UNIT – V Static and Digital Relays & Protection against over voltage and grounding

Essential components of static relays:

The essential components of static relays are shown in the figure here the relaying quantity i.e., the output of act or pt of a transducer is rectified by a rectifier. The rectified circuit is supplied to a measuring unit comprising of comparators, level detectors, filters, logic circuits .The output is actuated when the dynamic input (i.e the relaying quantity) attains the threshold value .This output of measuring unit is amplified by amplifier and fed to the output device, which is usually an electro-magnetic one .The output energizes the trip coil only when relay operates.

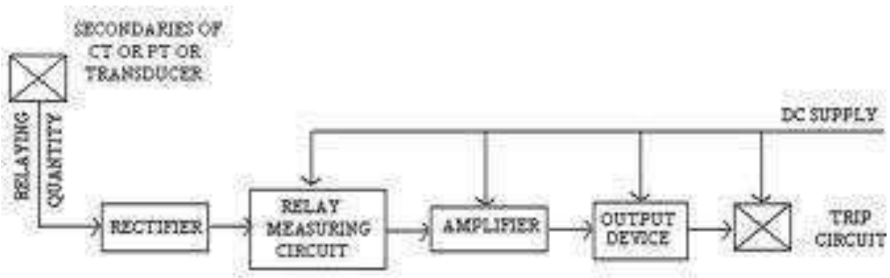


fig 20

In a static relay the measurement is carried out by static circuits consisting of comparators, level detectors, filters etc., while in a conventional electromagnetic relay it is done by comparing operating torque or restraining torque. In individual relays there is a wide variation. The relaying quantity such as voltage/current is rectified and measured. When the quantity under measurement attains certain well defined value, the output device is triggered and thereby the circuit breaker trip circuit is energized.

Static relays can be arranged to respond electrical inputs. The other type of inputs such as heat, light, magnetic field, travelling waves etc, can be suitably converted into equivalent analogue or digital signals and then supplied to the static relays. A multi input static relay can accept several inputs. The logic circuit in the multi input digital static relay can determine conditions for relay response and sequence of events in the response.

Comparison of static and Electro-magnetic Relays:

The conventional electro-magnetic relays are robust and quite reliable ., but are required to operate under different forces under fault conditions. This lead to delicate setting small contact gaps , special bearing systems , special clutch assemblies and several measuring problems. These require instrument transformers (CTs and PTs) with high burden and are bulky in size also.

The static relays in comparison to the corresponding electro-magnetic relays have many advantages and a few limitations.

Advantages of static relays:

1. The consumption in case of static relay is usually is much lower than that in case of their electro-mechanical equivalents. Hence burden on the instrument transformers is reduced and their accuracy is increased, possibility of use of air gaped CTs is there , problems arising out of CT saturation are eliminated, and there is an overall reduction in cost of CTs and PTs.
2. Quick response, long life, shock proof, fewer problems of maintenance, high reliability and high degree of accuracy.
3. Absence of moving contacts and associated problems of arcing, contact bounce, erosion, replacement of contacts etc.
4. Quick reset action a high reset value of overshoot can be easily achieved because of absence of mechanical inertia and thermal storage.
5. There is no effect of gravity on operation of static relays and therefore they can be installed in vessels, aircrafts etc.
6. Ease of providing amplification enables greater sensitivity to be obtained.
7. Use of printed or integrated circuits avoids wiring errors and facilitates rationalization of batch products.
8. The basic building blocks of semiconductor circuitry permit a greater degree of sophistication in the of operating characteristics, enabling the practical realization of relays with threshold characteristics more closely approaching the ideal requirements.
9. By combining various functional circuits ,several conventional relays can be substituted by a single ststic relay .For example a single static relay can provide over current ,under voltage, single phasing, short circuit protection in an ac motor by incorporating respective functional blocks.
10. Static relays are very compact. A single static relay can perform several functions. The space required for installation of protective relays and control relays etc, are reduced.
11. The characteristics of static relays are accurate and superior. They can be altered within certain range as per protection needs.
12. Static relays assisted by power line carrier can be employed for remote back-up and network monitoring.
13. Static relays can be designed for repeated operations. This is possible because ofabsence of moving parts in measuring circuits.
14. The risk of unwanted tripping is less with static relays.
15. Static relays are quite suitable for earth quake prone areas, ships, vehicles, locomotives, aero planes etc. This is because of high resistance to shock and vibration.
16. The static relays are provided with integrated features for self monitoring, easy testing and servicing. Defective module can be replaced easily.
17. A static protection control and monitoring system can perform several functions such as

protection, monitoring, measurement, memory, indication, data communication etc.

Limitations of static relays:

1. Auxiliary dc supply is required. However, this drawback is not very important as auxiliary dc supply can be obtained from station battery supply and conveniently changed as per local needs.
2. Semiconductor components are sensitive to electrostatic discharges. Some components are more sensitive than others. Even small discharges can damage the components and therefore precautions are necessary in the manufacturing of static relays to avoid component failure due to electrostatic discharges.
3. Static relays are sensitive voltage spikes or voltage transients. Special measures are taken to avoid such problem.
4. The characteristics of static relays are influenced by ambient temperature and ageing. However, temperature can be provided by using thermistor circuits and digital measuring techniques etc. While ageing can be minimized by pre-soaking for a several at a relatively high temperature.
5. The reliability of the system depends upon the large number of small components and their electrical connections.
6. The static relays have low short-time over-load capacity compared with electro-magnetic relays.
7. Static relays are costlier, for example and single function, than their equivalent electro-mechanical counter parts. But for multi function protection, static relays prove economical. The production technology of plug in type static relays on the panel permits the manufacturing of standard relays in mass and customers needs can be met quickly by incorporating required relay units on the panel. Static relays with ICs are cheaper than those with discrete components.
8. Static relay characteristic is likely to be affected by the operation of the output device but this is not so in case of electro-magnetic relay because its operation is based on the comparison between operating torques/forces.
9. Highly trained person are required for their servicing.
10. Static relays are not very robust in construction and affected by surrounding interference.

Static over current relays:

The block diagram of an instantaneous over-current relay is shown in the fig. The same construction may be used for under-voltage or earth fault relays too.

The secondaries of the line CTs are connected to the summation circuit (not shown in the figure). The output of this summation CT is fed to an auxiliary CT, whose output is rectified, smoothed and supplied to the measuring (level detector). The measuring unit determines whether the quantity has attained the threshold value (set value) or not.When the input to measuring unit is less than the threshold value, the output of the level detector is zero.

Simplified Block Diagram of Static Over-Current Relay

For an over-current relay

After operation of the measuring unit , the output is amplified by the amplifier. The amplified output is given to the output circuit to cause trip/alarm.

If time delay is desired , a timing circuit is introduced before the level detector. Smoothing circuit and filters are introduced in the output of the bridge rectifier. Static over-current relay is made in the form of a single unit in which diodes, transistors, resistors, capacitors etc. are arranged on printed board and are bolted with epoxy resin.The general equation for the time characteristics is given as

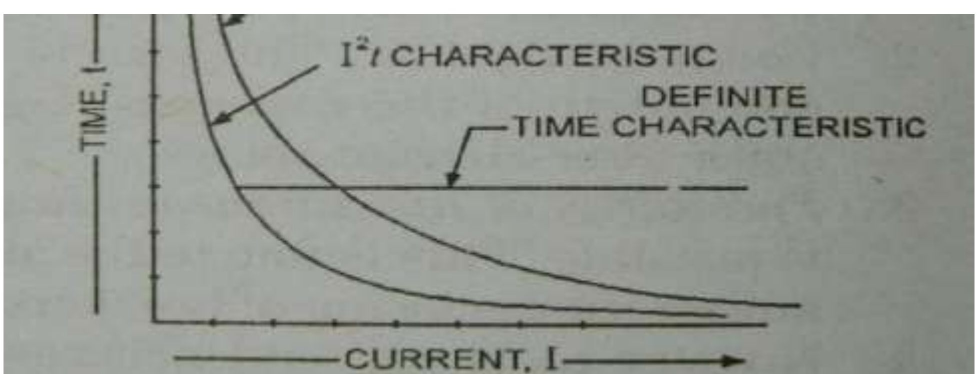
$$I^n t = K$$

Where I is the relay current, t is the time of operation and n is the characteristic index of relay and K is constant

In conventional electro-magnetic relays, n may vary between 2 and 8. The characteristic become a straight line parallel to current axis for n=0 .Such a characteristic is known as definite time characteristic of over current relay.

With n=1 ;It=k .The characteristic becomes inverse characteristic.

With higher value of n , the characteristic becomes more and more inverse .With n=7 or 8, the characteristic becomes extremely inverse.



Time Characteristics of Over-Current Relays
Fig. 7.93

The static instantaneous over-current relays can have operating time of as small as 10 or 20 ms while in case of a conventional electro-magnetic relays it is of the order of 0.1 second.

Definite time over-current relays are used for wide variations of systems conditions, as back-up relays for differential and distance protection and differential protection of transformers to avoid mal operation during magnetization in rush-currents. Inverse – time relays are used where the source impedance is much smaller than the line impedance. Extremely inverse over current relays are used for the fuse coordination and thermal protection of transformers and induction motors.

The general expression for the operating time of a static time-current relays may be given as

$$t = \frac{KM}{I^n \quad I_p^n}$$

Where M is time multiple settins , I is multiple of tap current ; I p is the multiple of tap current at which pick-up occurs ,n is characteristic index of relay , t is time of operation in seconds and K is design constant of the relay.

If the relay picks up at top value current i.e ., $I_p = 1$, then $t = \frac{KM}{I^n - 1}$

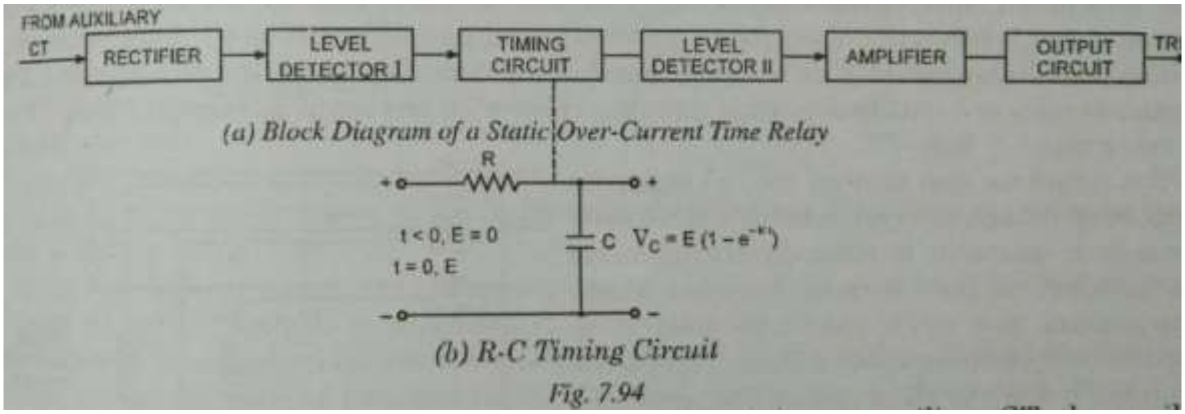
The static over-current time relays have the following typical characteristics

I D M T standard inverse $t = \frac{0.14}{I^{0.02} - 1}$

Very inverse $t = \frac{13.5}{I - 1}$

Extremely inverse $t = \frac{80}{I^2 - 1}$

In static relays it is advantageous to choose a circuit accommodating a wide range of alter native inverse time characteristics , precise minimum operating levels , definite minimum times and additional high set features if necessary. The block diagram of a static over-current time relay is shown in fig 7.94(a)



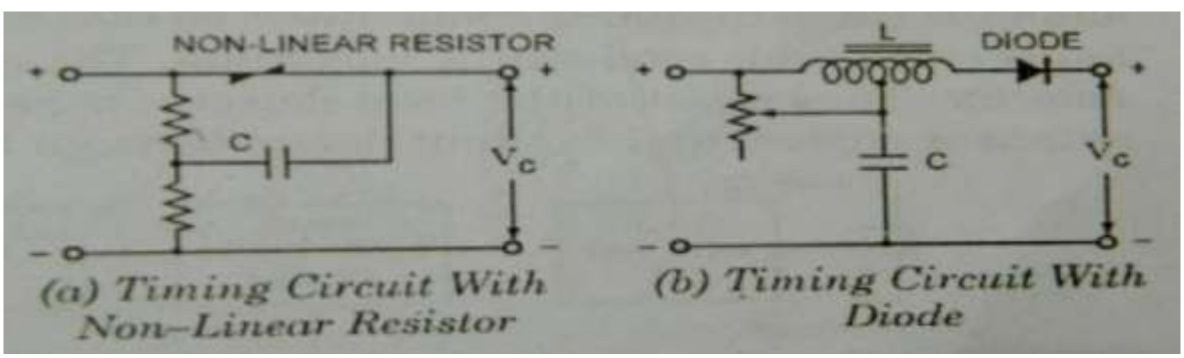
(a) Block Diagram of a Static Over-Current Time Relay

(b) R-C Timing Circuit

Fig. 7.94

The current from the line CT is reduced to 1/1000 th by an auxiliary CT, the auxiliary CT has taps on the primary for selecting the desired pick-up and current range and its rectified output is supplied to level detector (1) (over-load level detector) and an R-C timing circuit. When the voltage on the timing capacitor Vc attains the threshold value of the level detector (2), tripping occurs.
Where Vt is the threshold value of the level detector (2)

By varying values of R and C the time can be varied without difficulties. The basic R-C circuit can also be arranged in several series-parallel combinations to have different values of Tc.



(a) Timing Circuit With Non–Linear Resistor

(b) Timing Circuit With Diode

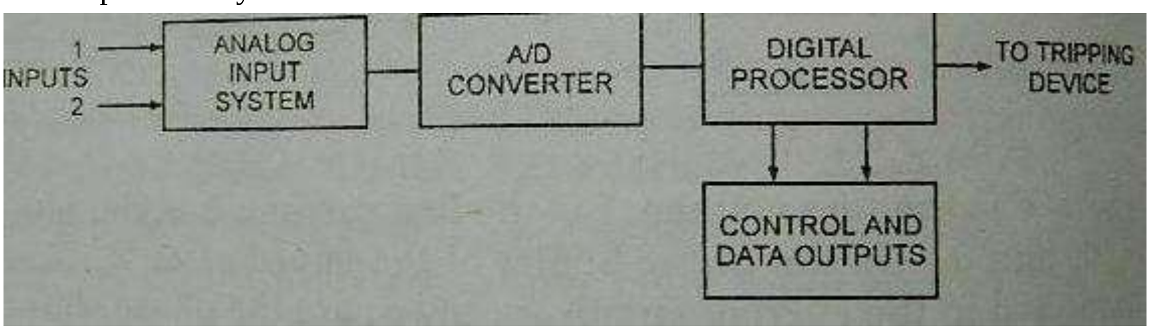
Non-linear resistors are used to have other time characteristics fig.

Time delay over-current relays are used in over-current protection of utility equipment, distribution circuits , protection of transformers , generators , motors etc.

In instantaneous over-current relays, the time delay circuit shown in fig. is detected Such a circuit would need only one level detector. As there is no moving part , operating time of the order of 0.02s (1 cycle) can be achieved. Instantaneous over current relays are used for short- circuit protection of large equipment. Instantaneous over-current relays are also useful in other protective relay systems.

MICROPROCESSOR BASED DIGITAL RELAYS:

With the fast development in fast scale integrated (LSI) technology, sophisticated and fast microprocessors are now available. With the rapid growth of modern complex large power system net works , fast , accurate and reliable protective schemes are essential . Microprocessor based schemes are becoming more and more popular for power system several protection as they offer attractive compactness and flexibility. They reduce the number of types of relay units. An interface employing op-amps, analog multiplexer analog-digital (A/D) converter voltage comparators and passive elements have been developed to provide the characteristics of various types of relays such as definite time relays, Inverse time over current relays, phase comparators relays and reverse power relays etc.



A block diagram of a microprocessor based digital programmable static relay is shown in figure.

The three phase A.C. quantities received from the power system through CTs PTs are sampled simultaneously or sequentially at uniform time intervals (4 to 32 samples per cycle).they are then converted into the digital form through an A/D converter and transfer to digital processor. digital signals are in the form of coded square pulses which represents discrete data .the signals are in binary form .the microprocessor/digital processor being set with the recommended values compares the dynamic inputs and decides accordingly to generate trip /alarm signal to the output device.

Microprocessor based relays have numerous advantages .they have a very small burden on the CTs and PTs .saturation can be avoided by using air gap CT having a limited output, they can process and display the signals very efficiently, accurately and in a fastest possible manner .due to their programmable characteristics ,they can be applied extensively in the protection of electrical power systems .moreover one microprocessor unit may be able to perform relaying function of systems .microprocessor relays are more reliable and secure to relay engineers because they can alert the user to a mal function before a false trip or failure to trip occurs .however the microprocessor should be properly shielded from external influences and the system earthing must be very good from which they receive their control voltage.

Protection against over voltage and grounding

TECHNICAL TERMS

1. **Transient voltage:** A sudden rise in voltage for a very short duration on the power system
2. **Switching Surges:** Over voltages produced on the power system due to switching Operations
3. **Arcing ground:** Phenomenon of intermittent arc taking place in line-to-ground fault of a 3φ system with consequent production of transients
4. **Lightning:** An electric discharge between cloud and earth, between clouds or between the charge centre of the same cloud
5. **Lightning arrester:** Protective device which conducts the high voltage surges on the power system to the ground.
6. **surge absorber:** Protective device which reduces the steepness of wave front of a surge by absorbing surge energy.

INTRODUCTION

There are several instances when the elements of a power system (e.g. generators, transformers, transmission lines, insulators etc.) are subjected to overvoltages i.e. voltages greater than the normal value. These over voltages on the power system may be caused due to many reasons such as lightning, the opening of a circuit breaker, the grounding of a conductor etc. Most of the overvoltages are not of large magnitude but may still be important because of their effect on the performance of circuit interrupting equipment and protective devices. An appreciable number of these overvoltages are of sufficient magnitude to cause insulation breakdown of the equipment in the power system. There-fore, power system engineers always device ways and means to limit the magnitude of the overvoltages produced and to control their effects on the operating equipment. In this chapter, we shall con-fine our attention to the various causes of over-voltages on the power system with special emphasis on the protective devices used for the purpose.

Voltage Surge sudden rise in voltage for a very short duration on the power system is known as a voltage surge or transient voltage. Transients or surges are of temporary nature and exist for a very short duration (a few hundred μs) but they cause overvoltages on the power system. They originate from switching and from other causes but by far the most important transients are those caused by lightning striking a transmission line. When lightning strikes a line, the surge rushes along the line, just as a flood of water rushes along a narrow valley when the retaining wall of a reservoir at its head suddenly gives way. In most of the cases, such surges may cause the line insulators (near the point where lightning has struck) to flash over and may also damage the nearby transformers, generators or other equipment connected to the line if the equipment is not suitably protected.

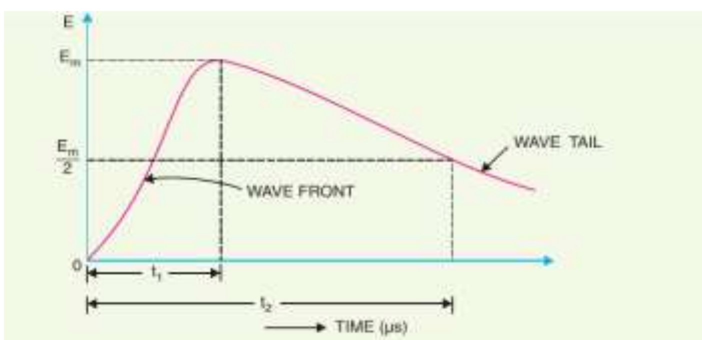


Figure 5.1 Waveform for lighting arrester.

Figure 5.1 shows the wave form of a typical lightning surge. The voltage build-up is taken along y-axis and the time along x-axis. It may be seen that lightning introduces a steep-fronted wave. The steeper the wave front, the more rapid is the build-up of voltage at any point in the network. In most of the cases, this build-up is comparatively rapid, being of the order of 1–5 μs. Voltage surges are generally specified in terms of rise time $t_1$and the time t_2 to decay to half of the peak value. For example, a 1/50 μs surge is one which reaches its maximum value in 1μs and decays to half of its peak value is 50 μs.

CAUSES OF OVERVOLTAGES

The over voltages on a power system may be broadly divided into two main categories viz.

Internal causes

- Switching surges
- Insulation failure
- Arcing ground
- Resonance

External causes i.e. lightning

Internal causes do not produce surges of large magnitude. Experience shows that surges due to internal causes hardly increase the system voltage to twice the normal value. Generally, surges due to internal causes are taken care of by providing proper insulation to the equipment in the power system. However, surges due to lightning are very severe and may increase the system voltage to several times the normal value. If the equipment in the power system is not protected against lightning surges, these surges may cause considerable damage. In fact, in a power system, the protective devices provided against overvoltages mainly take care of lightning surges.

Internal Causes of Over voltages

Internal causes of overvoltages on the power system are primarily due to oscillations set up by the sudden changes in the circuit conditions. This circuit change may be a normal switching operation such as opening of a circuit breaker, or it may be the fault condition such as grounding of a line conductor. In practice, the normal system insulation is suitably designed to withstand such surges. We shall briefly discuss the internal causes of overvoltages.

Switching Surges

The overvoltages produced on the power system due to switching operations are known as switching surges.

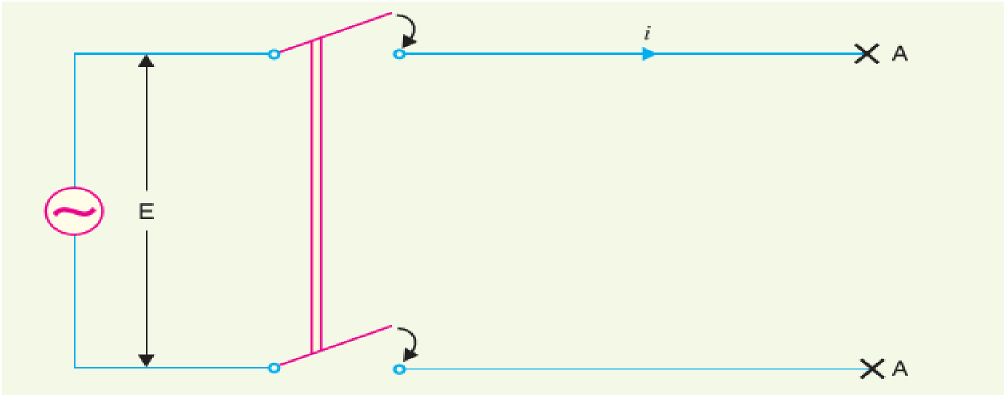


Fig 5.2 Internal Causes of Over voltages

- **Case of an open line**

During switching operations of an unloaded line, travelling waves are set up which produce overvoltages on the line. As an illustration, consider an unloaded line being connected to a voltage source as shown in Fig 5.2.

When the unloaded line is connected to the voltage source, a voltage wave is set up which travels along the line. On reaching the terminal point A, it is reflected back to the supply end without change of sign. This causes voltage doubling i.e. voltage on the line becomes twice the normal value. If $E_{r.m.s.}$ is the supply voltage, then instantaneous voltage which the line will have to withstand will be $2\sqrt{2}E$. This overvoltage is of temporary nature. It is because the line losses attenuate the wave and in a very short time, the line settles down to its normal supply voltage E. Similarly, if an unloaded line is switched off, the line will attain a voltage of $2\sqrt{2}E$. for a moment before settling down to the normal value.

- **Case of a loaded line**

Over voltages will also be produced during the switching operations of a loaded line. Suppose a loaded line is suddenly interrupted. This will set up a voltage of $2Z_n$ I across the break (i.e. switch) where I is the instantaneous value of current at the time of opening of line and Z_n is the natural impedance of the line. For example, suppose the line having Z_n= 1000 Ω carries a current of 100 A (r.m.s.) and the break occurs at the moment when current is maximum. The voltage across the breaker (i.e. switch) $= 2\sqrt{2} \times 100 \times 1000/1000 = 282 \cdot 8\,kV$. If V_m is the peak value of voltage in kV, the maximum voltage to which the line may be subjected is

$= (V_m + 282 \cdot 8)$ kV.

- **Current chopping**

Current chopping results in the production of high voltage transients across the contacts of the air blast circuit breaker. Unlike oil circuit breakers, which are independent for the effectiveness on the magnitude of the current being interrupted, air-blast circuit breakers retain the same extinguishing power irrespective of the magnitude of this current. When breaking low currents (e.g.transformer magnetizing current) with air-blast breaker, the powerful deionising effect of air-blast causes the current to fall abruptly to zero well before the natural current zero is reached. This phenomenon is called current chopping and produces high transient voltage across the breaker contacts. Over voltages due to current chopping are prevented by resistance switching .

a. **Insulation failure**

The most common case of insulation failure in a power system is the grounding of conductor which may cause over voltages in the system. This is illustrated in Fig. 5.3 Suppose a line at potential E is earthed at point X. The earthing of the line causes two equal voltages of –E to travel along XQ and XP containing currents $-E/Z_n$ and $+E/Z_n$ respectively. Both these currents pass through Xto earth so that current to earth is 2 E/Z_n.

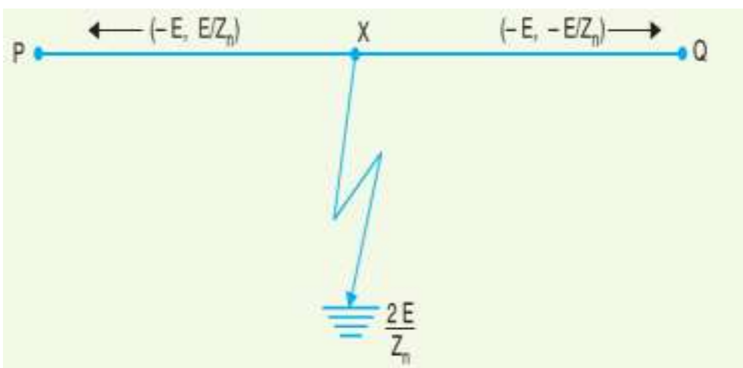


Fig 5.3 Insulation failure

b. **Arcing ground**

In the early days of transmission, the neutral of three phase lines was not earthed to gain two advantages. Firstly, in case of line-to-ground fault, the line is not put out of action. Secondly, the zero sequence currents are eliminated, resulting in the decrease of interference with communication lines. Insulated neutrals give no problem with short lines and comparatively low voltages. However, when the lines are long and operate at high voltages, serious problem called arcing ground is often witnessed. The arcing ground produces severe oscillations of three to four times the normal voltage.

The phenomenon of intermittent arc taking place in line-to-ground fault of a 3φsystem with consequent production of transients is known as arcing ground. The transients produced due to arcing ground are cumulative and may cause serious damage to the equipment in the power system by causing breakdown of insulation. Arcing ground can be pre-vented by earthing the neutral.

c. Resonance.

Resonance in an electrical system occurs when inductive reactance of the circuit becomes equal to capacitive reactance. Under resonance, the impedance of the circuit is equal to resistance of the circuit and the power factor. is unity. Resonance causes high voltages in the electrical system. In the usual transmission lines, the capacitance is very small so that resonance rarely occurs at the fundamental supply frequency. However, if generator e.m.f. wave is distorted, the trouble of resonance may occur due to 5th or higher harmonics and in case of underground cables too.

LIGHTNING

An electric discharge between cloud and earth, between clouds or between the charge centres of the same cloud is known as lightning. Lightning is a huge spark and takes place when clouds are charged to such a high potential (+ve or −ve) with respect to earth or a neighbouring cloud that the dielectric strength of neighbouring medium (air) is destroyed. There are several theories which exist to explain how the clouds acquire charge.

The most accepted one is that during the up rush of warm moist air from earth, the friction between the air and the tiny particles of water causes the building up of charges. When drops of water are formed, the larger drops become positively charged and the smaller drops become negatively charged. When the drops of water accumulate, they form clouds, and hence cloud may possess either a positive or a negative charge, depending upon the charge of drops of water they contain. The charge on a cloud may become so great that it may discharge to another cloud or to earth and we call this discharge as lightning. The thunder which accompanies lightning is due to the fact that lightning suddenly heats up the air, thereby causing it to expand.

The surrounding air pushes the expanded air back and forth causing the wave motion of air which we recognise as thunder.

Mechanism of Lightning Discharge

When a charged cloud passes over the earth, it induces equal and opposite charge on the earth below. Fig. 5.4 shows a negatively charged cloud inducing a positive charge on the earth below it. As the charge acquired by the cloud increases, the potential between cloud and earth increases and, therefore, gradient in the air increases.

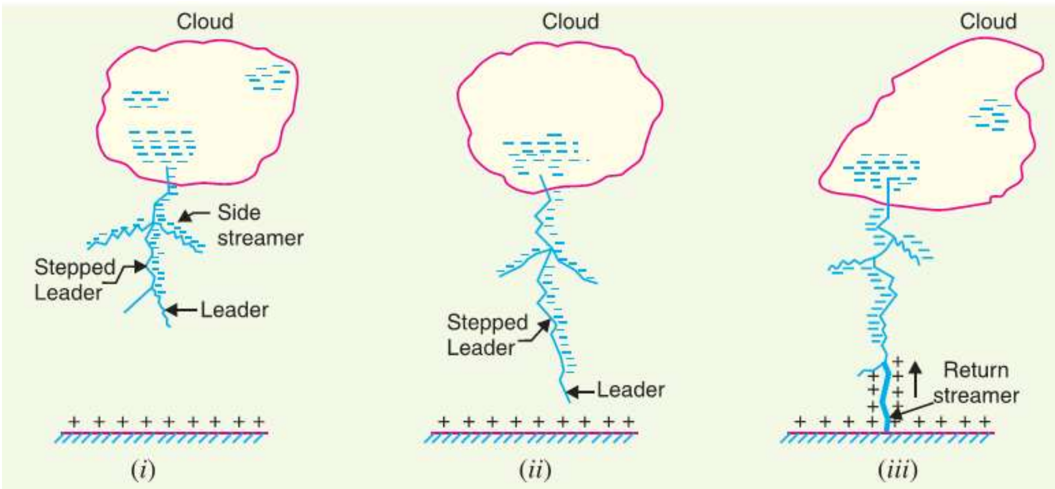


Fig 5.4 Lighting discharge

When the potential gradient is sufficient (5 kV/cm to 10 kV/cm) to break down the surrounding air, the lightning stroke starts. The stroke mechanism is as under

- As soon as the air near the cloud breaks down, a streamer called leader streamer or pilot streamer starts from the cloud towards the earth and carries charge with it as shown in Fig 5.4. The leader streamer will continue its journey towards earth as long as the cloud, from which it originates, feeds enough charge to it to maintain gradient at the tip of leader streamer above the strength of air. If this gradient is not maintained, the leader streamer stops and the charge is dissipated without the formation of a complete stroke. In other words, the leader streamer will not reach the earth. Fig5.4 (i) shows the leader streamer being unable to reach the earth as gradient at its end cloud not be maintained above the strength of air. It may be noted that current in the leader streamer is low (<100 A) and its velocity of propagation is about 0·05% that of velocity of light. Moreover, the luminosity of leader is also very low.

- In many cases, the leader streamer continues its journey towards earth [See Fig5.4 (ii)] until it makes contact with earth or some object on the earth. As the leader streamer moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leaders. The velocity of stepped leader exceeds one-sixth of that of light and distance travelled in one step is about 50 m. It may be noted that stepped leaders have sufficient luminosity and give rise to first visual phenomenon of discharge.
- The path of leader streamer is a path of ionisation and, therefore, of complete breakdown of insulation. As the leader streamer reaches near the earth, a return streamer shoots up from the earth to the cloud, following the same path as the main channel of the downward leader. The action can be compared with the closing of a switch between the positive and negative terminals; the downward leader having negative charge and re-turn streamer the positive charge. This phenomenon causes a sudden spark which we call lightning. With the resulting neutralisation of much of the negative charge on the cloud, any further discharge from the cloud may have to originate from some other portion of it.

Types of Lightning Strokes

There are two main ways in which a lightning may strike the power system

- Direct stroke
- Indirect stroke

Direct stroke

In the direct stroke, the lightning discharge is directly from the cloud to the subject equipment e.g. an overhead line. From the line, the current path may be over the insulators down the pole to the ground. The overvoltages set up due to the stroke may be large enough to flashover this path directly to the ground. The direct strokes can be of two types viz. Stroke A and stroke B.

- **In stroke A**

  the lightning discharge is from the cloud to the subject equipment i.e. an over-head line in this case as shown in Fig5.5 (i). The cloud will induce a charge of opposite

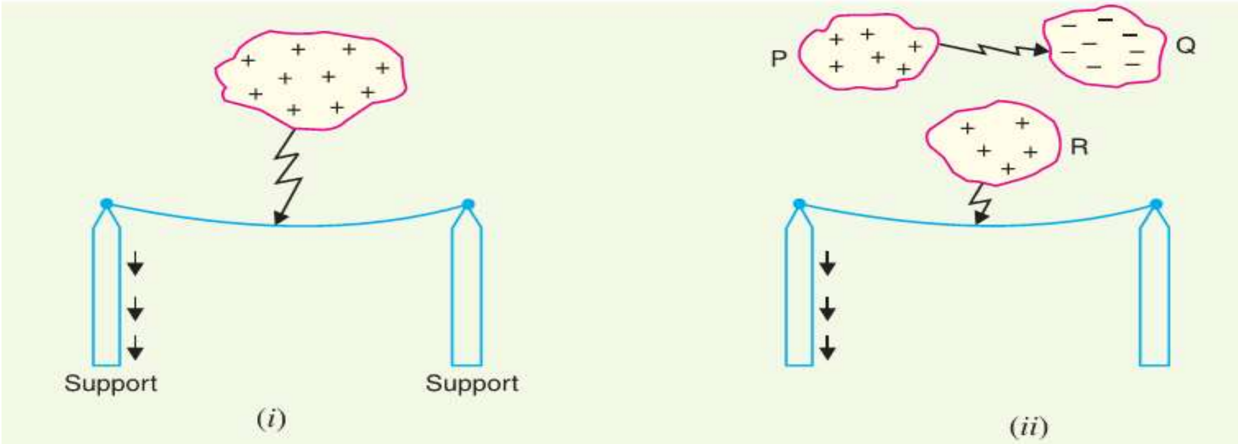


Figure 5.5 Direct stroke

sign on the tall object (e.g. an overhead line in this case). When the potential between the cloud and line exceeds the breakdown value of air, the lightning discharge occurs between the cloud and the line.

- In stroke B, the lightning discharge occurs on the overhead line as a result of stroke A between the clouds as shown in Fig.5.5 (ii). There are three clouds P, Q and R having positive, negative and positive charges respectively. The charge on the cloud Q is bound by the cloud R. If the cloud P shifts too near the cloud Q, then lightning discharge will occur between them and charges on both these clouds disappear quickly. The result is that charge on cloud suddenly becomes free and it then discharges rapidly to earth, ignoring tall objects.

Two points are worth noting about direct strokes. Firstly, direct strokes on the power system are very rare. Secondly, stroke A will always occur on tall objects and hence protection can be provided against it. However, stroke Bcompletely ignores the height of the object and can even strike the ground. Therefore, it is not possible to provide protection against stroke B.

Indirect stroke

Indirect strokes result from the electro statically induced charges on the conductors due to the presence of charged clouds. This is illustrated in Fig. 5.6. A positively charged cloud is above the line and induces a negative charge on the line by electrostatic induction. This negative charge, however, will be only on that portion of the line right under the cloud and the portions of the line away from it will be positively charged as shown in Fig. 5.6. The induced positive charge leaks slowly to earth via the insulators. When the cloud discharges to earth or to another cloud, the negative charge on the wire is isolated as it cannot flow quickly to earth over the insulators.

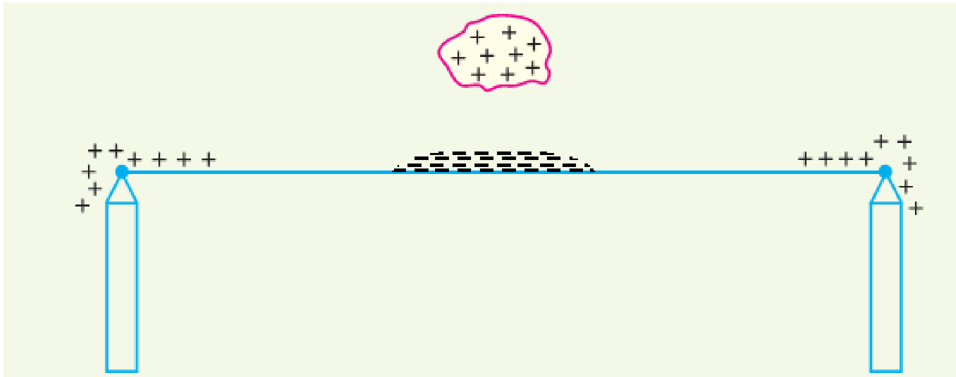


Figure 5.6 Lighting Stroke

The result is that negative charge rushes along the line is both directions in the form of travelling waves. It may be worthwhile to mention here that majority of the surges in a transmission line are caused by indirect lightning strokes.

Harmful Effects of Lightning

A direct or indirect lightning stroke on a transmission line produces a steep-fronted voltage wave on the line. The voltage of this wave may rise from zero to peak value (perhaps 2000 kV) in about 1 μs and decay to half the peak value in about 5μs. Such a steep-fronted voltage wave will initiate travel-ling waves along the line in both directions with the velocity dependent upon the Land C parameters of the line.

- The travelling waves produced due to lightning surges will shatter the insulators and may even wreck poles.
- If the travelling waves produced due to lightning hit the windings of a transformer or generator, it may cause considerable damage. The inductance of the windings opposes any sudden passage of electric charge through it. Therefore, the electric charges "piles up" against the transformer (or generator). This induces such an excessive pressure between the windings that insulation may breakdown, resulting in the production of arc. While the normal voltage between the turns is never enough to start an arc, once the insulation has broken down and an arc has been started by a momentary overvoltage, the line voltage is usually sufficient to maintain the arc long enough to severely damage the machine.

- If the arc is initiated in any part of the power system by the lightning stroke, this arc will setup very disturbing oscillations in the line. This may damage other equipment connected to the line.

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.) either by direct strokes on the equipment or by strokes on the transmission lines that reach the equipment as travelling waves. It is necessary to provide protection against both kinds of surges. The most commonly used devices for protection against lightning surges are :

- Earthing screen
- Overhead ground wires
- Lightning arresters or surge diverters

Earthing screen provides protection to power stations and sub-stations against direct strokes whereas overhead ground wires protect the transmission lines against direct lightning strokes. How-ever, lightning arresters or surge diverters protect the station apparatus against both direct strokes and the strokes that come into the apparatus as travelling waves. We shall briefly discuss these methods of protection.

The Earthing Screen

The power stations and sub-stations generally house expensive equipment. These stations can be protected against direct lightning strokes by providing earthing screen. It consists of a network of copper conductors mounted all over the electrical equipment in the sub-station or power station. The shield is properly connected to earth on atleast two points through a low impedance. On the occurrence of direct stroke on the station, screen provides a low resistance path by which lightning surges are conducted to ground. In this way, station equipment is protected against damage. The limitation of this method is that it does not provide protection against the travelling waves which may reach the equipment in the station.

Overhead Ground Wires

The most effective method of providing protection to transmission lines against direct lightning strokes is by the use of overhead ground wires as shown in Figure. 5.7. For simplicity, one ground wire and one line conductor are shown. The ground wires are placed above the line conductors at such positions that practically all lightning strokes are intercepted by them (i.e. ground wires). The ground wires are grounded at each tower or pole through as low resistance as possible. Due to their proper location, the *ground wires will take up all the lightning strokes instead of allowing them to line conductors. When the direct lightning stroke occurs on the transmission line, it will be taken up by the ground wires.

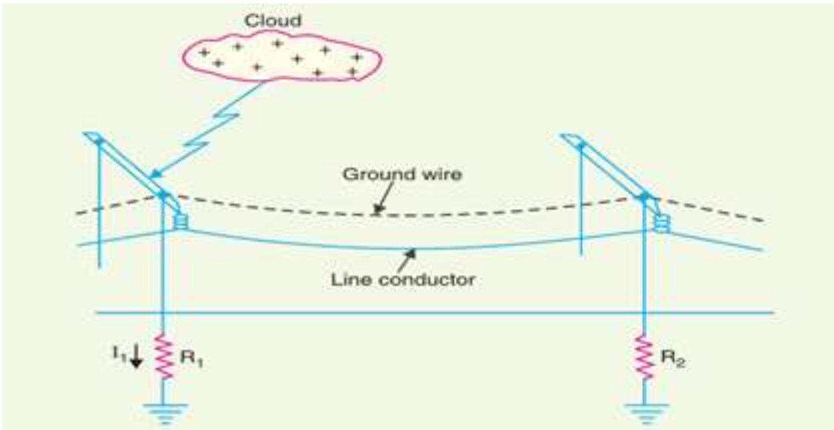


Figure 5.7 Ground wires

The heavy lightning current (10 kA to 50 kA) from the ground wire flows to the ground, thus protecting the line from the harmful effects of lightning. It may be mentioned here that the degree of protection provided by the ground wires depends upon the footing resistance of the tower. Suppose, for example, tower-footing resistance is R 1 ohms and that the lightning current from tower to ground is I_1 amperes. Then the tower rises to a potential V_t given by $V_t = I_1R_1$ Since V_t is the approximate voltage between tower and line conductor, this is also the voltage that will appear across the string of insulators. If the value of V_t is less than that required to cause insulator flashover, no trouble results. On the other hand, if V t is excessive, the insulator flashover may occur. Since the value of V_t depends upon tower-footing resistance R_1, the value of this resistance must be kept as low as possible to avoid insulator flashover.

Advantages

- It provides considerable protection against direct lightning strokes on transmission lines.
- A grounding wire provides damping effect on any disturbance travelling along the line as it acts as a short-circuited secondary.
- It provides a certain amount of electrostatic shielding against external fields. Thus it reduces the voltages induced in the line conductors due to the discharge of a neighbouring cloud.

Disadvantages

- It requires additional cost
- There is a possibility of its breaking and falling across the line conductors, thereby causing a short-circuit fault. This objection has been greatly eliminated by using galvanised stranded steel conductors as ground wires. This provides sufficient strength to the ground wires

LIGHTNING ARRESTERS

The earthing screen and ground wires can well protect the electrical system against direct lightning strokes but they fail to provide protection against travelling waves which may reach the terminal apparatus. The lightning arresters or surge diverters provide protection against such surges. A lightning arrester or a surge diverter is a protective device which conducts the high voltage surges on the power system to the ground.

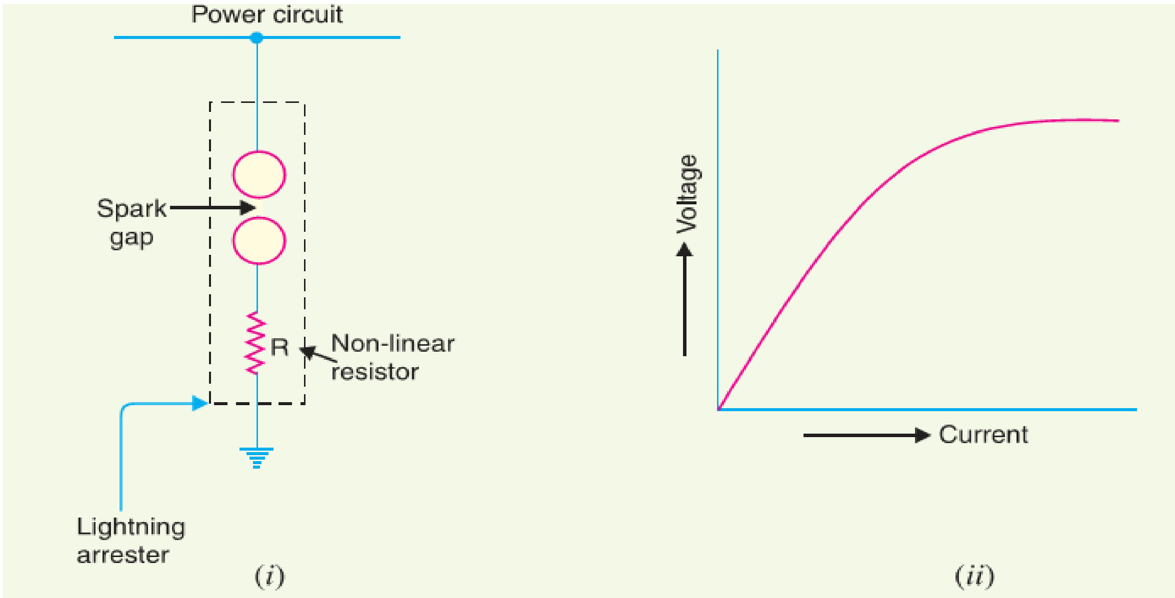


Figure 5.8 Lightning arresters

Figure.5.8 (i) shows the basic form of a surge diverter. It consists of a spark gap in series with a non-linear resistor. One end of the diverter is connected to the terminal of the equipment to be protected and the other end is effectively grounded.

The length of the gap is so set that normal line voltage is not enough to cause an arc across the gap but a dangerously high voltage will break down the air insulation and form an arc. The property of the non-linear resistance is that its resistance decreases as the voltage (or current) increases and vice-versa. This is clear from the volt/amp characteristic of the resistor shown in Figure. 5.8 (ii).

- Under normal operation, the lightning arrester is off the line i.e. it conducts no current to earth or the gap is non-conducting.
- On the occurrence of overvoltage, the air insulation across the gap breaks down and an arc is formed, providing a low resistance path for the surge to the ground. In this way, the excess charge on the line due to the surge is harmlessly conducted through the arrester to the ground instead of being sent back over the line.
- It is worthwhile to mention the function of non-linear resistor in the operation of arrester. As the gap sparks over due to overvoltage, the arc would be a short circuit on the power system and may cause power follow current in the arrester. Since the characteristic of the

resistor is to offer high resistance to high voltage (or current), it prevents the effect of a short circuit. After the surge is over, the resistor offers high resistance to make the gap non-conducting.

Two things must be taken care of in the design of a lightning arrester. Firstly, when the surge is over, the arc in gap should cease. If the arc does not go out, the current would continue to flow through the resistor and both resistor and gap may be destroyed. Secondly, IR drop (where I is the surge current) across the arrester when carrying surge current should not exceed the breakdown strength of the insulation of the equipment to be protected.

Types of Lightning Arresters

There are several types of lightning arresters in general use. They differ only in constructional details but operate on the same principle viz. providing low resistance path for the surges to the ground. We shall discuss the following types of lightning arresters

1. Rod gap arrester
2. Horn gap arrester
3. Multigap arrester
4. Expulsion type lightning arrester
5. Valve type lightning arrester

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 Figure. 5.9. One rod is connected to the line circuit and the other rod is connected to earth. The distance between gap and insulator must not be less than one-third of the gap length so that the arc may not reach the insulator and damage it.

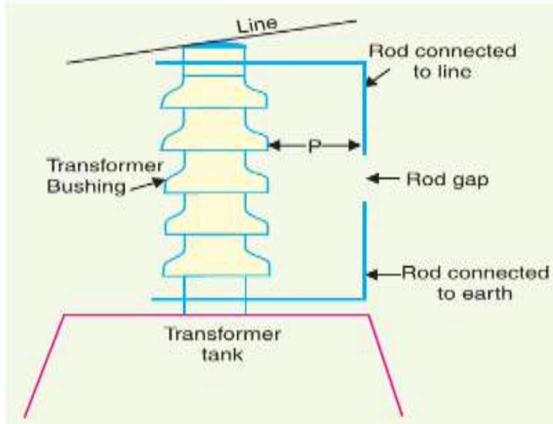


Figure 5.9 Road gap arrester

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. Figure 5.9 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.

Limitations

- After the surge is over, the arc in the gap is maintained by the normal supply voltage, leading to a short circuit on the system.
- The rods may melt or get damaged due to excessive heat produced by the arc.
- The climatic conditions (e.g. rain, humidity, temperature etc.) affect the performance of rod gap arrester.
- The polarity of the surge also affects the performance of this arrester.

Due to the above limitations, the rod gap arrester is only used as a 'back-up' protection in case of main arresters.

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 Rand 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.

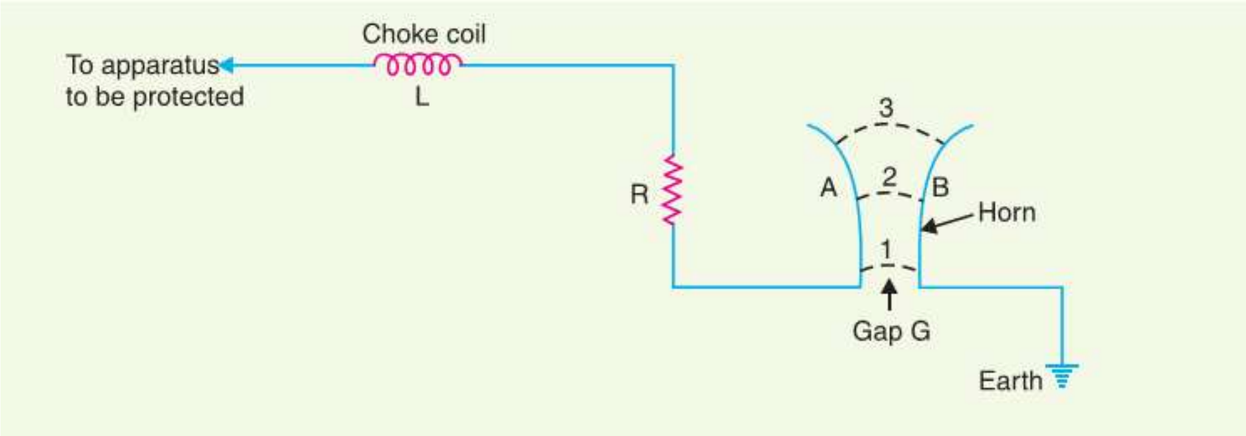


Figure 5.10 Horn gap arrester

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.

Advantages

- The arc is self-clearing. Therefore, this type of arrester does not cause short-circuiting of the system after the surge is over as in the case of rod gap.
- Series resistance helps in limiting the follow current to a small value.

Limitations

- The bridging of gap by some external agency (e.g. birds) can render the device useless.
- The setting of horn gap is likely to change due to corrosion or pitting. This adversely affects the performance of the arrester.

- The time of operation is comparatively long, say about 3 seconds. In view of the very short operating time of modern protective gear for feeders, this time is far long.

Due to the above limitations, this type of arrester is not reliable and can only be used as a second line of defence like the rod gap arrester.

Multigap arrester

It consists of a series of metallic (generally alloy of zinc) cylinders insulated from one another and separated by small intervals of air gaps. The first cylinder (i.e. A) in the series is connected to the line and the other to the ground through a series resistance. The series resistance limits the power arc. By the inclusion of series resistance, the degree of protection against travelling waves is reduced. In order to overcome this difficulty, some of the gaps (B to C in Figure. 5.11) are shunted by a resistance

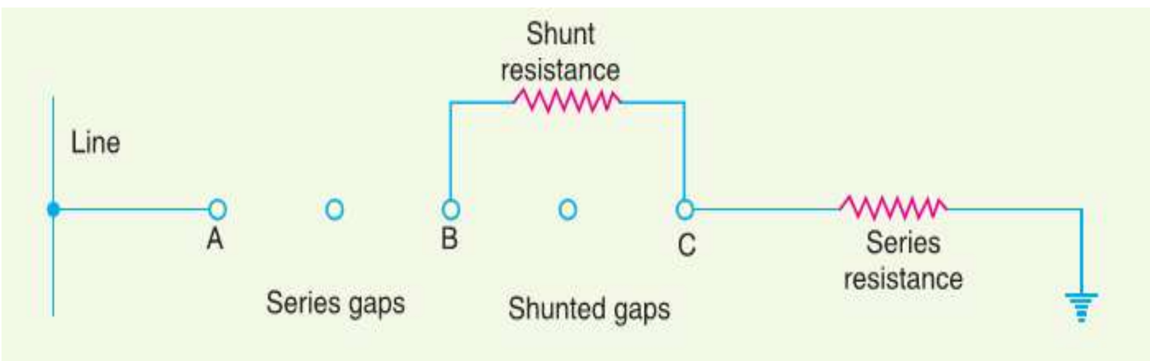


Figure 5.11 Multigap arrester

Under normal conditions, the point B is at earth potential and the normal supply voltage is unable to break down the series gaps. On the occurrence of an overvoltage, the breakdown of series gaps A to B occurs. The heavy current after breakdown will choose the straight - through path to earth via the shunted gaps Band C, instead of the alternative path through the shunt resistance. When the surge is over, the arcs B to C go out and any power current following the surge is limited by the two resistances (shunt resistance and series resistance) which are now in series. The current is too small to maintain the arcs in the gaps A to Band normal conditions are restored. Such arresters can be employed where system voltage does not exceed 33 kV.

Expulsion type arrester

This type of arrester is also called 'protector tube' and is commonly used on system operating at voltages upto 33 kV. Figure. 5.12 (i) shows the essential parts of an expulsion type lightning arrester. It essentially consists of a rod gap AA′ 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. Figure.5.12 (ii) shows the installation of expulsion arrester on an overhead line. On the occurrence of an overvoltage on the line, the series gap AA′ is spanned and an arc is struck between the electrodes in the tube. The heat of the arc vaporizes 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 deionising effect is generally so strong that arc goes out at a current zero and will not be re-established.

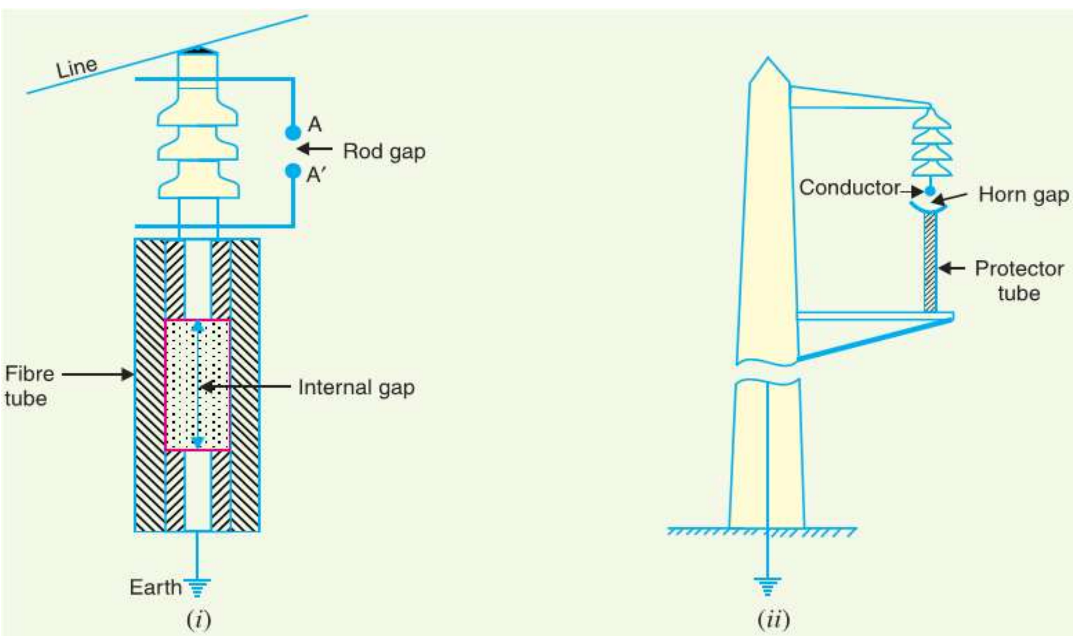


Figure 5.12 Expulsion type arrester

Advantages

- They are not very expensive.
- They are improved form of rod gap arresters as they block the flow of power frequency

follow currents.

- They can be easily installed.

Limitations

- An expulsion type arrester can perform only limited number of operations as during each operation some of the fibre material is used up.
- This type of arrester cannot be mounted in an enclosed equipment due to the discharge of gases during operation.
- Due to the poor volt/amp characteristic of the arrester, it is not suitable for the protection of expensive equipment.

Valve type arrester

Valve type arresters incorporate non-linear resistors and are extensively used on systems operating at high voltages. Figure.5.13 (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.

The spark gap is a multiple assembly consisting of a number of identical spark gaps in series. Each gap consists of two electrodes with 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.

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.

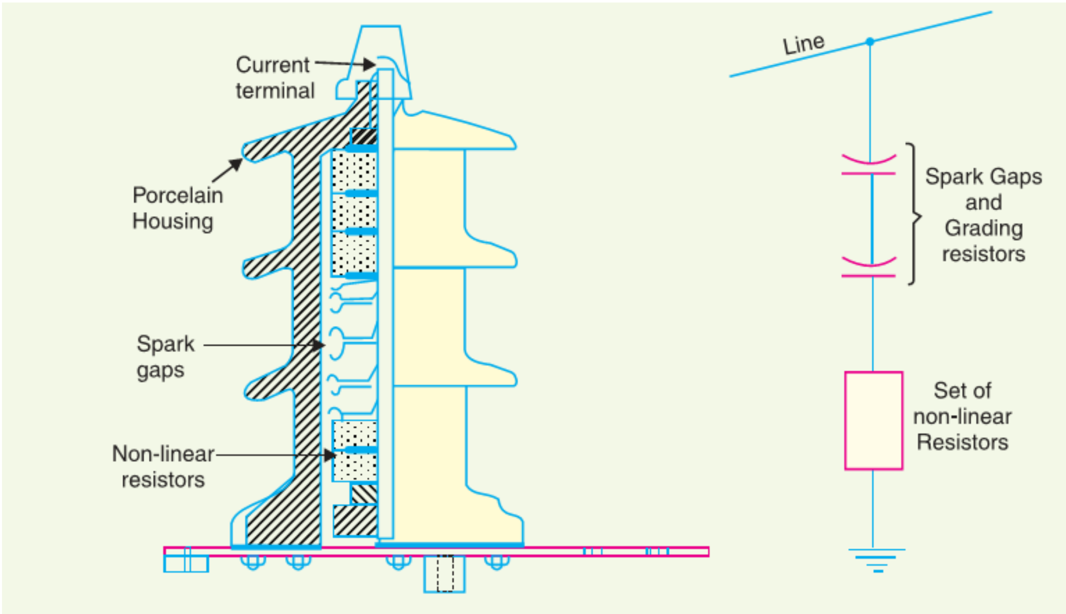


Figure 5.13 Valve type arrester

Under normal conditions, the normal system voltage is insufficient to cause the break-down 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.

Advantages

- They provide very effective protection (especially for transformers and cables) against surges.
- They operate very rapidly taking less than a second.
- The impulse ratio is practically unity.

Limitations

- They may fail to check the surges of very steep wave front from reaching the terminal apparatus. This calls for additional steps to check steep-fronted waves.
- Their performance is adversely affected by the entry of moisture into the enclosure. This necessitates effective sealing of the enclosure at all times.

Applications

According to their application, the valve type arresters are classified as (i) station type and (ii) line type. The station type arresters are generally used for the protection of important equipment in power stations operating on voltages upto 220 kV or higher. The line type arresters are also used for stations handling voltages upto 66 kV.

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. Although both surge diverter and surge absorber eliminate the surge, the manner in which it is done is different in the two devices.

The surge diverter diverts the surge to earth but the surge absorber absorbs the surge energy. A few cases of surge absorption are discussed below

- A condenser connected between the line and earth can act as a surge absorber. Figure. 5.14 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.

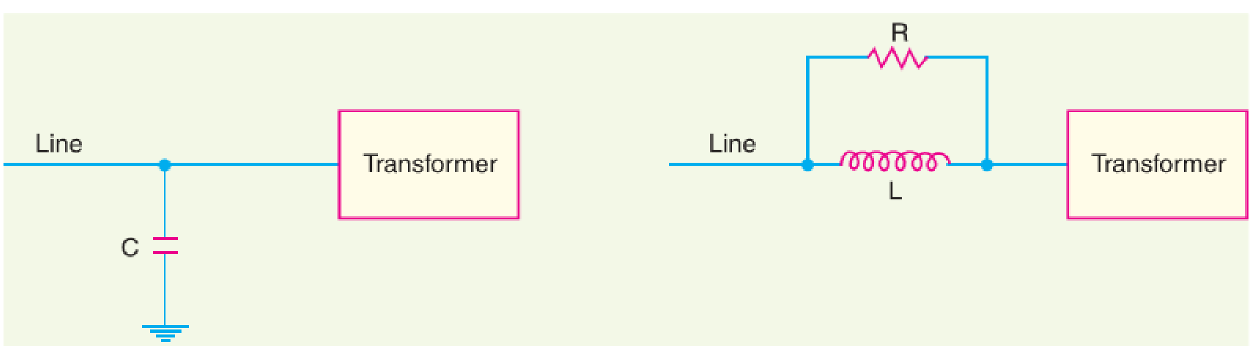


Figure 5.14 Parallel combination of Resistance

- Another type of surge absorber consists of a parallel combination of choke and resistance connected in series with the line as shown in Figure.5.14. 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.
- Figure.5.15 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 dissipater. This arrangement is equivalent to a transformer with short-circuited secondary. The inductor forms the primary whereas the dissipater forms the short circuited secondary. The energy of the surge is used up in the form of heat generated in the dissipater due to transformer action. This type of surge absorber is mainly used for the protection of transformers.

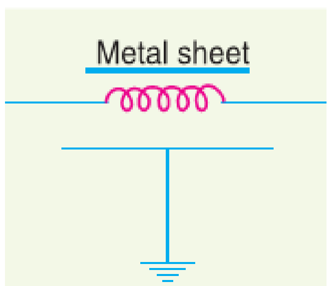


Figure 5.14 (i) Metal Sheet

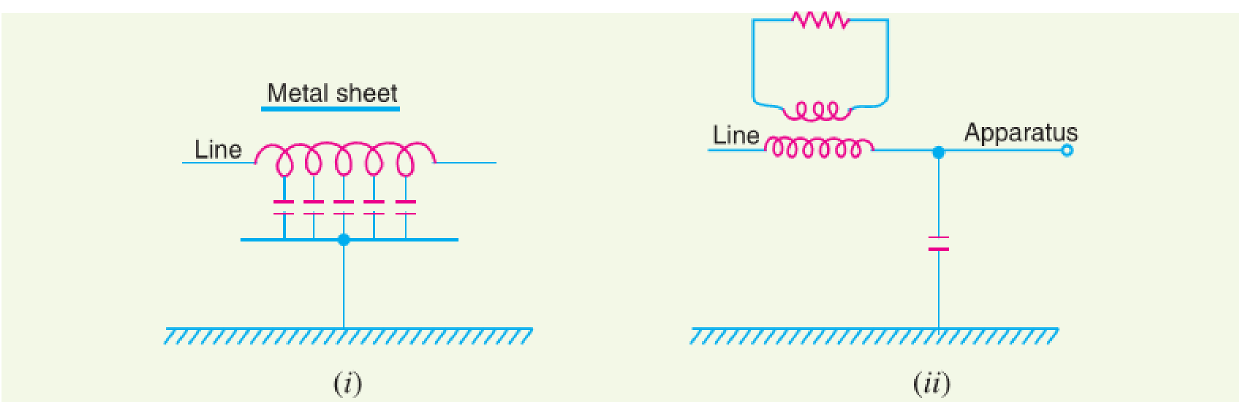


Figure 5.15 (ii) Metal sheet

Figure 5.14 (i) Shows the schematic diagram of 66 kV Ferranti surge absorber while Figure. 5.15 (i),(ii) shows its equivalent circuit.

PETERSON COIL (ARC SUPPRESSION COIL)

An arc suppression coil is an iron-cored reactor similar to oil immersed transformer connected between neutral of system and earth. This coil is provided with number of tappings so that it can be tuned with the capacitance which may vary due to varying operational conditions.

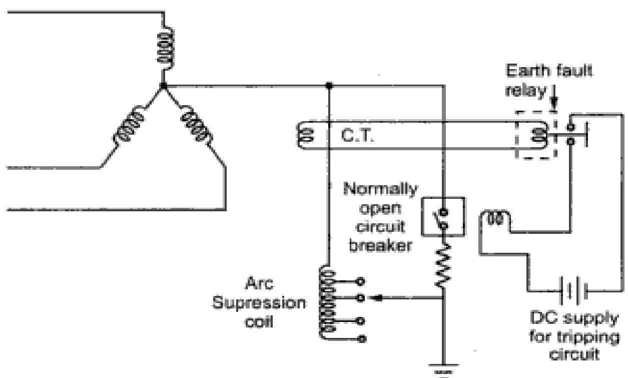


Figure 1.33 Arc Suppression coil

An arc suppression coil is an iron-cored reactor similar to oil immersed transformer connected between neutral of system and earth. This coil is provided with number of tappings so that it can be tuned with the capacitance which may vary due to varying operational conditions.

INSULATION CO-ORDINATION

The term Insulation Co-ordination was originally introduced to arrange the insulation levels of the several components in the transmission system in such a manner that an insulation failure, if it did occur, would be confined to the place on the system where it would result in the least damage, be the least expensive to repair, and cause the least disturbance to the continuity of the supply. The present usage of the term is broader. Insulation co-ordination now comprises the selection of the electric strength of equipment in relation to the voltages which can appear on the system for which the equipment is intended.

The overall aim is to reduce to an economically and operationally acceptable level the cost and disturbance caused by insulation failure and resulting system outages. To keep interruptions to a minimum, the insulation of the various parts of the system must be so graded that flashovers only occur at intended points. With increasing system voltage, the need to reduce the amount of insulation in the system, by proper co-ordination of the insulating levels becomes more critical.

Conventional method of insulation co-ordination

In order to avoid insulation failure, the insulation level of different types of equipment connected to the system has to be higher than the magnitude of transient over voltages that appear on the system. The magnitude of transient over voltages is usually limited to a protective level by protective devices. Thus the insulation level has to be above the protective level by a safe margin. Normally the impulse insulation level is established at a value 15-25% above the protective level.

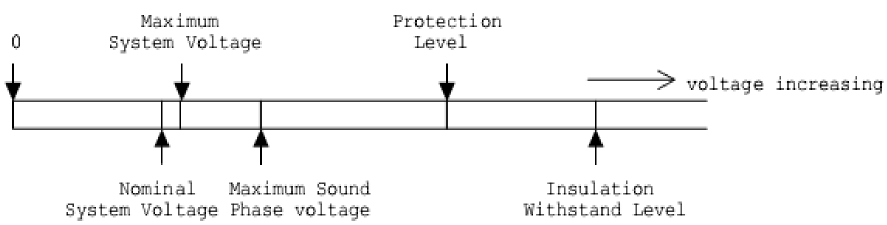


Figure 5.16 Conventional method of insulation co-ordination

Consider the typical co-ordination of a 132 kV transmission line between the transformer insulation, a line gap (across an insulator string) and a co-ordinating gap (across the transformer bushing)

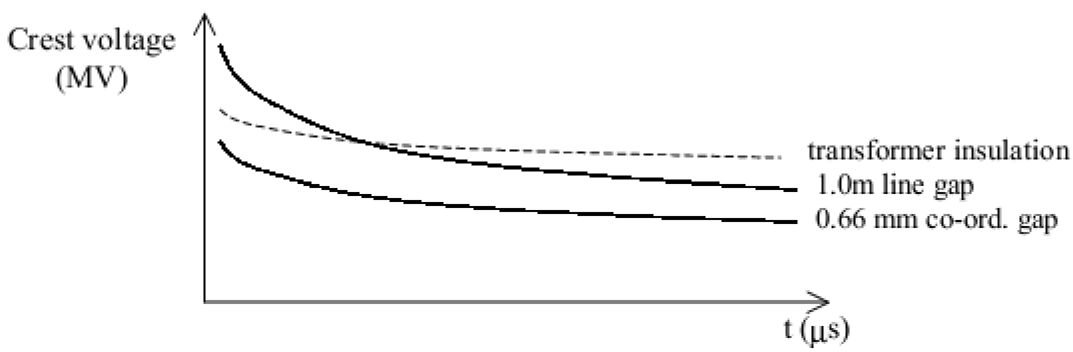


Figure 5.17 Characteristics curve

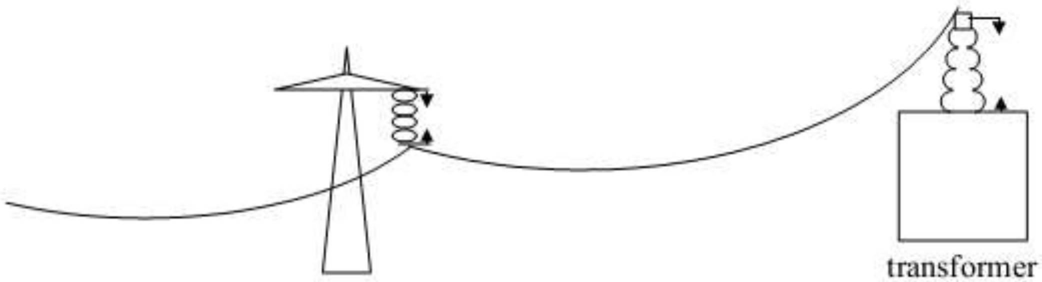


Figure 5.18 coordination using gaps

In co-ordinating the system under consideration, we have to ensure that the equipment used are protected, and that inadvertent interruptions are kept to a minimum. The co-ordinating gap must be chosen so as to provide protection of the transformer under all conditions. However, the line gaps protecting the line insulation can be set to a higher characteristic to reduce unnecessary interruptions.

A typical set of characteristics for insulation co-ordination by conventional methods, in which lightning impulse voltages are the main source of insulation failure, is shown in the Figure 5.18.

For the higher system voltages, the simple approach used above is inadequate. Also, economic considerations dictate that insulation co-ordination be placed on a more scientific basis.

Statistical Method of Insulation Co-ordination

At the higher transmission voltages, the length of insulator strings and the clearances in air do not increase linearly with voltage but approximately to $V^{1.6}$ The required number of suspension units for different overvoltage factors is shown. It is seen that the increase in the number of disc units is only slight for the 220 kV system, with the increase in the overvoltage factor from 2.0 to 3.5, but that there is a rapid increase in the 750 kV system. Thus, while it may be economically feasible to protect the lower voltage lines up to an overvoltage factor of 3.5 (say), it is definitely not economically feasible to have an overvoltage factor of more than about 2.0 or 2.5 on the higher voltage lines. In the higher voltage systems, it is the switching over voltages that is predominant. However, these may be controlled by proper design of switching devices.

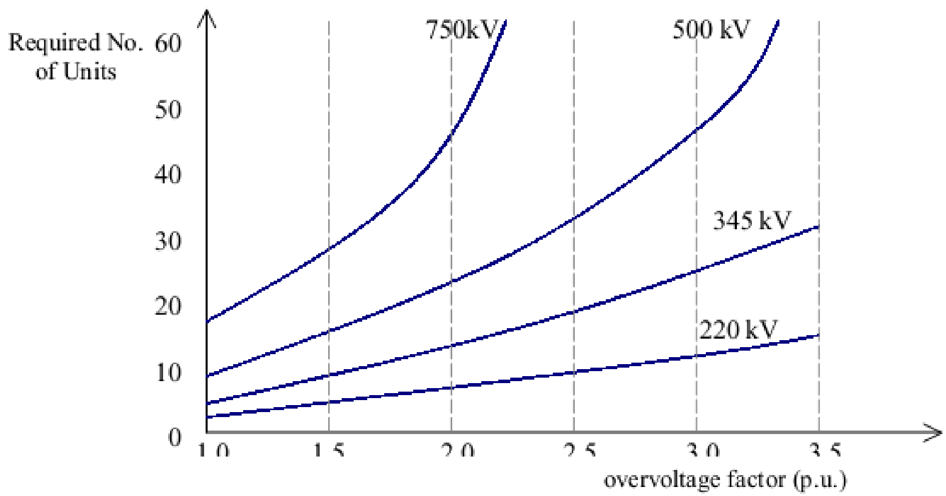


Figure 5.19 Requirement of number of units for different voltages

In a statistical study, what has to be known is not the highest overvoltage possible, but the statistical distribution of over voltages. The switching overvoltage probability in typical line is shown. It is seen that probability of overvoltage decreases very rapidly.

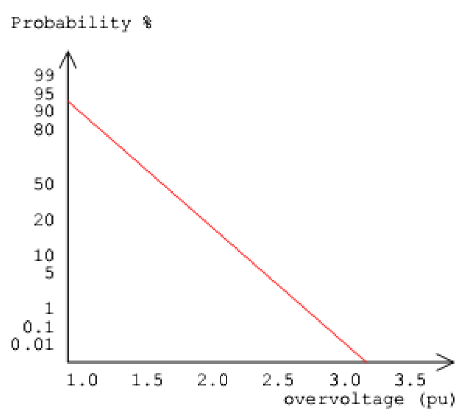


Figure 2.10 Probability of overvoltage exceeding abscissae

Thus it is not economic to provide insulation above a certain overvoltage value. In practice, the overvoltage distribution characteristic is modified by the use of switching resistors which damp out the switching over voltages or by the use of surge diverters set to operate on the higher switching over voltages. In such cases, the failure probability would be extremely low.

RELAY COORDINATION

Protective relays are to be designed to isolate the faulted portion of the system at the earliest, to prevent equipment damage and with minimum system disruption to ensure continuity of service to healthy portion of the network. When relays meant to protect specific equipments, transmission/distribution lines/feeders or primary zone do not operate and clear the fault in their primary protection zone, backup relays must act to isolate the fault, after providing sufficient time discrimination for the operation of the primary zone relays. The relays must also be able to discriminate between faulted conditions, normal operating conditions and abnormal operating conditions and function for the specific protection for which they are designed.

Relay coordination calculation module must consider the operating characteristics of the relays, normal operating and with stand characteristics of the equipments and must determine the optimum relay settings to achieve the objectives stated. The parameters of the under frequency and under voltage relays can be set and their performance can be evaluated using detailed transient stability studies. Protection system must also be designed to provide protection against thermal-withstand limits, motor stalling, negative sequence current with-stand limits, protection against abnormal frequencies, and protection against unbalance operating conditions as applicable to various equipments and operating situations.

SELECTION OF PROTECTIVE SYSTEM

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.) either by direct strokes on the equipment or by strokes on the transmission lines that reach the equipment as travelling waves. It is necessary to provide protection against both kinds of surges. The most commonly used devices for protection against lightning surges are

- Earthing screen
- Overhead ground wires
- Lightning arresters or surge diverters

Earthing screen provides protection to power stations and sub-stations against direct strokes whereas overhead ground wires protect the transmission lines against direct lightning strokes. How-ever, lightning arresters or surge diverters protect the station apparatus against both direct strokes and the strokes that come into the apparatus as travelling waves. We shall briefly discuss these methods of protection.

The power stations and sub-stations generally house expensive equipment. These stations can be protected against direct lightning strokes by providing earthing screen. It consists of a network of copper conductors (generally called shield or screen) mounted all over the electrical equipment in the sub-station or power station. The shield is properly connected to earth on at least two points through low impedance. On the occurrence of direct stroke on the station, screen provides a low resistance path by which lightning surges are conducted to ground. In this way, station equipment is protected against damage. The limitation of this method is that it does not provide protection against the travelling waves which may reach the equipment in the station.

The most effective method of providing protection to transmission lines against direct lightning strokes is by the use of overhead ground wires. For simplicity, one ground wire and one line conductor are shown. The ground wires are placed above the line conductors at such positions that practically all lightning strokes are intercepted by them (i.e. ground wires). The ground wires are grounded at each tower or pole through as low resistance as possible. Due to their proper location, the ground wires will take up all the lightning strokes instead of allowing them to line conductors.