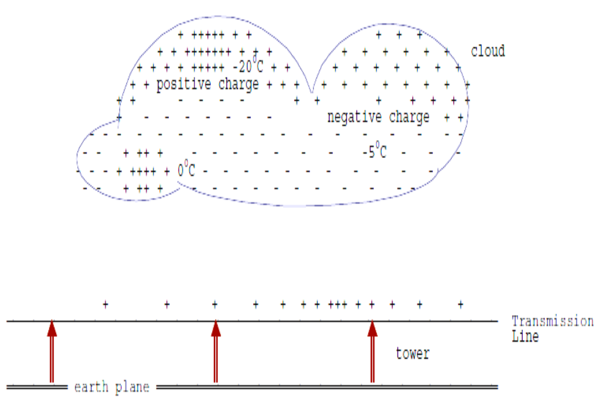
UNIT – 5

SURGE PROTECTION AND INSULATION CO ORDINATION

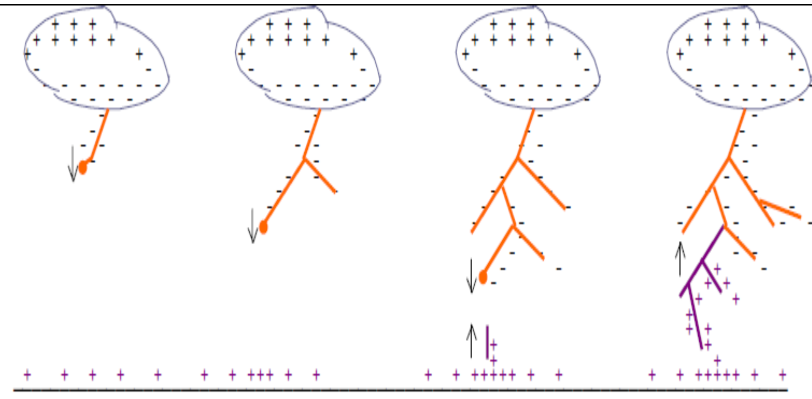
Unit-05 /Lecture-01

INTRODUCTION ABOUT LIGHTENING –

- Lightning is an electric discharge in the form of a spark or flash originating in a charged cloud. It has now been known for a long time that thunder clouds are charged, and that the negative charge centre is located in the lower part of the cloud where the temperature is about - 50C, and that the main positive charge centre is located several kilometres higher up, where the temperature is usually below - 200C. In the majority of storm clouds, there is also a localised positively charged region near the base of the cloud where the temperature is 00C. Figure 3.1 shows such a cloud located above a overhead transmission line.
- Fields of about 1000 V/m exist near the centre of a single bipolar cloud in which charges of about 20 C are separated by distances of about 3 km, and indicate the total potential difference between the main charge centres to be between 100 and1000 MV. The energy dissipated in a lightning flash is therefore of the order of 1000 to 10,000 MJ, much of which is spent in heating up a narrow air column surrounding the discharge, the temperature rising to about 15,000 0 C in a few tens of microseconds. Vertical separation of the positive and negative charge centres is about 2 - 5 km, and the charges involved are 10 - 30 C. The average current dissipated by lightning is of the order of kilo-amperes. During an average lightning storm, a total of the order of kilo-coulombs of charge would be generated, between the 00 C and the -40 0 C levels, in a volume of about 50 KM^3.



Induced charges on transmission line (Lightning Phenomena)



Formation of Streamer and Stepped leader

Breakdown Process

- Under the influence of sufficiently strong fields, large water drops become elongated in the direction of the field and become unstable, and streamers develop at their ends with the onset of corona discharges. Drops of radius 2 mm develop streamers in fields exceeding a 9 kV/cm - much less than the 30 kV/cm required to initiate the breakdown of dry air. The high field need only be very localised, because a streamer starting from one drop may propagate itself from drop to drop under a much weaker field. When the electric field in the vicinity of one of the negative charge centres builds up to the critical value (about 10 kV/cm), an ionised channel (or streamer) is formed, which propagates from the cloud to earth with a velocity that might be as high as one-tenth the speed of light. Usually this streamer is extinguished when only a short distance from the cloud.Forty micro-seconds or so after the first streamer, a second streamer occurs, closely following the path of the first, and propagating the ionised channel a little further before it is also spent. This process continues a number of times, each step increasing the channel length by 10 to 200 m. Because of the step like sequence in which this streamer travels to earth, this process is termed the stepped leader stroke. This process is shown diagrammatically in figure.
- When eventually the stepped leader has approached to within 15 to 50 m of the earth, the field intensity at earth is sufficient for an upward streamer to develop and bridge the remaining gap. A large neutralising current flows along the ionised path, produced by the stepped leader, to neutralise the charge. This current flow is termed the return stroke and may carry currents as high as 200 kA, although the average current is about 20 kA.
- The luminescence of the stepped leader decreases towards the cloud and in one instances it appears to vanish some distance below the cloud. This would suggest that the current is confined to the stepped leader itself. Following the first, or main stroke and after about 40 ms, a second leader stroke propagates to earth in a continuous and rapid manner and againa return stroke follows. This second and subsequent leader strokes which travel along the already energised channel are termed dart leaders.
- What appears as a single flash of lightning usually consist of a number of successive strokes, following the same track in space, at intervals of a few hundredths of a second. The average number of strokes in a multiple stroke is four, but as manyas 40 have been reported. The time interval between strokes ranges from 20 to 700 ms, but is most frequently 40-50 ms. The average duration of a complete flash being about 250 ms.
- The approximate time durations of the various components of a lightning stroke are summarised as follows.
  Stepped leader = 10 ms
  Return stroke = 40 ms
  period between strokes = 40 ms
  duration of dart leader = 1 ms

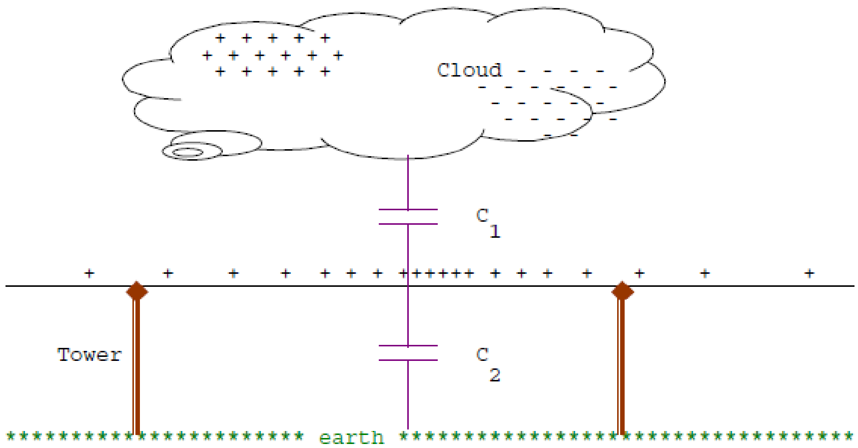
The standard voltage waveform used in high voltage testing has a 1.2/50 micro sec.

Frequency of occurrence of lightning flashes;

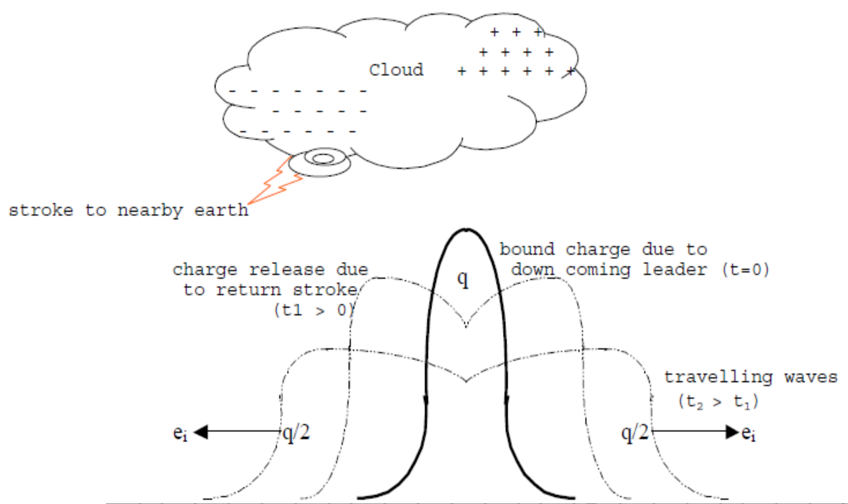
- Knowledge of the frequency of occurrence of lightning strokes is of utmost importance in the design of protection against lightning. The frequency of occurrence is defined as the flashes occurring per unit area per year.

Strokes to nearby objects (Indirect Strokes)

- In any lightning discharge, the charge on the down coming leader causes the conductors of the line to have a charge induced in them (figure).These charges are bound (held in that portion of the line nearest to the cloud) so long as the cloud remains near without discharging its electricity by a lightning stroke to an object. If however, the cloud is suddenly discharged, as it is when lightning strikes some object nearby, the induced charges are no longer bound, but travel with nearly the velocity of light, along the line to equalise the potential at all points of the line.



Induced Charge on cloud



Propagation of travelling waves

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain phenomenon of lightening. How over voltage is produced due to lightening.	RGPV/June 2012,2013	7
Q.2	Explain lightening, how transient voltage produced due lightening .	RGPV/ June 2011	7

Unit-05 /Lecture-02

RGPV/ June 2013

<u>OVER VOLTAGE DUE TO LIGHTENING</u>

- There are always a chance of suffering an electrical power system from abnormal over voltages. These abnormal over voltages may be caused due to various reason such as, sudden interruption of heavy load, lightening impulses, switching impulses etc. These over voltage stresses may damage insulation of various equipments and insulators of the power system. Although, all the over voltage stresses are not strong enough to damage insulation of system, but still these over voltages also to be avoided to ensure the smooth operation of electrical power system.

These all types of destructive and non destructive abnormal over voltages are eliminated from the system by means of overvoltage protection.

<u>Voltage Surge</u>

- The over voltage stresses applied upon the power system, are generally transient in nature. Transient voltage or voltage surge is defined as sudden sizing of voltage to a high peak in very short duration. The voltage surges are transient in nature that means they exist for very short duration. The main cause of these voltage surges in power system are due to lightning impulses and switching impulses of the system. But over voltage in the power system may also be caused by, insulation failure, arcing ground and resonance etc.
- The voltage surges appear in the electrical power system due to switching surge, insulation failure, arcing ground and resonance are not very large in magnitude. These over voltages hardly cross the twice of the normal voltage level. Generally, proper insulation to the different equipment of power system is sufficient to prevent any damage due to these over voltages. But over voltages occur in the power system due to lightning is very high. If over voltage protection is not provided to the power system, there may be high chance of severe damage. Hence all over voltage protection devices used in power system mainly due to lightning surges.

<u>Different causes of over voltages :</u>

Switching Impulse or Switching Surge

When a no load transmission line is suddenly switched on, the voltage on the line becomes twice of normal system voltage. This voltage is transient in nature. When a loaded line is suddenly switched off or interrupted, voltage across the line also becomes high enough current chopping in the system mainly during opening operation of air blast circuit breaker, causes over voltage in the system. During insulation failure, a live conductor is suddenly earthed. This may also caused sudden over voltage in the system. If emf wave produced by alternator is distorted, the trouble of resonance may occur due to 5^{th} or higher harmonics. Actually for frequencies of 5^{th} or higher harmonics, a critical situation in the system so appears, that inductive reactance of the system becomes just equal to capacitive reactance of the system. As these both reactance cancel each other the system becomes purely resistive. This phenomenon is called resonance and at resonance the system voltage may be increased enough.

But all these above mentioned reasons create over voltages in the system which are not very high in magnitude.

But over voltage surges appear in the system due to lightning impulses are very high in amplitude and highly destructive. The affect of lightning impulse hence must be avoided for over voltage protection of power system.

Methods of Protection Against Lightning

These are mainly three main methods generally used for protection against lightning. They are

1. Earthing screen.
2. Overhead earth wire.
3. Lightening arrester or surge dividers.

Earthing Screen

Earthing screen is generally used over electrical sub-station. In this arrangement a net of GI wire is mounted over the sub-station. The GI wires, used for earthing screen are properly grounded through different sub-station structures. This network of grounded GI wire over electrical sub-station, provides very low resistance path to the ground for lightning strokes.

This method of high voltage protection is very simple and economic but the main drawback is, it can not protect the system from travelling wave which may reach to the sub-station via different feeders.

Overhead Earth Wire

This method of over voltage protection is similar as earthing screen. The only difference is, an earthing screen is placed over an electrical sub-station, whereas, overhead earthwire is placed over electrical transmission network. One or two stranded GI wires of suitable cross-section are placed over the transmission conductors. These GI wires are properly grounded at each transmission tower. These overhead ground wires or earthwire divert all the lightning strokes to the ground instead of allowing them to strike directly on the transmission conductors.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain how the system can be protected against lightening over voltage.	RGPV/ Dec 2013	7
Q.2	Explain various causes of over voltage due to lightening	RGPV/ June 2011	7

Unit-05 /Lecture-03

RGPV/ June 2011

Lightning Arrester

- The previously discussed two methods, i.e. earthing screen and over-head earth wire are very suitable for protecting an electrical power system from directed lightning strokes but system from directed lightning strokes but these methods can not provide any protection against high voltage travelling wave which may propagate through the line to the equipment of the sub-station.
- The lightning arrester is a devices which provides very low impedance path to the ground for high voltage travelling waves.
- The concept of a lightning arrester is very simple. This device behaves like a nonlinear electrical resistance. The resistance decreases as voltage increases and vice-versa, after a certain level of voltage.

The functions of a lightning arrester or surge dividers can be listed as below.

- Under normal voltage level, these devices withstand easily the system voltage as electrical and provide no conducting path to the system current.
- On occurrence of voltage surge in the system, these devices provide very low impedance path for the excess charge of the surge to the ground. After conducting the charges of surge, to the ground, the voltage becomes to its normal level. Then lightning arrester regains its insulation properly and prevents regains its insulation property and prevents further conduction of current, to the ground.
- There are different types of lightning arresters used in power system, such as rod gap arrester, horn gap arrester, multi-gap arrester, expulsion type LA, value type LA.In addition to these the most commonly used lightning arrester for over voltage protection now-a-days gapless ZnO lightning arrester is also used.

Lighting and Voltage Surge

- Lightning can create voltage surges in several of the following ways. Lightning can score a direct hit on your house. It can strike the overhead power line which enters your house, or a main power line that is blocks away from your home. Lightning can strike branch circuitry wiring in the walls of your house. Lightning can strike an object near your home such as a tree or the ground itself and cause a surge. Voltage surges can be created by cloud to cloud lightning near your home. A highly charged cloud which passes over your home can also induce a voltage surge.

- Voltage surges can also be caused by standard on and off switching activities of large electric motors or pieces of equipment. These surges can be created by a neighbor, or by a business or manufacturing facility some distance from your house. These surges are insidious and for the most part are silent. They can occur with little or no warning.

Method to Suppress Lighting and Voltage Surge:

- When a voltage surge is created, it wants to equalize itself and it wants to do it as quickly as possible. These things seem to have very little patience. The surges will do whatever it takes to equalize or neutralize themselves, even if it means short circuiting all of your electronic equipment.
- The method of providing maximum protection for equipment is quite simple. Create a pathway for the voltage surge (electricity) to get to and into the ground outside your house as quickly as possible. This is not, in most cases, a difficult task.
- The first step is simple. Create an excellent grounding system for your household electrical system. The grounding rods should be at least ten feet apart from one another. They should be located in soil which readily accepts electricity. Moist clay soils are very desirable. Rocky, sandy, or soils with gravel generally have high resistance factors. Electricity has a tough time dissipating into them. Resistance readings should be in the range of 10 to 30 ohms. The lower the better.
- The second step in household surge protection is to install a lightning arrester inside of your electric service panel.

What is a surge arrester?

- Surge arresters are devices that help prevent damage to apparatus due to high voltages. The arrester provides a low-impedance path to ground for the current from a lightning strike or transient voltage and then restores to a normal operating conditions.
- A surge arrester may be compared to a relief valve on a boiler or hot water heater. It will release high pressure until a normal operating condition is reached. When the pressure is returned to normal, the safety valve is ready for the next operation.
- When a high voltage (greater than the normal line voltage) exists on the line, the arrester immediately furnishes a path to ground and thus limits and drains off the excess voltage. The arrester must provide this relief and then prevent any further flow of current to ground. The arrester has two functions; it must provide a point in the circuit at which an over-voltage pulse can pass to ground and second, to prevent any follow-up current from flowing to ground.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Differentiate between Lightening arrester and lightening conductor	RGPV/ June 2013	7
Q.2	Differentiate lightening arrester and surge diverter	RGPV/ June 2011	7

Unit-05 /Lecture-03

RGPV June / 2012

Causes of over voltages

1. Internal causes
2. External causes

Internal causes

- Switching surge
- Insulation failure
- Arcing ground
- Resonance

Switching surge: The over voltages produced on the power system due to switching are known as switching surge

Insulation failure: The most common case of insulation failure in a power system is the grounding of conductors (i.e. insulation failure between line and earth) which may cause overvoltage in the system.

Arcing ground: The phenomenon of intermittent arc taking place in line to ground fault of a 3phase system with consequent production of transients is known as arcing ground.

Resonance: It occurs in an electrical system 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 p.f is unity.

Types of lightning strokes

- Direct stroke
- Indirect stroke

(1) Direct stroke

In direct stroke, the lightning discharge is directly from the cloud to the subject equipment. From the line, the current path may be over the insulator down the pole to the ground.

(2) Indirect stroke

Indirect stroke results from the electro statically induced charges on the conductors due to the presence of charge clouds.

Harmful effects of lightning

- The traveling waves produced due to lightning will shatter the insulators.
- If the traveling waves hit the windings of a transformer or generator it may cause considerable damage.

Protection against lightning

Different types of protective devices are:-

- Earthing screen
- Overhead ground wires
- Lightning arresters

(1) The Earthing screen

The power station & sub-station can be protected against direct lightning strokes by providing earthing screens. On occurrence of direct stroke on the station ,screen provides a low resistance path by which lightning surges are conducted to ground.

Limitation: It does not provide protection against the traveling waves which may reach the equipments in the station.

(2) Overhead ground wires

It is the most effective way of providing protection to transmission lines against direct lightning strokes.It provides damping effect on any disturbance traveling along the lines as it acts as a short-circuited secondary.

Limitation:

It requires additional cost.There is a possibility of its breaking and falling across the line conductors, thereby causing a short-circuit fault.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain various causes of Over voltages	RGPV/ June 2013	7
Q.2	Explain various type of protective devices required for protection against lightening	RGPV/ June 2011	7

Unit-05 /Lecture-04

RGPV/ Dec 2011

(3)Lightning Arresters

It is a protective device which conducts the high voltage surge on the power system to ground

The earthing screen and ground wires fail to provide protection against traveling waves. The lightning arrester provides protection against surges.

Working Principle of LA:

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

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

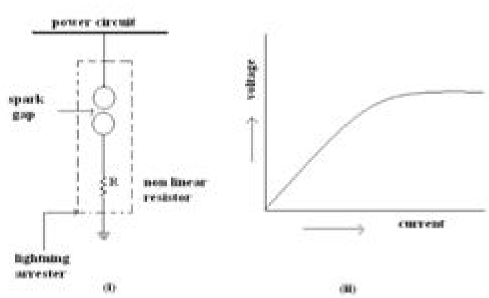


Fig shows the basic form of a surge diverter. It consists of a spark gap in series with a non-linear resistor. One end of the diverter is connected to the terminal of the equipment to be protected and the other end is effectively grounded. The length of the gap is so set that normal voltage is not enough to cause an arc 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 increases as the voltage (or current) increases and vice-versa. This is clear from the volt/amp characteristic of the resistor shown in Fig

The action of the lightning arrester or surge divert er is as under:

(i) Under normal operation, the lightning arrester is off the line i.e. it conducts no current to earth or the gap is non-conducting

(ii) On the occurrence of over voltage, 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.

(iii) It is worthwhile to mention the function of non-linear resistor in the operation of arrester. As the gap sparks over due to over voltage, 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 low resistance to high voltage (or current), it gives the effect of short-circuit. After the surge is over, the resistor offers high resistance to make the gap non-conducting.

Type of LA for Outdoor Applications:

There are several types of lightning arresters in general use. They differ only in constructional details but operate on the same principle, providing low resistance path for the surges to the round.

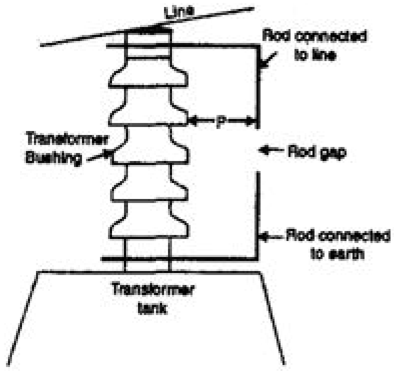
1. Rod arrester
2. Horn gap arrester
3. Multi gap arrester
4. Expulsion type lightning arrester
5. Valve type lightning arrester

(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-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 8 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:

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

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain working of various types Lightening arrester	RGPV/ Dec 2011	7
Q.2	Explain various type of protective devices required for protection against lightening	RGPV/ June 2011	7

Unit-05 /Lecture-05

RGPV/ Dec 2011

(2) Horn Gap Arrester:

- Fig shows the horn gap arrester. It consists of a 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 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.

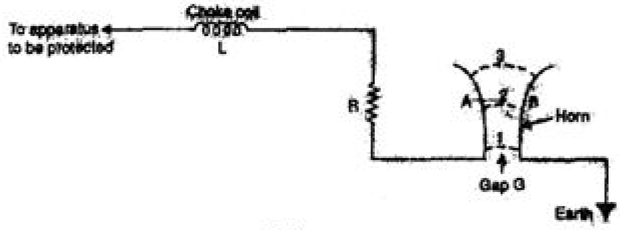
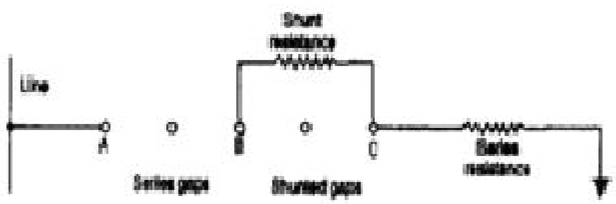


fig 9

- 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 over voltage, 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 (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) **Multi Gap Arrester:**

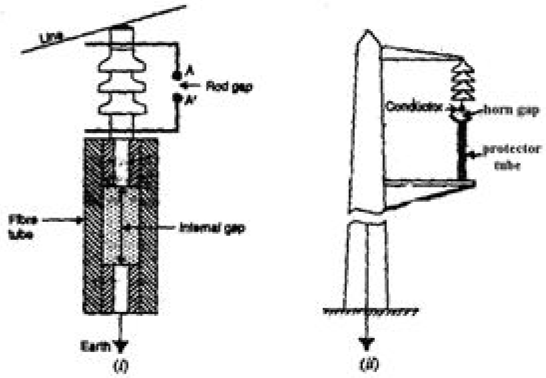
- Fig shows the multi gap arrester. It consists of a series of metallic (generally alloy of zinc) cylinders insulated from one another and separated by small intervals of air gaps. The first cylinder (i.e. A) in the series is connected to the line and the others to the ground through a series resistance. The series resistance limits the power arc. By the inclusion of series resistance, the degree of protection against traveling waves is reduced.
- In order to overcome this difficulty, some of the gaps (B to C in Fig) are shunted by resistance. 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 an over voltage, the breakdown of series gaps A to B occurs.
- he heavy current after breakdown will choose the straight – through path to earth via the shunted gaps B and C, instead of the alternative path through the shunt resistance.



Hence 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 B and normal conditions are restored. Such arresters can be employed where system voltage does not exceed 33kV.

(4**) Expulsion Type Arrester:**

- This type of arrester is also called ‘protector tube’ and is commonly used on system operating at voltages up to 33kV. Fig 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 fiber tube. The gap in the fiber 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 shows the installation of expulsion arrester on an overhead line.



- On the occurrence of an over voltage on the line, the series gap AA' spanned and an arc is stuck between the electrodes in the tube. The heat of the arc vaporizes some of the fiber of tube walls resulting in the production of 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 ionized air around the arc. This de ionizing effect is generally so strong that the arc goes out at a current zero and will not be re-established.

Advantages:

(i) They are not very expensive.

(ii)They are improved form of rod gap arresters as they block the flow of power frequency follow currents

(iii)They can be easily installed.

Limitations:

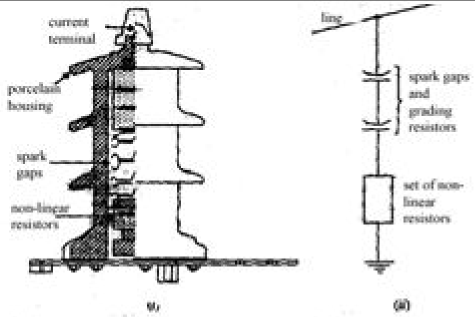
(i)An expulsion type arrester can perform only limited number of operations as during each operation some of the fiber material is used up.

(ii) This type of arrester cannot be mounted on enclosed equipment due to discharge of gases during operation.

(iii)Due to the poor volt/am characteristic of the arrester, it is not suitable for protection of expensive equipment

(5) Valve Type Arrester:

- Valve type arresters incorporate non linear resistors and are extensively used on systems, operating at high voltages. Fig shows the various parts of a valve type arrester. It consists of two assemblies (i) series spark gaps and (ii) non-linear resistor discs 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 gap is line raised by means of additional resistance elements called grading resistors across the gap. The spacing of the series gaps is such that it will withstand the normal circuit voltage. However an over voltage will cause the gap to break down causing the surge current to ground via the non-linear resistors.
- The non-linear resistor discs are made of 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 break down of air gap assembly. On the occurrence of an over voltage, 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.

(6) Silicon carbide arresters:

- A great number of silicon carbide arresters are still in service. The silicon carbide arrester has some unusual electrical characteristics. It has a very high resistance to low voltage, but a very low resistance to high-voltage.
- When lightning strikes or a transient voltage occurs on the system, there is a sudden rise in voltage and current. The silicon carbide resistance breaks down allowing the current to be conducted to ground. After the surge has passed, the resistance of the silicon carbide blocks increases allowing normal operation.
- The silicon carbide arrester uses nonlinear resistors made of bonded silicon carbide placed in series with gaps. The function of the gaps is to isolate the resistors from the normal steady-state system voltage. One major drawback is the gaps require elaborate design to ensure consistent spark-over level and positive clearing (resealing) after a surge passes. It should be recognized that over a period of operations that melted particles of copper might form which could lead to a reduction of the breakdown voltage due to the pinpoint effect. Over a period of time, the arrester gap will break down at small over voltages or even at normal operating voltages. Extreme care should be taken on arresters that have failed but the over pressure relief valve did not operate. This pressure may cause the arrester to

(7) Metal Oxide Arrestor:

- The MOV arrester is the arrester usually installed todayThe metal oxide arresters are without gaps, unlike the SIC arrester. This “gap-less” design eliminates the high heat associated with the arcing discharges.The MOV arrester has two-voltage rating: duty cycle and maximum continuous operating voltage, unlike the silicon carbide that just has the duty cycle rating. A metal-oxide surge arrester utilizing zinc-oxide blocks provides the best performance, as surge voltage conduction starts and stops promptly at a precise voltage level, thereby improving system protection. Failure is reduced, as there is no air gap contamination possibility; but there is always a small value of leakage current present at operating frequency.
- It is important for the test personnel to be aware that when a metal oxide arrester is disconnected from an energized line a small amount of static charge can be retained by the arrester. As a safety precaution, the tester should install a temporary ground to discharge any stored energy.

- Duty cycle rating: The silicon carbide and MOV arrester have a duty cycle rating in KV, which is determined by duty cycle testing. Duty cycle testing of an arrester is performed by subjecting an arrester to an AC rms voltage equal to its rating for 24 minutes. During which the arrester must be able to withstand lightning surges at 1-minute intervals.

- Maximum continuous operating voltage rating: The MCOV rating is usually 80 to 90% of the duty cycle rating.

- **Installation of LA:**

The arrester should be connected to ground to a low resistance for effective discharge of the surge current.
The arrester should be mounted close to the equipment to be protected & connected with shortest possible lead on both the line & ground side to reduce the inductive effects of the leads while discharging large surge current.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain various types of Lightening Arrester	RGPV/ Dec 2013	7
Q.2	Explain Expulsion type and horn type lightening arrester	RGPV/ June 2011	7

Unit-05 /Lecture-06

Importance of System Earthing

- In the early power systems were mainly Neutral ungrounded due to the fact that the first ground fault did not require the tripping of the system. An unscheduled shutdown on the first ground fault was particularly undesirable for continuous process industries. These power systems required ground detection systems, but locating the fault often proved difficult. Although achieving the initial goal, the ungrounded system provided no control of transient over-voltages.

- A capacitive coupling exists between the system conductors and ground in a typical distribution system. As a result, this series resonant L-C circuit can create over-voltages well in excess of line-to-line voltage when subjected to repetitive re-strikes of one phase to ground.This in turn, reduces insulation life resulting in possible equipment failure.
- Neutral grounding systems are similar to fuses in that they do nothing until something in the system goes wrong. Then, like fuses, they protect personnel and equipment from damage. Damage comes from two factors, how long the fault lasts and how large the fault current is. Ground relays trip breakers and limits how long a fault lasts and Neutral grounding resistors limit how large the fault current is.

Importance of Neutral Grounding

- There are many neutral grounding options available for both Low and Medium voltage power systems. The neutral points of transformers, generators and rotating machinery to the earth ground network provides a reference point of zero volts. This protective measure offers many advantages over an ungrounded system, like:

1. Reduced magnitude of transient over voltages
2. Simplified ground fault location
3. Improved system and equipment fault protection
4. Reduced maintenance time and expense
5. Greater safety for personnel
6. Improved lightning protection
7. Reduction in frequency of faults.

Methods of Neutral Earthing

There are five methods for Neutral earthing:

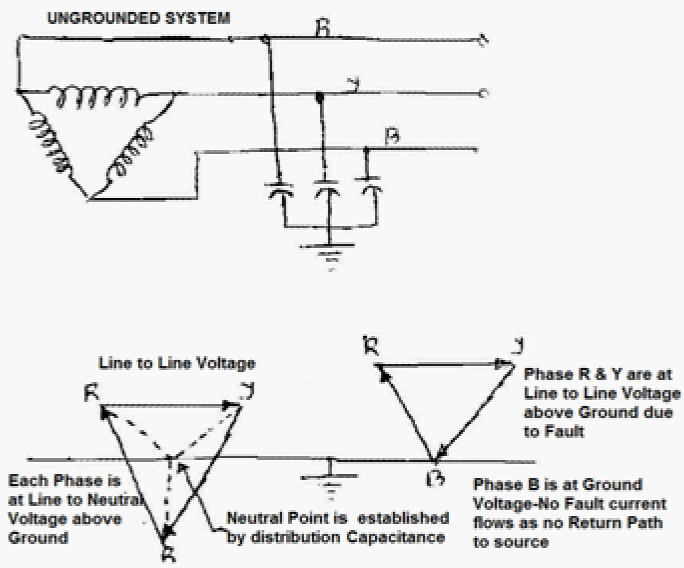
1. Unearthed Neutral System
2. Solid Neutral Earthed System
3. Resistance Neutral Earthing System
    1. Low Resistance Earthing
    2. High Resistance Earthing
4. Resonant Neutral Earthing System
5. Earthing Transformer Earthing

Top

1. Ungrounded Neutral Systems

- In ungrounded system there is no internal connection between the conductors and earth. However, as system, a capacitive coupling exists between the system conductors and the adjacent grounded surfaces. Consequently, the “ungrounded system” is, in reality, a “capacitive grounded system” by virtue of the distributed capacitance.
- Under normal operating conditions, this distributed capacitance causes no problems. In fact, it is beneficial because it establishes, in effect, a neutral point for the system; As a result, the phase conductors are stressed at only line-to-neutral voltage above ground.

But problems can rise in ground fault conditions. A ground fault on one line results in full line-to-line voltage appearing throughout the system. Thus, a voltage 1.73 times the normal voltage is present on all insulation in the system.This situation can often cause failures in older motors and transformers, due to insulation breakdown.



Ungrounded neutral system

Advantages

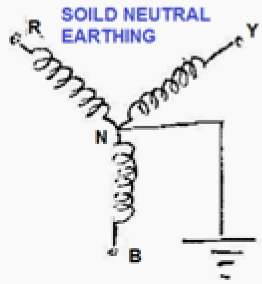
After the first ground fault, assuming it remains as a single fault, the circuit may continue in operation, permitting continued production until a convenient shut down for maintenance can be scheduled.

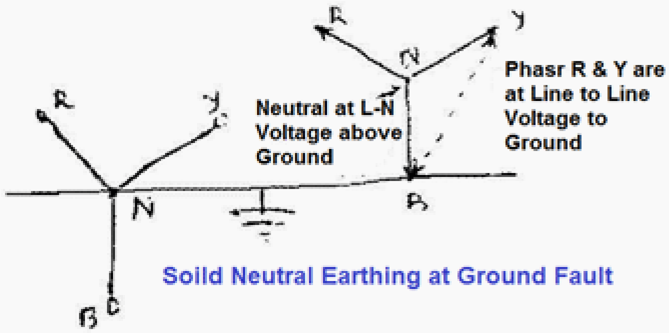
Disadvantages

1. The interaction between the faulted system and its distributed capacitance may cause transient over-voltages (several times normal) to appear from line to ground during normal switching of a circuit having a line-to ground fault (short). These over voltages may cause insulation failures at points other than the original fault.
2. A second fault on another phase may occur before the first fault can be cleared. This can result in very high line-to-line fault currents, equipment damage and disruption of both circuits.
3. The cost of equipment damage.

Solidly Neutral Grounded Systems

- Solidly grounded systems are usually used in low voltage applications at 600 volts or less. In solidly grounded system, the neutral point is connected to earth.
- Solidly Neutral Grounding slightly reduces the problem of transient over voltages found on the ungrounded system and provided path for the ground fault current is in the range of 25 to 100% of the system three phase fault current.
- However, if the reactance of the generator or transformer is too great, the problem of transient over voltages will not be solved.
- While solidly grounded systems are an improvement over ungrounded systems, and speed up the location of faults, they lack the current limiting ability of resistance grounding and the extra protection this provides.
- To maintain systems health and safe, Transformer neutral is grounded and grounding conductor must be extend from the source to the furthest point of the system within the same raceway or conduit. Its purpose is to maintain very low impedance to ground faults so that a relatively high fault current will flow thus insuring that circuit breakers or fuses will clear the fault quickly and therefore minimize damage.





Solidly Neutral Grounded Systems

It also greatly reduces the shock hazard to personnel!

- If the system is not solidly grounded, the neutral point of the system would “float” with respect to ground as a function of load subjecting the line-to-neutral loads to voltage unbalances and instability. The single-phase earth fault current in a solidly earthed system may exceed the three phase fault current. The magnitude of the current depends on the fault location and the fault resistance.

One way to reduce the earth fault current is to leave some of the transformer neutrals unearthed.

Advantages

The main advantage of solidly earthed systems is low over voltages, which makes the earthing design common at high voltage levels (HV).

Disadvantages

1. This system involves all the drawbacks and hazards of high earth fault current: maximum damage and disturbances.
2. There is no service continuity on the faulty feeder.
3. The danger for personnel is high during the fault since the touch voltages created are high.

Applications

1. Distributed neutral conductor
2. 3-phase + neutral distribution
3. Use of the neutral conductor as a protective conductor with systematic earthing at each transmission pole

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain various type of Earthing	RGPV/ Dec 2011	7
Q.2	Differentiate grounding neutral and ungrounded neutral system	RGPV/ June 2011	7

Resistor neutral earthing

- Neither of these grounding systems (low or high resistance) reduces arc-flash hazards associated with phase-to-phase faults, but both systems significantly reduce or essentially eliminate the arc-flash hazards associated with phase-to-ground faults. Both types of grounding systems limit mechanical stresses and reduce thermal damage to electrical equipment, circuits, and apparatus carrying faulted current.
- The difference between Low Resistance Grounding and High Resistance Grounding is a matter of perception and, therefore, is not well defined. Generally speaking high-resistance grounding refers to a system in which the NGR let-through current is less than 50 to 100 A.Low resistance grounding indicates that NGR current would be above 100 A.
- A better distinction between the two levels might be alarm only and tripping. An alarm-only system continues to operate with a single ground fault on the system for an unspecified amount of time. In a tripping system a ground fault is automatically removed by protective relaying and circuit interrupting devices. Alarm-only systems usually limit NGR current to 10 A or less.

Rating of The Neutral grounding resistor:

1. Voltage: Line-to-neutral voltage of the system to which it is connected.
2. Initial Current: The initial current which will flow through the resistor with rated voltage applied.
3. Time: The "on time" for which the resistor can operate without exceeding the allowable temperature rise.

Resistance Grounding

The main reasons for limiting the phase to ground fault current by resistance grounding are:

1. To reduce burning and melting effects in faulted electrical equipment like switchgear, transformers, cables, and rotating machines.
2. To reduce mechanical stresses in circuits/Equipments carrying fault currents.
3. To reduce electrical-shock hazards to personnel caused by stray ground fault.
4. To reduce the arc blast or flash hazard.
5. To reduce the momentary line-voltage dip.
6. To secure control of the transient over-voltages while at the same time.
7. To improve the detection of the earth fault in a power system.

Grounding Resistors are generally connected between ground and neutral of transformers, generators and grounding transformers to limit maximum fault current as per Ohms Law to a value which will not damage the equipment in the power system and allow sufficient flow of fault current to detect and operate Earth protective relays to clear the fault. Although it is possible to limit fault currents with high resistance Neutral grounding Resistors, earth short circuit currents can be extremely reduced.

As a result of this fact, protection devices may not sense the fault.

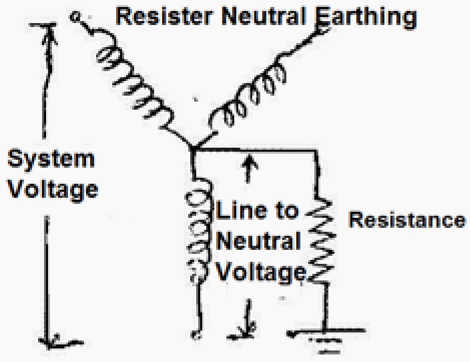
Therefore, it is the most common application to limit single phase fault currents with low resistance Neutral Grounding Resistors to approximately rated current of transformer and / or generator.In addition, limiting fault currents to predetermined maximum values permits the designer to selectively coordinate the operation of protective devices, which minimizes system disruption and allows for quick location of the fault.

There are two categories of resistance grounding:

1. Low resistance Grounding
2. High resistance Grounding

Ground fault current flowing through either type of resistor when a single phase faults to ground will increase the phase-to-ground voltage of the remaining two phases. As a result, conductor insulation and surge arrestor ratings must be based on line-to-line voltage. This temporary increase in phase-to-ground voltage should also be considered when selecting two and three pole breakers installed on resistance grounded low voltage systems.

The increase in phase-to-ground voltage associated with ground fault currents also precludes the connection of line-to-neutral loads directly to the system. If line-to neutral loads (such as 277V lighting) are present, they must be served by a solidly grounded system. This can be achieved with an isolation transformer that has a three-phase delta primary and a three-phase, four-wire, wye secondary.



Resistor neutral earthing

Neither of these grounding systems (low or high resistance) reduces arc-flash hazards associated with phase-to-phase faults, but both systems significantly reduce or essentially eliminate the arc-flash hazards associated with phase-to-ground faults. Both types of grounding systems limit mechanical stresses and reduce thermal damage to electrical equipment, circuits, and apparatus carrying faulted current.The difference between Low Resistance Grounding and High Resistance Grounding is a matter of perception and, therefore, is not well defined. Generally speaking high-resistance grounding refers to a system in which the NGR let-through current is less than 50 to 100 A.Low resistance grounding indicates that NGR current would be above 100 A.

A better distinction between the two levels might be alarm only and tripping. An alarm-only system continues to operate with a single ground fault on the system for an unspecified amount of time. In a tripping system a ground fault is automatically removed by protective relaying and circuit interrupting devices. Alarm-only systems usually limit NGR current to 10 A or less.

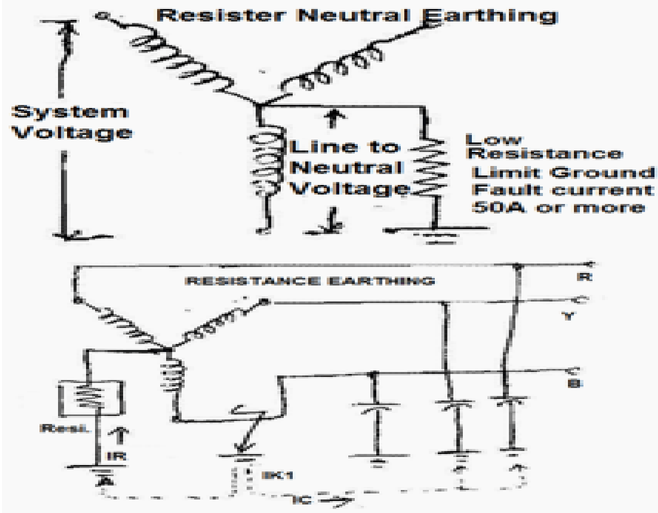
Rating of The Neutral grounding resistor:

1. Voltage: Line-to-neutral voltage of the system to which it is connected.
2. Initial Current: The initial current which will flow through the resistor with rated voltage applied.
3. Time: The “on time” for which the resistor can operate without exceeding the allowable temperature rise.

A. Low Resistance Grounded

Low Resistance Grounding is used for large electrical systems where there is a high investment in capital equipment or prolonged loss of service of equipment has a significant economic impact and it is not commonly used in low voltage systems because the limited ground fault current is too low to reliably operate breaker trip units or fuses. This makes system selectivity hard to achieve. Moreover, low resistance grounded systems are not suitable for 4-wire loads and hence have not been used in commercial market applications.

A resistor is connected from the system neutral point to ground and generally sized to permit only 200A to 1200 amps of ground fault current to flow. Enough current must flow such that protective devices can detect the faulted circuit and trip it off-line but not so much current as to create major damage at the fault point.



Low resistance grounded

Since the grounding impedance is in the form of resistance, any transient over voltages are quickly damped out and the whole transient overvoltage phenomena is no longer applicable. Although theoretically possible to be applied in low voltage systems (e.g. 480V),significant amount of the system voltage dropped across the grounding resistor, there is not enough voltage across the arc forcing current to flow, for the fault to be reliably detected.

For this reason low resistance grounding is not used for low voltage systems (under 1000 volts line to-line).

Advantages

1. Limits phase-to-ground currents to 200-400A.
2. Reduces arcing current and, to some extent, limits arc-flash hazards associated with phase-to-ground arcing current conditions only.
3. May limit the mechanical damage and thermal damage to shorted transformer and rotating machinery windings.

Disadvantages:

1. Does not prevent operation of over current devices.
2. Does not require a ground fault detection system.
3. May be utilized on medium or high voltage systems.
4. Conductor insulation and surge arrestors must be rated based on the line to-line voltage. Phase-to-neutral loads must be served through an isolation transformer.
5. Used: Up to 400 amps for 10 sec are commonly found on medium voltage systems.

Unit-05 /Lecture-08

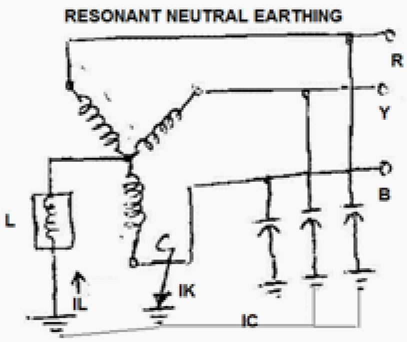
4. Resonant earthed system

Adding inductive reactance from the system neutral point to ground is an easy method of

limiting the available ground fault from something near the maximum 3 phase short circuit capacity (thousands of amperes) to a relatively low value (200 to 800 amperes).
To limit the reactive part of the earth fault current in a power system a neutral point reactor can be connected between the transformer neutral and the station earthing system.
A system in which at least one of the neutrals is connected to earth through an

1. Inductive reactance.
2. Petersen coil / Arc Suppression Coil / Earth Fault Neutralizer.

The current generated by the reactance during an earth fault approximately compensates the capacitive component of the single phase earth fault current, is called a resonant earthed system.The system is hardly ever exactly tuned, i.e. the reactive current does not exactly equal the capacitive earth fault current of the system. A system in which the inductive current is slightly larger than the capacitive earth fault current is over compensated. A system in which the induced earth fault current is slightly smaller than the capacitive earth fault current is under compensated.



Resonant neutral earthing
However, experience indicated that this inductive reactance to ground resonates with the system shunt capacitance to ground under arcing ground fault conditions and creates very high transient over voltages on the system. To control the transient over voltages, the design must permit at least 60% of the 3 phase short circuit current to flow underground fault conditions.
<u>Example</u> – A 6000 amp grounding reactor for a system having 10,000 amps 3 phase short circuit capacity available. Due to the high magnitude of ground fault current required to control transient over voltages, inductance grounding is rarely used within industry.

<u>Petersen Coils</u>
A Petersen Coil is connected between the neutral point of the system and earth, and is rated so that the capacitive current in the earth fault is compensated by an inductive current passed by the Petersen Coil. A small residual current will remain, but this is so small that any arc between the faulted phase and earth will not be maintained and the fault will extinguish. Minor earth faults such as a broken pin insulator, could be held on the system without the supply being interrupted. Transient faults would not result in supply interruptions.
Although the standard 'Peterson coil' does not compensate the entire earth fault current in a network due to the presence of resistive losses in the lines and coil, it is now possible to apply 'residual current compensation' by injecting an additional 180° out of phase current into the neutral via the Peterson coil. The fault current is thereby reduced to practically zero. Such systems are known as 'Resonant earthing with residual compensation', and can be considered as a special case of reactive earthing.
Resonant earthing can reduce EPR to a safe level. This is because the Petersen coil can often effectively act as a high impedance NER, which will substantially reduce any earth fault currents, and hence also any corresponding EPR hazards (e.g. touch voltages, step voltages and transferred voltages, including any EPR hazards impressed onto nearby telecommunication networks).
Advantages

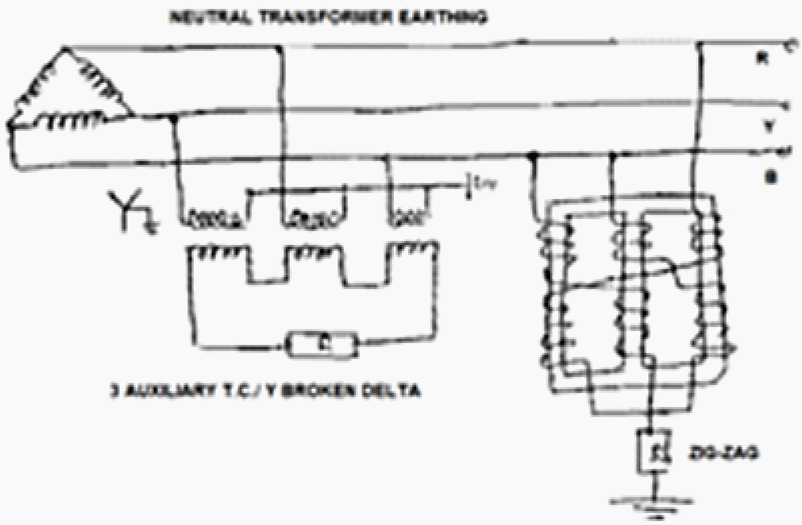
1. Small reactive earth fault current independent of the phase to earth capacitance of the system.
2. Enables high impedance fault detection.

Disadvantages

1. Risk of extensive active earth fault losses.
2. High costs associated.

5. Earthing Transformers

For cases where there is no neutral point available for Neutral Earthing (e.g. for a delta winding), an earthing transformer may be used to provide a return path for single phase fault currents.



Earthing transformers

In such cases the impedance of the earthing transformer may be sufficient to act as effective earthing impedance. Additional impedance can be added in series if required. A special 'zig-zag' transformer is sometimes used for earthing delta windings to provide a low zero-sequence impedance and high positive and negative sequence impedance to fault currents.

Conclusion

Resistance Grounding Systems have many advantages over solidly grounded systems including arc-flash hazard reduction, limiting mechanical and thermal damage associated with faults, and controlling transient over voltages.

High resistance grounding systems may also be employed to maintain service continuity and assist with locating the source of a fault.

When designing a system with resistors, the design/consulting engineer must consider the specific requirements for conductor insulation ratings, surge arrestor ratings, breaker single-pole duty ratings, and method of serving phase-to-neutral loads.

Insulation Coordination in Power System

Insulation levels of different components in the electrical power system including transmission network, in such a manner, that the failure of insulator, if occurs, confides to the place where it would result in the least damage of the system, easy to repair and replace, and results least disturbance to the power supply. When any over voltage appears in the electrical power system, then there may be a chance of failure of its insulation system. Probability of failure of insulation, is high at the weakest insulation point nearest to the source of over voltage. In power system and transmission networks, insulation is provided to the all equipment and components. Insulators in some points are easily replaceable and repairable compared to other. Insulation in some points are not so easily replaceable and repairable and the replacement and repairing may be highly expensive and require long interruption of power. Moreover failure of insulator at these points may causes bigger part of electrical network to be out of service. So it is desirable that in situation of insulator failure, only the easily replaceable and repairable insulator fails.

- The overall aim of insulation coordination is to reduce to an economically and operationally acceptable level the cost and disturbance caused by insulation failure. In insulation coordination method, the insulation of the various parts of the system must be so graded that flash over if occurs it must be at intended points.

Nominal System Voltage

Nominal System Voltage is the phase to phase voltage of the system for which the system is normally designed. Such as 11KV, 33KV, 132KV, 220KV, 400KV systems.

Maximum System Voltage

Maximum System Voltage is the maximum allowable power frequency voltage which can occurs may be for long time during no load or low load condition of the power system. It is also measured in phase to phase manner.

List of different nominal system voltage and their corresponding maximum system voltage is given below for reference,

NOMINAL SYSTEM VOLTAGE IN KV	11	33	66	132	220	400
MAXIMUM SYSTEM VOLTAGE IN KV	12	36	72.5	145	245	420

NB – It is observed from above table that generally maximum system voltage is 110% of corresponding nominal system voltage up to voltage level of 220 KV, and for 400 KV and above it is 105%.

Factor of Earthing

This is the ratio of the highest rms phase to earth power frequency voltage on a sound phase during an earth fault to the rms phase to phase power frequency voltage which would be obtained at the selected location without the fault.

This ratio characterizes, in general terms, the earthing conditions of a system as viewed from the selected fault location.

Effectively Earthed System

A system is said to be effectively earthed if the factor of earthing does not exceed 80% and non-effectively earthed if it does.

Factor of earthing is 100% for an isolated neutral system, while it is 57.7% ($1/\sqrt{3} = 0.577$) for solidly earthed system.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain the insulation co ordination in a power system.	RGPV/ June 2014	7

	Why it is required.		
Q.2	Explain various methods of Earthing	RGPV/ June 2011	7

Unit-05 /Lecture-10

RGPV / June 2012

Insulation Level

Every electrical equipment has to undergo different abnormal transient over voltagesituation in different times during its total service life period. The equipment may have to withstand lightning impulses, switching impulses and/or short duration power frequency over voltages. Depending upon the maximum level of impulse voltages andshort duration power frequency over voltages that one power system component can withstand, the insulation level of high voltage power system is determined.

During determining the insulation level of the system rated less than 300 KV, the lightning impulse withstand voltage and short duration power frequency withstand voltage are considered. For equipment rated more or equal 300 KV, switching impulse withstand voltage and short duration power frequency withstand voltage are considered.

Lightning Impulse Voltage

The system disturbances occur due to natural lightning, can be represented by three different basic wave shapes. If a lightning impulse voltage travels some distance along the transmission line before it reaches to a insulator its wave shaped approaches to full wave, and this wave is referred as 1.2/50 wave. If during travelling, the lightning disturbance wave causes flash over across an insulator the shape of the wave becomes chopped wave. If a lightning stroke hits directly on the insulator then the lightning impulse voltage may rise steep until it is relieved by flash over, causing sudden, very steep collapse in voltage. These three waves are quite different in duration and in shapes.

Switching Impulse

During switching operation there may be uni-polar voltage appears in the system. The wave form of which may be periodically damped or oscillating one. Switching impulsewave form has steep front and long damped oscillating tale.

Short Duration Power Frequency Withstand Voltage

Short duration power frequency withstand voltage is the prescribed rms value of sinusoidal power frequency voltage that the electrical equipment shall withstand for a specific period of time normally 60 seconds.

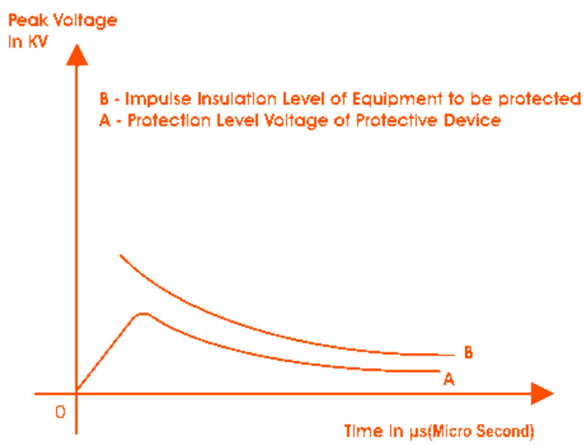
Protection Level Voltage of Protective Device

Over voltage protective device like surge arrestors or lightning arrestors are designed to withstand a certain level of transient over voltage beyond which the devices drain the surge energy to the ground and therefore maintain the level of transient over voltage up to a specific level. Thus transient over voltage can not exceed that level. The protection level of over voltage protective device is the highest peak voltage value which should not be exceeded at the terminals of over voltage protective device when switching impulses and lightening impulses are applied.

Using Shield Wire or Earth Wire

Lightning surge in over head transmission line may be caused due to direct hits of lightening strokes. It can be protected by providing a shield wire or earth wire at a suitable height from the top conductor of transmission line. If the conducting shield wire is properly connected to transmission tower body and the tower is properly earthed then direct lightning strokes can be avoided from all the conductors come under the protective angle of earth wire. Over head earth wire or ground wire or shield wire is also used to over the electrical substation to protect different electrical equipment from lightning strokes.

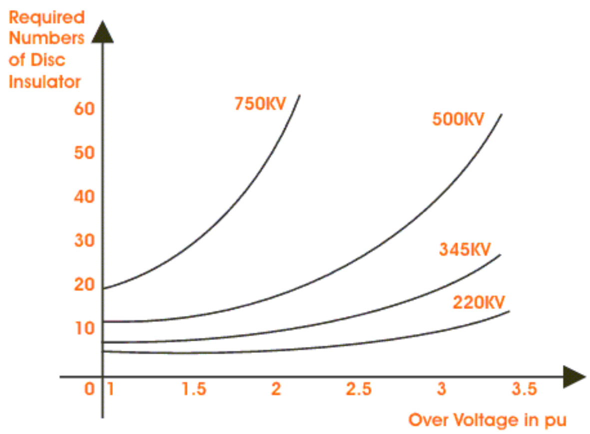
Conventional Method of Insulation Coordination



Voltage - Time Curve used for Insulation Coordination

As we discussed above that a component of electrical power system may suffer from different level of transient voltage stresses, switching impulse voltage and lightning impulse voltage. The maximum amplitude of transient over voltages reach the components, can be limited by using protecting device like lightning arrestor in the system. If we maintain the insulation level of all the power system component above the protection level of protective device, then ideally there will be no chance of breakdown of insulation of any component. Since the transient over voltage reaches at the insulation after crossing the surge protective devices will have amplitude equals to protection levelvoltage and protection level voltage < impulse insulation level of the components. Generally, the impulse insulation level is established at 15 to 25% above the protective level voltage of protective devices.

Statistical Methods of Insulation Coordination



Required Number of Disc Insulator in Different Voltages

At higher transmission voltages, the length of the insulator strings and the clearance in air do not increase linearly with voltage but approximately to $V^{1.6}$. The required number of insulator disc in suspension string for different over voltages is shown below. It is seen that increase in the number of disc is only slight for 220 KV system, with the increase in the over voltage factor from 2 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 over voltage factor of 3.5(say), it is definitely not economically feasible to have an overvoltage factor of more than about 2 to 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.

S.NO	RGPV QUESTIONS	Year	Marks

Q.1	Explain the insulation co ordination in a power system. Why it is required.	RGPV/ June 2014	7
Q.2	Explain voltage-time curve of Insulation co ordination	RGPV/ June 2011	7

Important Model Questions for Unit Test and MID SEM Examinations

Switchgear and protection (EX-603)

(Strictly Based on RGPV EXAMINATION)

Unit-5

1. Write short notes on switching surges. **RGPV/ June 2014, 2013**
2. Explain how the system can be protected against lightening over voltage.

   RGPV/ June 2014
3. Write short notes on horn gap lightening arrester**.** **RGPV/ June 2014, 2013**
4. Explain the insulation co ordination in a power system. Why it is required.

   RGPV/ June 2014
5. What are the requirements of lightening arrester? **RGPV/ June 2013**
6. Differentiate between Lightening arrester and lightening conductor.

   RGPV/ June 2013
7. Explain (i) Insulation co ordination (ii) Surge arrester (iii) BIL (iv) Transient surge

   RGPV/ June 2013, 2012
8. Explain phenomenon of lightening. How over voltage is produced due to lightening. **RGPV/ June 2013, 2012**
9. Explain (i) Earthling transformer (ii) arc suppression coil earthling **RGPV/ Dec 2012**
10. Explain different type of earthling. **RGPV/ Dec 2011**

11. Working of various types of lightening arresters. **RGPV/ Dec 2011**