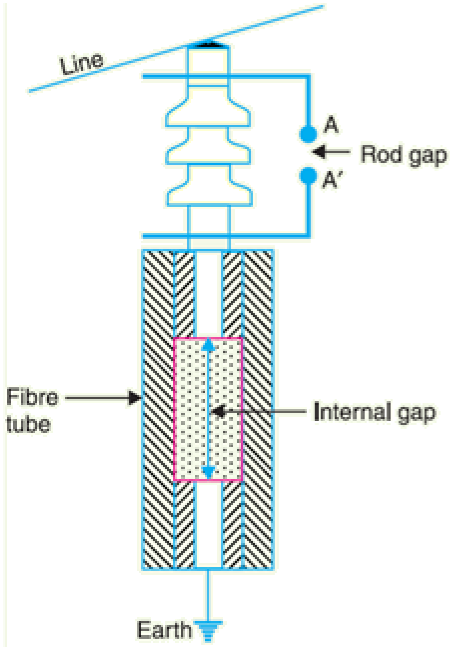


Fig. (*i*)

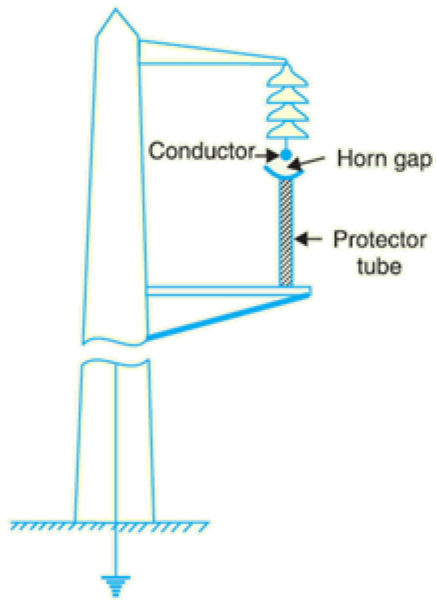


Fig. (*ii*)

5. Valve type or Thyrite type arrester. Valve type arresters incorporate non-linear resistors and are extensively used on systems operating at high voltages. Fig. (*i*) shows the various parts of a valve type arrester. It consists of two assemblies (*i*) series spark gaps and (*ii*) non-linear resistor discs (made of material such as thyrite or metrosil) in series. The non-linear elements are connected in series with the spark gaps. Both the assemblies are accommodated in tight porcelain container.

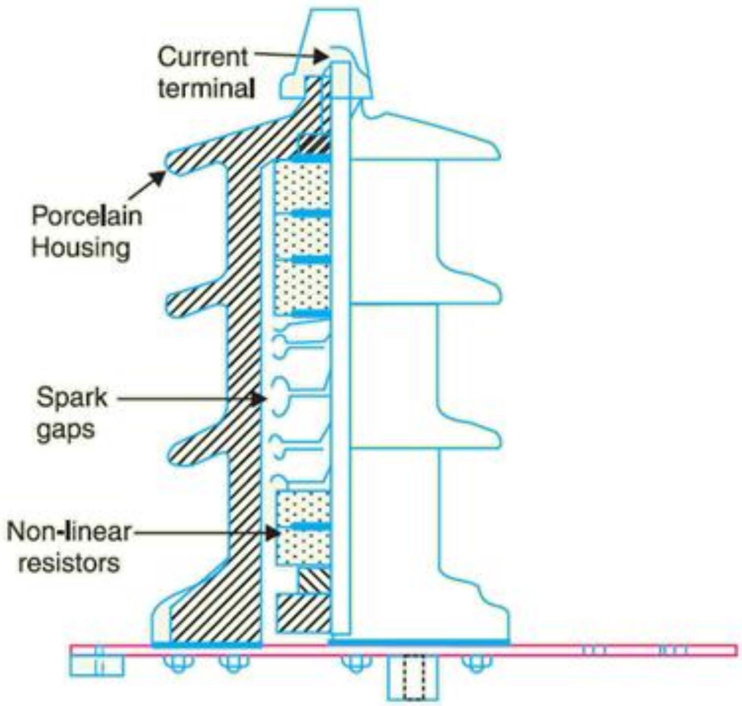


Fig. (*i*)

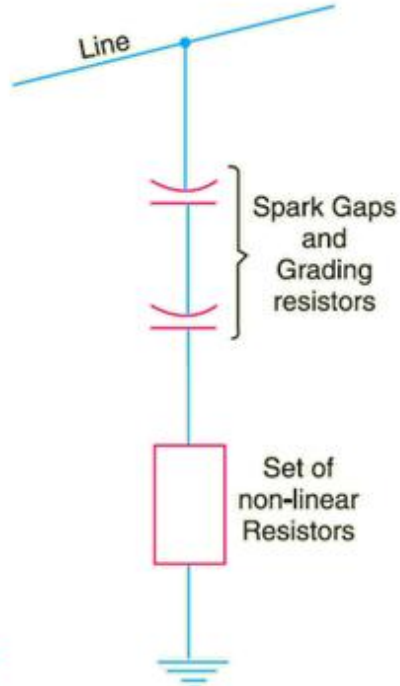


Fig. (*ii*)

(*i*) The spark gap is a multiple assembly consisting of a number of identical spark gaps in series. Each gap consists of two electrodes with a fixed gap spacing. The voltage distribution across the gaps is linearised by means of additional resistance elements (called grading resistors) across the gaps. The spacing of the series gaps is such that it will withstand the normal circuit voltage. However, an overvoltage will cause the gap to breakdown, causing

the surge current to ground via the non-linear resistors.

(*ii*) The non-linear resistor discs are made of an inorganic compound such as Thyrite or Metrosil.These discs are connected in series. The non-linear resistors have the property of offering a high resistance to current flow when normal system voltage is applied, but a low resistance to the flow of high-surge currents. In other words, the resistance of these non-linear elements decreases with the increase in current through them and vice-versa.

Working:

Under normal conditions, the normal system voltage is insufficient to cause the breakdown of air gap assembly. On the occurrence of an overvoltage, the breakdown of the series spark gap takes place and the surge current is conducted to earth *via* the non-linear resistors. Since the magnitude of surge current is very large, the non-linear elements will offer a very low resistance to the passage of surge. The result is that the surge will rapidly go to earth instead of being sent back over the line. When the surge is over, the non-linear resistors assume high resistance to stop the flow of current.

Surge Absorber:

The travelling waves set up on the transmission lines by the surges may reach the terminals apparatus and cause damage to it. The amount of damage caused not only depends upon the amplitude of the surge but also upon the steepness of its wave front. The steeper the wave front of the surge, the more the damage caused to the equipment. In order to reduce the steepness of the wave front of a surge, we generally use surge absorber.

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

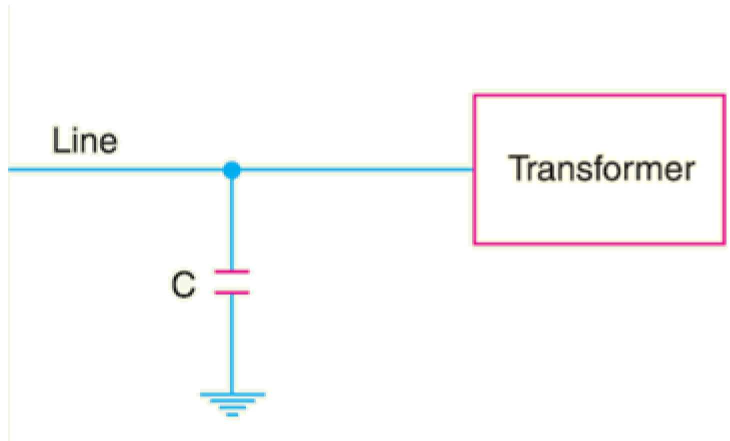
A few cases of surge absorption are discussed below:

(*i*) A condenser connected between the line and earth can act as a surge absorber.

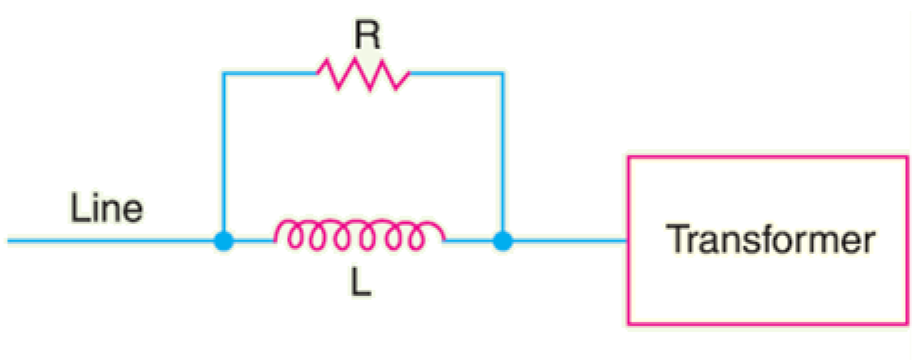
(*ii*) Another type of surge absorber consists of a parallel combination of choke and resistance connected in series with the line.

(*iii*)Another type of surge absorber it is called Ferranti surge absorber. It consists of an air cored inductor connected in series with the line. The inductor is surrounded by but insulated from an earthed metallic sheet called dissipater.

(i) A condenser connected between the line and earth can act as a surge absorber. Fig. shows how a capacitor acts as surge absorber to protect the transformer winding. Since the reactance of a condenser is inversely proportional to frequency, it will be low at high frequency and high at low frequency. Since the surges are of high frequency, the capacitor acts as a short circuit and passes them directly to earth. However, for power frequency, the reactance of the capacitor is very high and practically no current flows to the ground.



(ii) Another type of surge absorber consists of a parallel combination of choke and resistance connected in series with the line as shown in Fig. The choke offers high reactance to surge frequencies ($X_L = 2\pi f L$). The surges are, therefore, forced to flow through the resistance *R* where they are dissipated.



(iii) Figure shows another type of surge absorber. It is called Ferranti surge absorber. It consists of an air cored inductor connected in series with the line. The inductor is surrounded by but insulated from an earthed metallic

sheet called dissipator. This arrangement is equivalent to a transformer with short-circuited secondary. The inductor forms the primary whereas the dissipator forms the short-circuited secondary. The energy of the surge is used up in the form of heat generated in the dissipator due to transformer action. This type of surge absorber is mainly used for the protection of transformers.