Module-3

Subject: Power Quality

Content: Over Voltages

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1. What is the phenomena of Overvoltage

An overvoltage is an increase in the rms ac voltage greater than 110% at the power frequency for a duration longer than 1 minute.

Overvoltages are usually the result of load switching (e.g., switching off a large load), or energizing a capacitor bank). The overvoltages result because the system is either too weak for the desired voltage regulation or voltage controls are inadequate. Incorrect tap settings on transformers can also result in system overvoltages.

2. Name the various sources of over voltages?

The various sources of overvoltages are ,

- capacitor switching
- Lightning
- Ferro resonance.

3. What is capacitance switching?

When a long unloaded line or a capacitor bank is switched off the capacitive current produces high voltage transients across the breaker contacts. This interrupting or chopping of capacitive current is called capacitive current chopping / braking.

4. What is lightning phenomena?

Lightning is a huge spark, which is due to the electrical discharges taking place between the separate charge centers in the same cloud or between cloud and earth.

Or

Lighting phenomenon is a peak discharge in which charge accumulated in the clouds discharges in to a neighboring cloud or to the ground

5. Define Ferro resonance? Give some practical instances under which Ferro resonance may occur?

The phenomenon of Ferroresonancerefers to a special kind of resonance that involves capacitance and iron core inductance .The most common condition in which it causes distrubances is when the magnetising impedances of a transformer is places in series with a system capacitor.

6. Give the Conditions/ practical instances for Ferroresonance.

Ferroresonance occurs when an unloaded 3-phase system consisting of an inductive and a capacitive component is interrupted by single phase means. In practice this is typical of a high voltage electrical distribution network of transformers (inductive component) and power cables (capacitive component). If such a network has no load and the applied voltage is then interrupted on a single phase, a ferroresonance may be observed. If the remaining phases are not interrupted and the phenomenon continues, overvoltage can lead to the breakdown of insulation in connected components resulting in failure

7. What is the difference between a ferro resonant circuit and a linear resonant circuit

The main differences between a ferro resonant circuit and a linear resonant circuit are for a given ω

- its resonance possibility in a wide range of values of C.
- the frequency of the voltage and current waves which may be different from that of the sinusoidal voltage source,
- the existence of several stable steady state responses for a given configuration and values

8.Mention the common indication of ferroresonance

Following are the common indications of ferroresonance

- Audible noise
- Overheating
- High voltages and surge arrester failures
- Flicker

9. Mention the various system conditions that help increase the probability of ferroresonance

- Switching of lightly loaded and un loaded transformer
- Ungrounded transformer primary connection
- Very lengthy underground cable circuit.
- Three phase systems with single phase switching devices.
- Cable damage and manual switching during construction of under ground cables.

10. Mention the most common events leading to ferroresonance

- Manual switching of an unloaded, cable-fed three phase transformer where only one phase is closed.

- Manual switching of an unloaded, cable-fed three phase transformer where only one phases is open
- One or two riser - pole fuse may blow leaving a transformer with one or two phases open

11. How to prevent ferrroresonance?

- Use grounded-wye/grounded-wye systems.
- Keep primary cable runs short.
- Place switch/ protection directly upstream of the transformer.
- Have some load on the transformer when switching.
- Surge arrestors may be used to help suppress overvoltages.
- Use three-phase switchgear instead of fuses. This is not economical in many cases.
- Open or close all three cutouts as simultaneously as possible.
- Eliminate fuses. Relay on feeder breaker for fault interruption.
- Various measures to prevent inadvertent fuse operation.

12. Name the various methods of mitigating voltage swell?

- DVR (Dynamic voltage restorer),
- Power Conditioners,
- Constant Voltage Transformers (CVT).

13. Name the various devices for over voltage protection?

- Surge arrester
- Transient voltage surge suppressor(TVSS)
- Isolation transformer
- Low pass filters
- Low impedance power conditioner
- Utility surge arrester.

14. What is a utility surge arrester?

Surge arrester is a protective device for limiting surge voltages by discharging or bypassing surge current, and it also prevents continued flow of follow current while remaining capable of repeating these functions

15.What does a surge arrester do?

A surge arrester, or surge diverter, acts like a trapdoor to excess electrical energy. Sometimes called over-voltages, or transients, or surges, unwanted bursts of electricity are lured(attracted) to the trapdoor by what is called a low-impedance path to ground. The trapdoor is a metal oxide varistor, or MOV, which opens or "clamps" when the overvoltage exceeds a certain level, and safely diverts most of the excess energy to the ground rod.

When the over-voltage or transient is over, the MOV automatically resets and is ready for the next one. It is important to note that with lightning or other fast acting impulses, the leading edge of the impulse will pass the first MOV, even as the majority of the surge is racing to, and through, the trapdoor, hence the need for a second stage "point of use" plug-in type surge arrester inside the home or business.

16. What is a low pass filter?

A low-pass filter is a filter that passes low-frequency signals but attenuates (reduces the amplitude of signals with frequencies higher than the cutoff frequency. Low pass filters are composed of series inductors and parallel capacitors this L-.C combination provides a low impedance path to ground for selected resonant frequencies.

17.What is a low impedance power conditioner?

These line conditioners provide the best all-round power conditioning and surge protection for sensitive electronic equipment. The integral low-impedance isolation transformer provides 100% isolation from the input ac line. The secondary neutral-to-ground bond eliminates all surge voltages between neutral and ground. Surge protection and noise filtering are superior to conventional surge protection and filtering devices.

18.Name the different methods Utility System Lightning protection?

- Shielding
- Line arrester

19.What is shielding?

Shielding is nothing but installing a ground conductor above the phase conductor.

- Common in transmission and substations.
- Not common in distribution.
- Goal is to prevent lightning from striking the phase conductor.
- Ground lead must be kept well away from phase conductors and be as straight as possible.
- Ground resistance needs to be as low as possible.

20. What is a line arrester?

These are mainly used for overhead line protection. Made up of MOV blocks encapsulated in a polymer housing. The arresters bleed off some of the stroke current as it passes along the line. And can be located at every second or third pole.

21.What is PSCAD ? What are it's application?

PSCAD is a general-purpose time domain simulation tool for studying transient behavior of electrical networks. The program includes a comprehensive library of models including all aspects of AC and DC power systems and controls. To augment(to increase) the component library, the program provides the ability to create user models and libraries with the built-in graphical component workshop.

22.What is EMTP? What are it’s application?

The Electromagnetic Transients Program (EMTP) is a computer program for simulating electromagnetic, electromechanical, and control system transients on multi-phase electric power systems. Studies involving use of the EMTP fall in two general categories.

Applications

- One is design, which includes insulation coordination, equipment ratings, protective device specification, control systems design, etc.
- Other is solving operational problems such as unexplained outages or equipment failures.

23. What is an isolation transformer?

An isolation transformer is a transformer, often with symmetrical windings, which is used to decouple two circuits. An isolation transformer allows an AC signal or power to be taken from one device and fed into another without electrically connecting the two circuits. Isolation transformers block transmission of DC signals from one circuit to the other, but allow AC signals to pass. They also block interference caused by ground loops. Isolation transformers with electrostatic shields are used for power supplies for sensitive equipment such as computers or laboratory instruments

24. What is the difference between a Surge arrester and TVSS?

A TVSS is an abbreviation for "transient voltage surge suppressor." A TVSS is a device that attenuates (reduces in magnitude) random, high energy, short duration electrical power anomalies (disturbances)caused by utilities, atmospheric phenomena, or inductive loads.

A surge diverter is a device that is connected between line and earth, ie., in parallel with the equipment under protection at the substation. It limits the duration and amplitude of the follow current by transferring the high voltage surges on power system to ground.

25. What is a TVSS?

Transient voltage surge suppressors is a protective device for limiting transient voltages by diverting or limiting surge current, it also prevents continued flow of follow current while remaining capable of repeating these functions.

26. Give the circuit diagram of a hybrid transient protector.

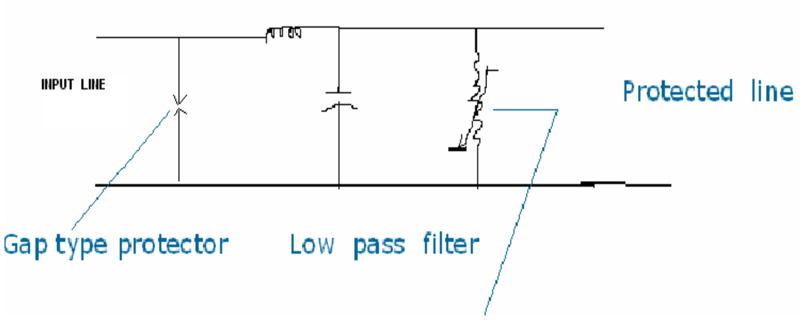


Fig 3.2 Hybrid transient protector.

27. Differentiate between crow bar devices and clamping devices

Crowbar devices: Normally open devices, that conduct current during over voltage transients. These devices are usually manufactured with a gap filled with air or a special gas. The gap arcs over when a sufficiently high overvoltage transient appears. In case of Crowbar devices the power frequency drops to zero or to a very low value.

Clamping devices: For ac circuits are commonly nonlinear resistors (varistors) that conducts very low amounts of current until an over voltage occurs. Then they starts to conduct heavily, and their impedance drops rapidly with increasing voltage. In case of clamping devices the voltage is not reduced below the conduction level. When they begin to conducts. Ex. MOV (Metal oxide varistors)

28. What are the clamping devices for ac circuits?

Clamping devices for ac circuits are commonly nonlinear resistors (varistors) that conducts very low amounts of current until an over voltage occurs. Then they starts to conduct heavily, and their impedance drops rapidly with increasing voltage Ex: MOV (Metal oxide varistors i.e the chief ingredient is zinc oxide)

A metal oxide varistor (MOV) is a device commonly used in surge protectors. There are two characteristics MOV’s that make them desirable for surge protection. First, the resistance of an MOV decreases with an increase in voltage. In addition, MOV’s are fast acting and can respond to a surge in just a few nanoseconds. This results in suppressing a surge before it has a chance to damage electronic equipment.

29. What is clamping voltage?

A Clamping voltage-also referred to as peak let through or suppressed voltage rating-is the amount of voltage a surge suppressor permits to pass through it to the attached load during a transient event. Clamping voltage is a performance measurement of a surge suppressor's ability to attenuate a transient. This performance value is confirmed by Underwriters Laboratories during tests conducted while evaluating a surge suppressor for listing.

30. Where are surge suppressors installed?

An AC surge suppressors are typically installed in these three areas:

- At a utility service entrance for protection of an entire facility.
- In distribution panel boards and switchboards for protection of sensitive downstream loads.
- Connected to a wall outlet for individual protection of a specific piece of equipment, such as a computer or solid-state controller.

31. Why the gapless MOV (Zno) arrester is preferred over gapped MOV & Gapped Silicon carbide arrester?

The gapless MOV provides a somewhat better discharge characteristics without high spark over transient and useful where there is a need for increased protective margin.

Disuses the various sources of Transient over voltages on utility systems.

There are two main sources of transient over voltages on utility systems.

i. Capacitor switching (de-energization of transmission lines cables capacitor banks).
ii. Lightning.
iii. Ferroresonance.

The making and breaking of circuits due to frequent switching operation in a power system may give rise to over voltage transient in the system owing to large inductances and capacitances the major of which is Ferroresonance.

i. Capacitor switching (de-energization of transmission lines cables capacitor banks)

one of the more common causes of electrical transients is switching of capacitor banks in power systems. Electrical utilities switch capacitor banks during peak load hours to offset the lagging kVAR demand of the load. The leading kVARs drawn by the capacitor banks offset the lagging kVAR demand of the load, reducing the net kVA load on the circuit.

Capacitor switching is one of the most common switching events on utility systems .During capacitance switching operations that result in excessive overvoltages, the stored energy in the electric field of capacitance is released in the system. Dropping of A long open-circuited line or an underground cable or disconnection of capacitor banks may present hazardous overvoltages. Fig 3.3 shows the single diagram of a typical utility feeder capacitor switching situation . Fig 3.4 shows the equivalent circuit for capacitance switching where L is the inductance up to the circuit breaker point and c is the Capacitance of the capacitor bank which is being isolated by the breaker the system voltage, current in fig.3.5b). Till instant ‘A’ (the current zero) The potential across the breaker contact is zero. After this, the potential across the contacts starts increasing to attain $2V_m$.(or1.3 to 1.4 per unit).

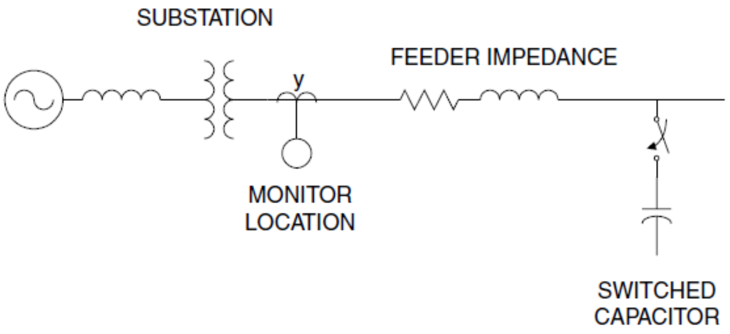


Fig 3.3 one line diagram of a capacitor switching operation.

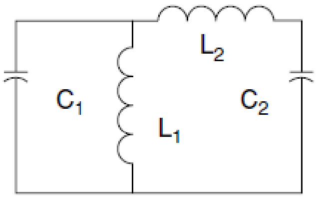


Fig 3.4 Equivalent circuit for capacitance switching

Magnification of capacitor- switching transient:

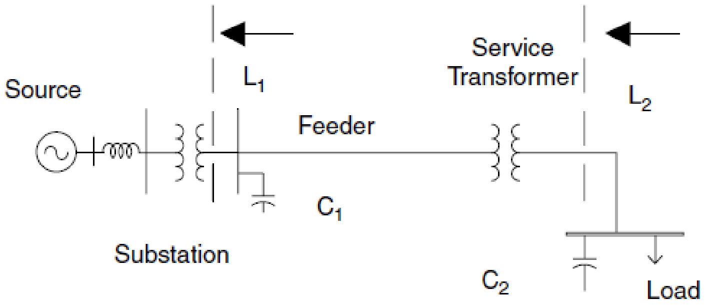


fig 3.5(a) voltage magnification at customer capacitor due to energizing capacitor on utility system

The problem of adding power factor correction capacitors at the customer location is that they may increase the impact of utility capacitor switching transients on end user equipments.

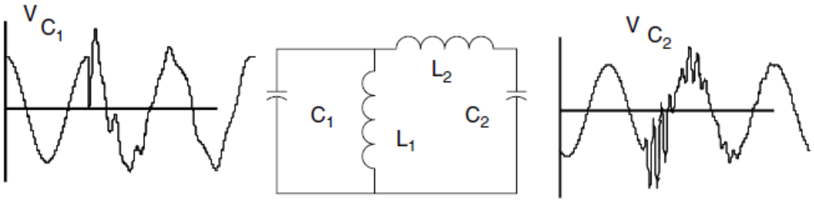


Fig 3.5(b) Voltage Magnification of capacitor bank switching

ii) Lightning

Lightning is a potent source of impulsive transient the common places where lightning may strike is primary phase, secondary phase , and point where secondary is grounded, of a transformer and on grounded structure.

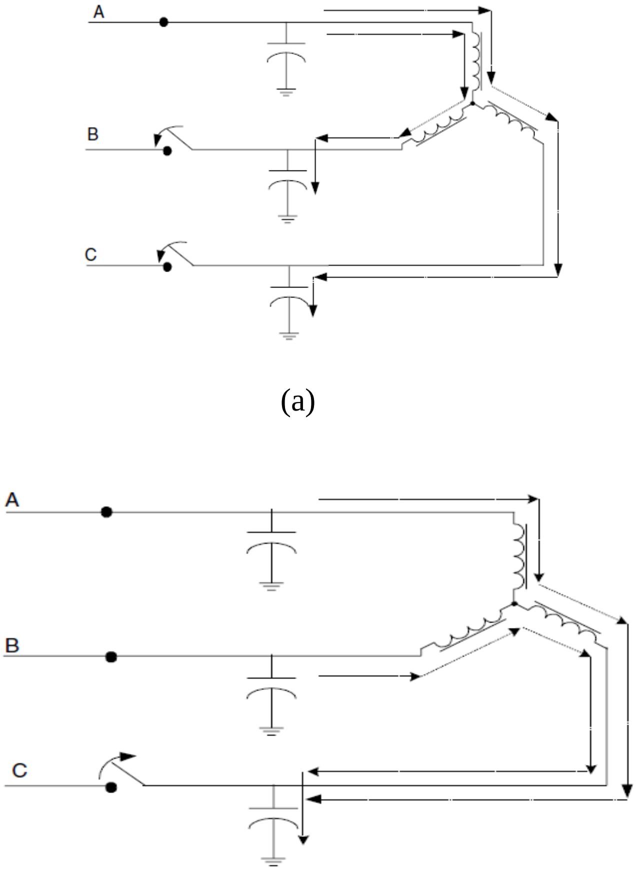
iii) Ferroresonance

The phenomenon of Ferroresonance refers to a special kind of resonance that involves capacitance and iron core inductance. The most common condition in which it causes distrubances is when the magnetising impedances of a transformer is places in series with a system capacitor.

Conditions (or) practical instances for Ferroresonance:

Ferroresonance occurs when an unloaded 3-phase system consisting of an inductive and a capacitive component is interrupted by single phase means. In practice this is typical of a high voltage electrical distribution network of transformers (inductive component) and power cables (capacitive component). If such a network has no load and the applied voltage is then interrupted on a single phase, a ferroresonance may be observed. If the remaining phases are not interrupted and the phenomenon continues, overvoltage can lead to the breakdown of insulation in connected components resulting in failure. The phenomenon of Ferroresonance is the occurrence of an unstable high voltage, typically on 3 phase electrical systems which only occurs under specific conditions. The nature of the overvoltage can cause the failure of equipment.

Conditions for Ferroresonance occurs when an unloaded 3-phase system consisting of an inductive and a capacitive component is interrupted by single phase means.



(a)

(b)

Figure 4.14 Common system conditions where ferroresonance may occur: (a) one phase closed, (b) one phase open.

In practice this is typical of a high voltage electrical distribution network of transformers (inductive component) and power cables (capacitive component). If such a network has no load and the applied voltage is then interrupted on a single phase, a ferroresonance may be observed. If the remaining phases are not interrupted and the phenomenon continues, overvoltage can lead to the breakdown of insulation in connected components resulting in failure.

How to prevent ferroresonance? (Or) Strategies for dealing with ferroresonance.

- Use three-phase switchgear instead of fuses. This is not economical in many cases.
- Open or close all three cutouts as simultaneously as possible.
- Eliminate fuses. Relay on feeder breaker for fault interruption.
- Various measures to prevent inadvertent fuse operation.

2. Explain the ferroresonance phenomena in detail with neat circuit diagram.

The term ferroresonance refers to a special kind of resonance that involves capacitance and iron-core inductance. The most common condition in which it causes disturbances is when the magnetizing impedance of a transformer is placed in series with a system capacitor. This happens when there is an open-phase conductor. Under controlled conditions, ferroresonance can be exploited for useful purpose such as in a constant-voltage transformer.

Ferroresonance is different than resonance in linear system elements. In linear systems, resonance results in high sinusoidal voltages and currents of the resonant frequency. Linear-system resonance is the phenomenon behind the magnification of harmonics in power systems.

Ferroresonance can also result in high voltages and currents, but the resulting waveforms are usually irregular and chaotic in shape. The concept of ferroresonance can be explained in terms of linear-system resonance as follows. Consider a simple series RLC circuit as shown in Fig. 4.9. Neglecting the resistance R for the moment, the current flowing in the circuit can be expressed as follows:

$$I = \frac{E}{j\,(X_L - |X_C|)}$$

Where, E = driving voltage
X_L =reactance of L
X_C =reactance of C

When $X_L = |X_C|$, a series-resonant circuit is formed, and the equation yields an infinitely large current that in reality would be limited by R. An alternate solution to the series RLC circuit can be obtained by writing two equations defining the voltage across the inductor, i.e.,

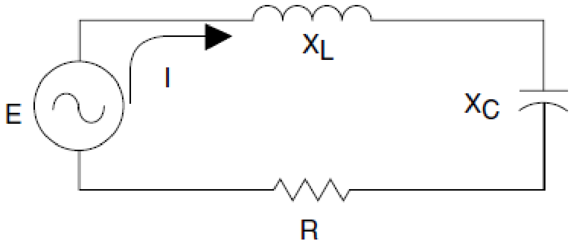


Figure 4.9 Simple series RLC circuit.

$$v = jX_L I$$

$$v = E + j|X_C|I$$

Where, v is a voltage variable. Figure 4.10 shows the graphical solution of these two equations for two different reactances, X_L and X_L'. X_L' represents the series-resonant condition. The intersection point between the capacitive and inductive lines gives the voltage across inductor EL. The voltage across capacitor E_C is determined as shown in Fig. 4.10. At resonance, the two lines will intersect at infinitely large voltage and current since the $|X_C|$ line is parallel to the X_L' line. Now, let us assume that the inductive element in the circuit has a nonlinear reactance characteristic like that found in transformer magnetizing reactance. Figure 4.11 illustrates the graphical solution of the equations following the methodology just presented for linear circuits.

While the analogy cannot be made perfectly, the diagram is useful to help understand ferroresonance phenomena. It is obvious that there may be as many as three intersections between the capacitive reactance line and the inductive reactance curve. Intersection 2 is an unstable solution, and this operating point gives rise to some of the chaotic behavior of ferroresonance. Intersections 1 and 3 are stable and will exist in the steady state. Intersection 3 results in high voltages and high currents. Figures 4.12 and 4.13 show examples of ferroresonant voltages that can result from this simple series circuit. The same inductive characteristic was assumed for each case. The capacitance was varied to achieve a different operating point after an initial transient that pushes the system into resonance. The unstable case yields voltages in excess of 4.0 pu, while the stable case settles in at voltages slightly over 2.0 pu. Either condition can impose excessive duty on power system elements and load equipment. For a small capacitance, the |XC| line is very steep, resulting in an intersection point on the third quadrant only. This can yield a range of voltages from less than 1.0 pu to voltages like those shown in Fig. 4.13.

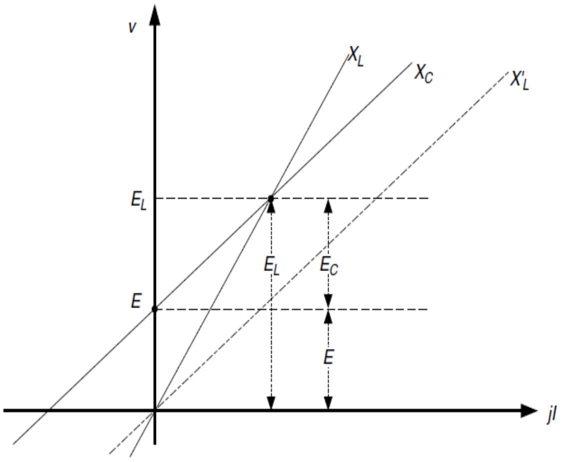


Figure 4.10 Graphical solution to the linear LC circuit.

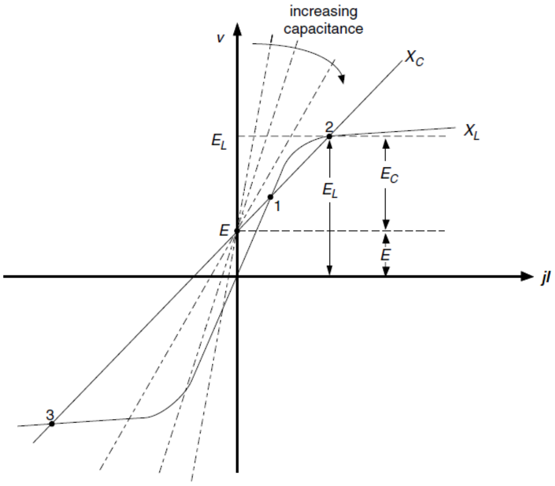


Figure 4.11 Graphical solution to the nonlinear LC circuit.

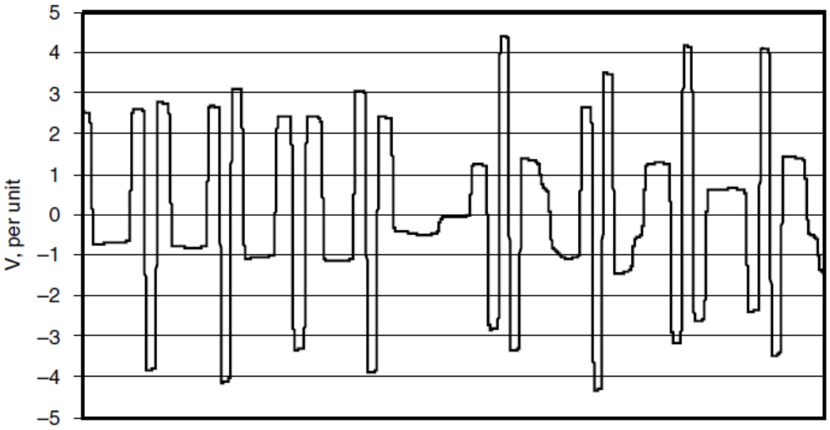


Figure 4.12 Example of unstable, chaotic ferroresonance voltages.

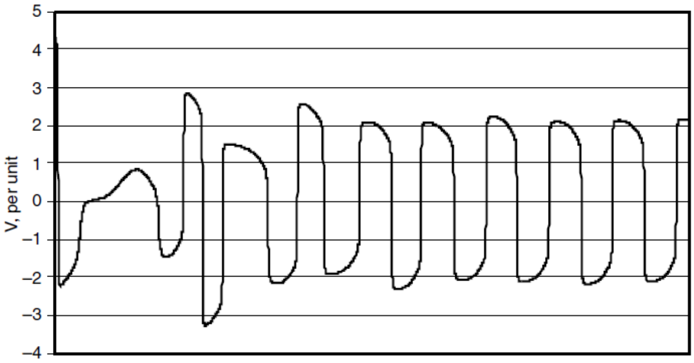


Figure 4.13 Example of ferroresonance voltages settling into a stable operating point (intersection 3) after an initial transient.

When C is very large, the capacitive reactance line will intersect only at points 1 and 3. One operating state is of low voltage and lagging current (intersection 1), and the other is of high voltage and leading current (intersection 3). The operating points during ferroresonance can oscillate between intersection points 1 and 3 depending on the applied voltage. Often, the resistance in the circuit prevents operation at point 3 and no high voltages will occur. In practice, ferroresonance most commonly occurs when unloaded transformers become isolated on underground cables of a certain range of lengths. The capacitance of overhead distribution lines is generally insufficient to yield the appropriate conditions. The minimum length of cable required to cause ferroresonance varies with the system voltage level. The capacitance of cables is nearly the same for all distribution voltage levels, varying from 40 to 100 nF per 1000 feet (ft), depending on conductor size. However, the magnetizing reactance of a 35-kV-class distribution transformer is several times higher (the curve is steeper) than a comparably sized 15-kV-class transformer. Therefore, damaging ferroresonance has been more common at the higher voltages. For delta-connected transformers, ferroresonance can occur for less than 100 ft of cable. For this reason, many utilities avoid this connection on cable-fed transformers.

The grounded wye-wye transformer has become the most commonly used connection in underground systems in North American. It is more resistant, but not immune, to ferroresonance because most units use a three-legged or five-legged core design that couples the phases magnetically. It may require a minimum of several hundred feet of cable to provide enough capacitance to create a ferroresonant condition for this connection. The most common events leading to ferroresonance are,

- Manual switching of an unloaded, cable-fed, three-phase transformer where only one phase is closed (Fig. 4.14a). Ferroresonance may be noted when the first phase is closed upon energization or before the last phase is opened on deenergization.

- Manual switching of an unloaded, cable-fed, three-phase transformer where one of the phases is open (Fig. 4.14b). Again, this may happen during energization or deenergization.
- One or two riser-pole fuses may blow leaving a transformer with one or two phases open. Single-phase reclosers may also cause this condition. Today, many modern commercial loads have controls that transfer the load to backup systems when they sense this condition.

Unfortunately, this leaves the transformer without any load to damp out the resonance. It should be noted that these events do not always yield noticeable ferroresonance. Some utility personnel claim to have worked with underground cable systems for decades without seeing ferroresonance. System conditions that help increase the likelihood of ferroresonance include

- Higher distribution voltage levels, most notably 25- and 35-kV-class systems.
- Switching of lightly loaded and unloaded transformers.
- Ungrounded transformer primary connections.

The most common events leading to ferroresonance

- Manual switching of an unloaded, cable-fed three phase transformer where only one phase is closed.
- Manual switching of an unloaded, cable-fed three phase transformer where only one phases is open
- One or two riser - pole fuse may blow leaving a transformer with one or two phases open

1. Explain the principle of over voltage protection of a load equipment.

The fundamental principles of overvoltage protection of load equipment are,

- Limit the voltage across sensitive insulation.
- Divert the surge current away from the load.
- Block the surge current from entering the load.
- Bond grounds together at the equipment.
- Reduce, or prevent, surge current from flowing between grounds.
- Create a low-pass filter using limiting and blocking principles.

Figure 4.16 illustrates these principles, which are applied to protect from a lightning strike. The main function of surge arresters and transient voltage surge suppressors (TVSSs) is to limit the voltage that can appear between two points in the circuit. This is an important concept to understand. One of the common misconceptions about varistors, and similar devices, is that they somehow are able to absorb the surge or divert it to ground independently of the rest of the system. That may be a beneficial side effect of the arrester application if there is a suitable path for the surge current to flow into, but the foremost concern in arrester application is to place the arresters directly across the sensitive insulation that is to be protected so that the voltage seen by the insulation is limited to a safe value. Surge currents, just like power currents, must obey Kirchoff's laws. They must flow in a complete circuit, and they cause a voltage drop in every conductor through which they flow. One of the points to which arresters, or surge suppressors, are connected is frequently the local ground, but this need not be the case.

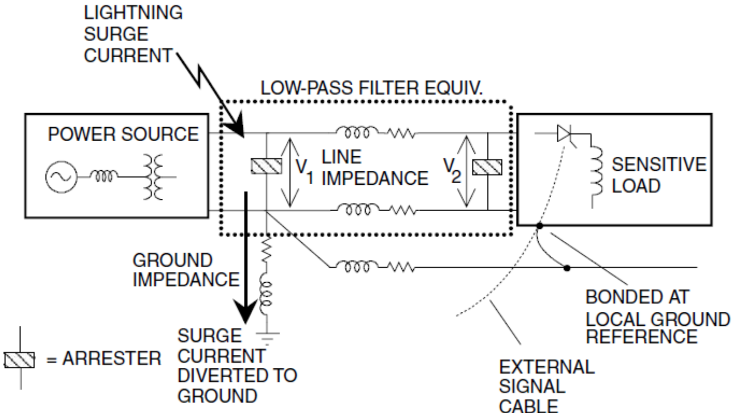


Figure 4.16 Demonstrating the principles of overvoltage protection.

Keep in mind that the local ground may not remain at zero potential during transient impulse events. Surge suppression devices should be located as closely as possible to the critical insulation with a minimum of lead length on all terminals. While it is common to find arresters located at the main panels and subpanels, arresters applied at the point where the power line enters the load equipment are generally the most effective in protecting that particular load. In some cases, the best location is actually inside the load device. For example, many electronic controls made for service in the power system environment have protectors [metal-oxide varistor (MOV) arresters, gaps, zener diodes, or surge capacitors] on every line that leaves the cabinet.

In Fig. 4.16 the first arrester is connected from the line to the neutral- ground bond at the service entrance. It limits the line voltage V1 from rising too high relative to the neutral and ground voltage at the panel. When it performs its voltage-limiting action, it provides a low impedance path for the surge current to travel onto the ground lead. Note that the ground lead and the ground connection itself have significant impedance. Therefore, the potential of the whole power system is raised with respect to that of the remote ground by the voltage drop across the ground impedance. For common values of surge currents and ground impedances, this can be several kilovolts.

One hopes, in this situation, that most of the surge energy will be discharged through the first arrester directly into ground. In that sense, the arrester becomes a surge “diverter.” This is another important function related to surge arrester application. In fact, some prefer to call a surge arrester a surge diverter because its voltage-limiting action offers a low-impedance path around the load being protected. However, it can only be a diverter if there is a suitable path into which the current can be diverted. That is not always easy to achieve, and the surge current is sometimes diverted toward another critical load where it is not wanted. In this figure, there is another possible path for the surge current the signal cable indicated by the dotted line and bonded to the safety ground. If this is connected to another device that is referenced to ground elsewhere, there will be some amount of surge current flowing down the safety ground conductor.

Damaging voltages can be impressed across the load as a result. The first arrester at the service entrance is electrically too remote to provide adequate load protection. Therefore, a second arrester is applied at the load—again, directly across the insulation to be protected. It is connected “line to neutral” so that it only protects against normal mode transients. This illustrates the principles without complicating the diagram but should be considered as the minimum protection one would apply to protect the load. Frequently, surge suppressors will have suppression on all lines to ground, all lines to neutral, and neutral to ground. While lightning surge currents are seeking a remote ground reference, many transient overvoltages generated by switching will be those of a normal mode and will not seek ground. In cases where surge currents are diverted into other load circuits, arresters must be applied at each load along the path to ensure protection.

Note that the signal cable is bonded to the local ground reference at the load just before the cable enters the cabinet. It might seem that this creates an unwanted ground loop. However, it is essential to achieving protection of the load and the low-voltage signal circuits. Otherwise, the power components can rise in potential with respect to the signal circuit reference by several kilovolts. Many loads have multiple power and signal cables connected to them. Also, a load may be in an environment where it is close to another load and operators or sensitive equipment are routinely in contact with both loads. This raises the possibility that a lightning strike may raise the potential of one ground much higher than the others. This can cause a flashover across the insulation that is between the two ground references or cause physical harm to operators. Thus, all ground reference conductors (safety grounds, cable shields, cabinets, etc.) should be bonded together at the load equipment.

The principle is not to prevent the local ground reference from rising in potential with the surge; with lightning, that is impossible. Rather, the principle is to tie the references together so that all power and signal cable references in the vicinity rise together. This phenomenon is a common reason for failure of electronic devices. The situation occurs in TV receivers connected to cables, computers connected to modems, computers with widespread peripherals powered from various sources, and in manufacturing facilities with networked machines.

Since a few feet of conductor make a significant difference at lightning surge frequencies, it is sometimes necessary to create a special low-inductance, ground reference plane for sensitive electronic equipment such as mainframe computers that occupy large spaces.4 Efforts to block the surge current are most effective for high-frequency surge currents such as those originating with lightning strokes and capacitor-switching events. Since power frequency currents must pass through the surge suppressor with minimal additional impedance, it is difficult and expensive to build filters that are capable of discriminating between low-frequency surges and power frequency currents.

Blocking can be done relatively easily for high-frequency transients by placing an inductor, or choke, in series with the load. The high surge voltage will drop across the inductor. One must carefully consider that high voltage could damage the insulation of both the inductor and the loads. However, a line choke alone is frequently an effective means to block such high-frequency transients as line-notching transients from adjustable-speed drives.

The blocking function is frequently combined with the voltage-limiting function to form a low-pass filter in which there is a shunt-connected voltage-limiting device on either side of the series choke. Figure 4.16 illustrates how such a circuit naturally occurs when there are arresters on both ends of the line feeding the load. The line provides the blocking function in proportion to its length. Such a circuit has very beneficial overvoltage protection characteristics. The inductance forces the bulk of fast-rising surges into the first arrester. The second arrester then simply has to accommodate what little surge energy gets through. Such circuits are commonly built into outlet strips for computer protection.

Many surge-protection problems occur because the surge current travels between two, or more, separate connections to ground. This is a particular problem with lightning protection because lightning currents are seeking ground and basically divide according to the ratios of the impedances of the ground paths. The surge current does not even have to enter the power, or phase, conductors to cause problems. There will be a significant voltage drop along the ground conductors that will frequently appear across critical insulation.

The grounds involved may be entirely within the load facility, or some of the grounds may be on the utility system. Ideally, there would be only one ground path for lightning within a facility, but many facilities have multiple paths. For example, there may be a driven ground at the service entrance or substation transformer and a second ground at a water well that actually creates a better ground. Thus, when lightning strikes, the bulk of the surge current will tend to flow toward the well. This can impress an excessively high voltage across the pump insulation, even if the electrical system is not intentionally bonded to a second ground. When lightning strikes, the potentials can become so great that the power system insulation will flash over somewhere.

The amount of current flowing between the grounds may be reduced by improving all the intentional grounds at the service entrance and nearby on the utility system. This will normally reduce, but not eliminate entirely, the incidence of equipment failure within the facility due to lightning. However, some structures also have significant lightning exposure, and the damaging surge currents can flow back into the utility grounds. It doesn’t matter which direction the currents flow; they cause the same problems. Again, the same principle applies, which is to improve the grounds for the structure to minimize the amount of current that might seek another path to ground.

When it is impractical to keep the currents from flowing between two grounds, both ends of any power or signal cables running between the two grounds must be protected with voltage-limiting devices to ensure adequate protection. This is common practice for both utility and enduser systems where a control cabinet is located quite some distance from the switch, or other device, being controlled.

2. Discuss the voltage Swell mitigation techniques?

i. DVR ,(Dynamic voltage restorer)
ii. Power Conditioners,
iii. Constant Voltage Transformers (CVT)

i. DVR,(Dynamic voltage restorer)

The DVR uses a voltage source converter (VSC) connected in series with the protected load (through an insertion transformer for medium voltage applications) to compensate amplitude and phase angle of the voltage applied to the load. The dc capacitor between the charger and the VSC serves as an energy buffer, generating and absorbing power during voltage sags and voltage swells, respectively. This process enables the voltage, as seen by the load, to be of the desired magnitude whenever disturbances occur upstream.

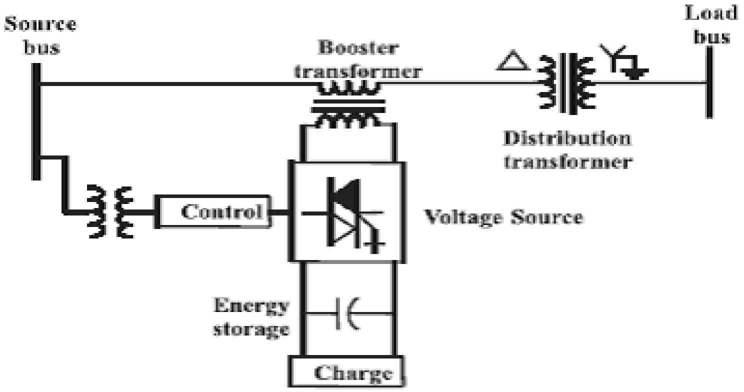


Fig2.6 Basic configuration of DVR

ii. Power Conditioners (we prefer low impedance power conditioner)

A power conditioner (also known as a line conditioner or power line conditioner) is a device intended

- To improve the “quality” of the power that is delivered to electrical load equipment.
- To deliver a voltage of the proper level and characteristics to enable load equipment to function properly. In some usages, “power conditioner” refers to a voltage regulator with at least one other function to improve power quality (e.g. noise suppression, transient impulse protection, etc.).
- Power or line conditioners regulate, filter, and suppress noise in AC power for sensitive computer and other solid state equipment.

- They provide electrical isolation and noise and spike attenuation to ensure the quality and consistency of power to sensitive medical, laboratory, computer, and other high technology equipment.

Construction

Power conditioners typically consist of voltage regulators in combination with output isolation transformers and transient voltage suppression circuitry.

Important Specification

Important specifications to consider when searching for power conditioners include power rating, input voltage, output voltage, voltage regulation accuracy, phase, and frequency

iii. Constant Voltage Transformers (CVT)

Constant Voltage Transformers (CVTs) (same as Ferroresonant transformers) Basically 1:1 transformers that can handle most voltage swell (sag also) conditions. secondary winding outputs a nearly constant voltage despite significant variations in supply (primary winding) voltage (nothing more to explain because there is no chance that it will be asked as an individual question if asked that will be under Unit-2.

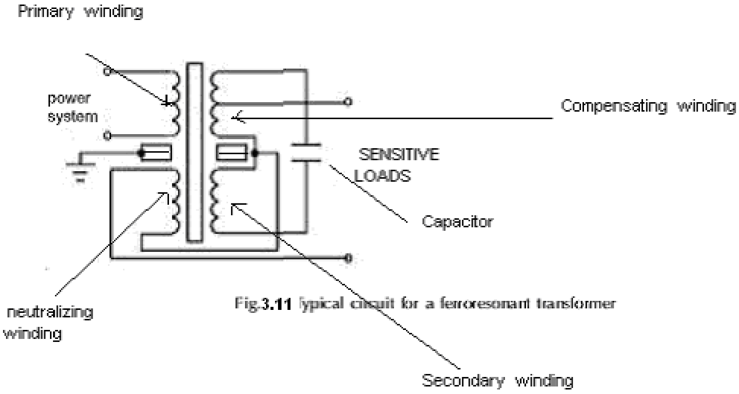


Fig.3.11 typical circuit for a ferroresonant transformer

3. Discuss the various devices for Overvoltage Protection

The various Devices for over voltage protection are

i. Surge arrester & transient voltage surge suppressor
ii. Isolation transformer
iii. Low-pass filters
iv. Low impedance power conditioner
v. Utility surge arrester

i. Surge arrester & transient voltage surge suppressor

A surge diverter is a device that is connected between line and earth, ie., in parallel with the equipment under protection at the substation. It limits the duration and amplitude of the follow current by transferring the high voltage surges on power system to ground. Transient voltage surge suppressor is a protective device for limiting transient voltages by diverting or limiting surge current. It also prevents continued flow of follow current while remaining capable of repeating these functions.

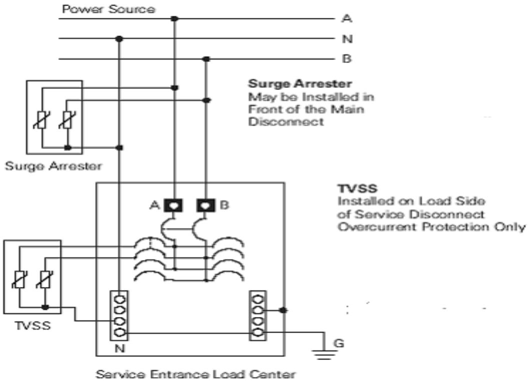


Fig 3.12 Location comparison of TVSS and surge arrester.

A surge arrester, or surge diverter, acts like a trapdoor to excess electrical energy. Sometimes called over-voltages, or transients, or surges, unwanted bursts of electricity are lured(attracted) to the trapdoor by what is called a low-impedance path to ground. The trapdoor is a metal oxide varistor, or MOV, which opens or "clamps" when the overvoltage exceeds a certain level, and safely diverts most of the excess energy to the ground rod.

When the over-voltage or transient is over, the MOV automatically resets and is ready for the next one. It is important to note that with lightning or other fast acting impulses, the leading edge of the impulse will pass the first MOV, even as the majority of the surge is racing to, and through, the trapdoor, hence the need for a second stage "point of use" plug-in type surge arrester inside the home or business.

ii. ISOLATION TRANSFRMER

If an isolation transformer (a transformer with the same number of “turns” in the primary and secondary coils) is connected between an AC source and an AC load, we will measure the same voltage and the same current at both source and load terminals.

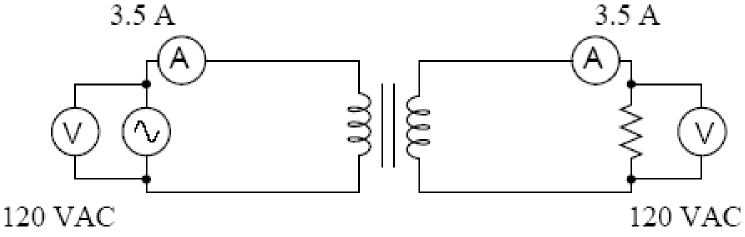


Fig 3.13 conceptual diagram of an isolation transformer.

An isolation transformer is a transformer, often with symmetrical windings, which is used to decouple two circuits. An isolation transformer allows an AC signal or power to be taken from one device and fed into another without electrically connecting the two circuits. Isolation transformers block transmission of DC signals from one circuit to the other, but allow AC signals to pass.

[In an electrical system, ground loop refers to a current, generally unwanted, in a conductor connecting two points that are supposed to be at the same potential, often ground, but are actually at different potentials. Ground loops can be detrimental to the intended operation of the electrical system.]

Isolation transformers with electrostatic shields are used for power supplies for sensitive equipment such as computers or laboratory instruments. as shown in fig3.14 below.

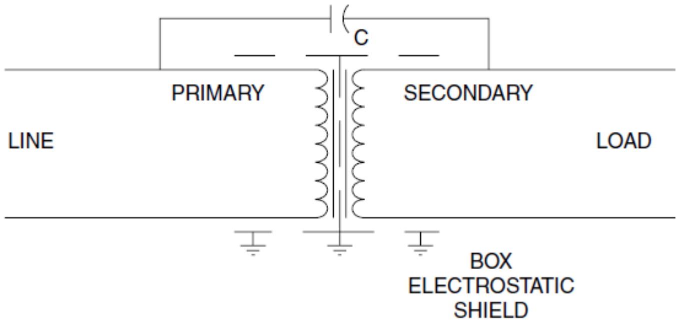


Fig.3.14 Isolation transformer with electrostatic shields

Advantages

- They also block interference caused by ground loops.
- They also attenuate high frequency noise and transients from one side to other.
- Voltage notching due to power electronic switching can be eliminated to the load side
- Capacitor switching and lightning transients coming from the utility system can be attenuated

- And moreover they allow the user to define a new ground reference

iii. Low pass filter

A low-pass filter is a filter that passes low-frequency signals but attenuates (reduces the amplitude of signals with frequencies higher than the cutoff frequency. Low pass filters are composed of series inductors and parallel capacitors this L-C combination provides a low impedance path to ground for selected resonant frequencies.

The low pass filter limits transfer of high frequency transients. The inductor helps in blocking high - frequency transients and forces them in to the first supressor. The capacitor limits the rate of riseof the voltage magnitude Fig 3.15 shows a hybrid transient protector where voltage clamping devices are added in parallel to the capacitors.

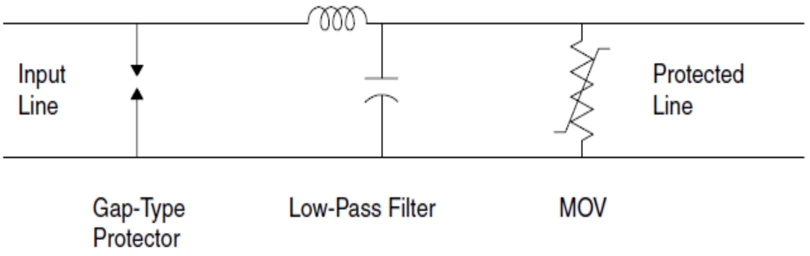


Fig 3.14 A hybrid transient protector with low pass filter.

iv. Low impedance power conditioner.

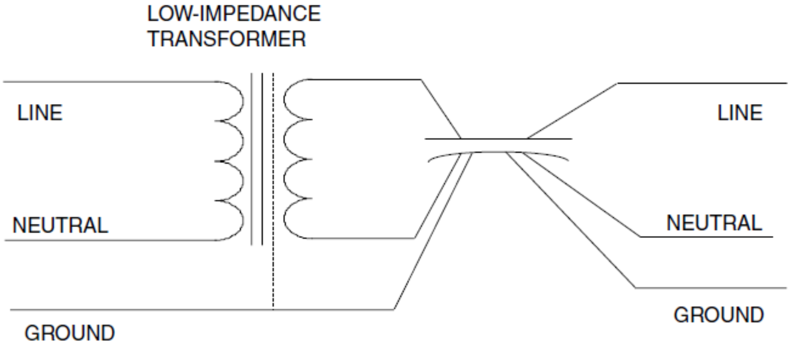


Fig3.15 Low impedance power conditioner

Switch mode power supplies in modern computer systems use current from the power line in large, brief “gulps”. They want little or no opposition to their demands for current. By definition, this makes switch mode power supplies a “low impedance load”.

Like an audio system, low impedance loads need to be matched with their power source. In this case of a system with a switch mode power supply, this source must be low impedance at power line frequencies but offer high impedance to noise and unwanted power disturbances. These modern power supplies should never be mismatched with a high impedance.

These line conditioners provide the best all-round power conditioning and surge protection for sensitive electronic equipment. . The integral isolation transformer provide complete isolation between the primary and secondary, and permits bonding its output neutral to ground, which completely eliminates all disturbances between neutral and ground, regardless of source. The series inductance of the isolation transformer in combination with capacitive elements and MOVs, provide superb noise filtering, as well as coordinated multi-stage surge protection.

Applications include:

- Sensitive telecommunications,
- Radio base stations (RBS)/base transmitter stations (BTS),
- Industrial and medical equipment,
- Other sensitive, specialized microprocessor-based equipment.

v. Utility surge arrestor

The three most common surge arrester technologies employed by utilities are,

I) Gapped silicon Carbide
II) Gapped MOV
III) Gapless MOV. Most arrester manufactured today use a MOV as the main voltage limiting elements. The Chief ingredient of a MOV is Zinc Oxide. (ZnO).

I) Gapped silicon Carbide

The older technology arrester use silicon carbide as the(SiC) energy dissipating non linear resistive element. As (SiC) is not ideal it is not non-linear enough and thus imposes certain design restriction. It allows the spark gap to clear and reseal without causing a fault and reduced the sparkover transient to 50% of the total sparkover voltage.

Gaps are necessary with the SiC because an economical SiC element giving the required discharge voltage is unable to withstand continues system operating voltage.

II) Gapped MOV

The gapped MOV tech. was introduced commercially in the early 90’s and accepted in some applications where there is need for increased protective margins. This technology combines resistance graded gaps and MOV blocks. It has a lower lightning discharge voltage but has a higher transient over voltage withstand characteristics.

III) Gapless MOV

The recently developed ideal surge arrester. It is a revolutionary advanced surge protective device for power systems. It is constructed by a series connection of zinc oxide (ZnO) elements having a highly non linear resistance. The excellent non-linear characteristic of zinc oxide elements has enabled to make surge arresters without series connected spark gaps. i.e. fully solid state arresters suitable for system protection up to the highest voltages. It is dimensioned so that the peak value of the phase to ground voltage in Normal operation never exceeds the sum of the rated voltages of the series connected disc. Fig 3.16 shows the comparative lightning wave discharge voltage characteristic for an 8X20μs(front time 8 μs and tail time 20 μs)

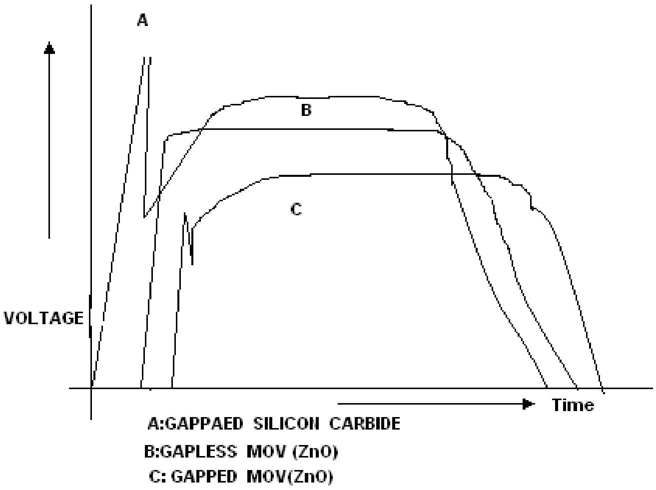


Fig 3.16

4. Discuss the common utility surge arresters with comparative wave discharge characteristics.

[ref previous question less chance for such a question because it come under HVE and PROTECTION.]

5. Name the different methods Utility System Lightning protection?

The different methods of Utility System Lightning protection are,

i. shielding
ii. line arrester

i. shielding

One of the strategies open to utilities for lines that are particularly susceptible to lightning strikes is to shield the line by installing a grounded neutral wire over the phase wires. This will intercept most lightning strokes before they strike the phase wires. This can help, but will not necessarily prevent line flashovers because of the possibility of back flashovers.

Shielding overhead utility lines is common at transmission voltage levels and in substations, but is not common on distribution lines because of the added cost of taller poles and the lower benefit due to lower flashover levels of the lines. On distribution circuits, the grounded neutral wire is typically installed underneath the phase conductors to facilitate the connection of line-to-neutral connected equipment such as transformers and capacitors. Shielding is not quite as simple as adding a wire and grounding it every few poles. When lightning strikes the shield wire, the voltages at the top of the pole will still be extremely high and could cause back flashovers to the line. This will result in a temporary fault. To minimize this possibility, the path of the ground lead down the pole must be carefully chosen to maintain adequate clearance with the phase conductors. Also, the grounding resistance plays an important role in the magnitude of the voltage and must be maintained as low as possible. However, when it becomes obvious that a particular section of feeder is being struck frequently, it may be justifiable to retrofit that section with a shield wire to reduce the number of transient faults and to maintain a higher level of power quality. Figure 4.29 illustrates this concept. It is not uncommon for a few spans near the substation to be shielded.

The substation is generally shielded anyway, and this helps prevent high-current faults close to the substation that can damage the substation transformer and breakers. It is also common near substations for distribution lines to be underbuilt on transmission or sub transmission structures. Since the transmission is shielded, this provides shielding for the distribution as well, provided adequate clearance can be maintained for the ground lead. This is not always an easy task. Another section of the feeder may crest a ridge giving it unusual exposure to lightning. Shielding in that area may be an effective way of Ref page 145 Dugan very clearly given. Draw the fig given in page 146.

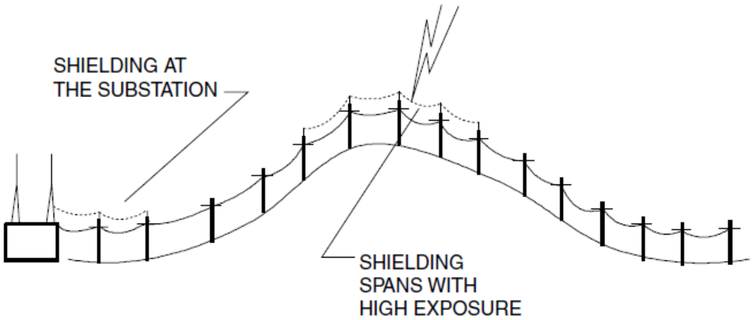


Figure 4.29 Shielding a portion of a distribution feeder to reduce the incidence of temporary lightning-induced faults.

reducing lightning-induced faults. Poles in the affected section may have to be extended to accommodate the shield wire and considerable effort put into improving the grounds. This increases the cost of this solution. It is possible that line arresters would be a more economical and effective option for many applications.

ii. Line arrester

Another strategy for lines that are struck frequently is to apply arresters periodically along the phase wires. Normally, lines flash over first at the pole insulators. Therefore, preventing insulator flashover will reduce the interruption and sag rate significantly. Stansberry6 argues that this is more economical than shielding and results in fewer line flashovers. Neither shielding nor line arresters will prevent all flashovers from lightning. The aim is to significantly reduce flashovers in particular trouble spots.

As shown in Fig. 4.30, the arresters bleed off some of the stroke current as it passes along the line. The amount that an individual arrester bleeds off will depend on the grounding resistance. The idea is to space the arresters sufficiently close to prevent the voltage at unprotected poles in the middle from exceeding the basic impulse level (BIL) of the line insulators. This usually requires an arrester at every second or third pole. In the case of a feeder supplying a highly critical load, or a feeder with high ground resistance, it may be necessary to place arresters at every pole.

A transients study of different configurations will show what is required. Some utilities place line arresters only on the top phase when one phase is mounted higher than the others. In other geometries, it will be necessary to put arresters on all three phases to achieve a consistent reduction in flashovers.

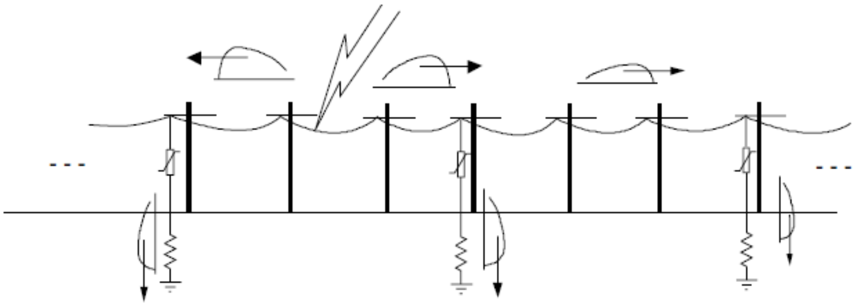


Figure 4.30 Periodically spaced line arresters help prevent flashovers.

Figure 4.31 Typical polymer-housed utility distribution arrester for overhead line applications. (Courtesy of Cooper Power Systems.)

Figure 4.31 shows a typical utility arrester that is used for overhead line protection applications. This model consists of MOV blocks encapsulated in a polymer housing that is resistant to sunlight and other natural elements. Older-technology models used porcelain housings like that shown on the primary side of the transformer in Fig. 4.33. There are already sufficient arresters on many lines in densely populated areas in North America to achieve sufficient line protection. These arresters are on the distribution transformers, which are installed close together and in sufficient numbers in these areas to help protect the lines from flashover.

6. Write a note on PSAD

PSCAD stands for **Power Systems Computer Aided Design,** and represents a family of power system simulation products. Presently, it is used as a Graphical User Interface for the EMTDC™ transients' instantaneous solution engine.

PSCAD becomes an indispensable tool for a variety of power system designs and studies. It is a multi-purpose tool. It is equally capable in the areas of power electronic design and simulation, power quality analysis, and electrical utility system planning studies.

As electrical power and power electronic systems become more prevalent in electric vehicles, ships, trains, and distributed generation systems, the need for easy-to-use and accurate simulation and modeling tools becomes ever more important. It is easier and much less expensive to design and optimize electrical devices and systems prior to prototyping or manufacturing. Thus, PSCAD is becoming a true Power System Computer-Aided Design tool for a variety of industry application.

PSCAD users include engineers and technologists from energy utilities, electrical equipment manufacturers, engineering consulting firms, and research and academic institutions. PSCAD is used in the planning, design, and operational phases of power systems. It is also very prevalent in power system research around the world.

Some typical examples of how PSCAD™ can be applied to better understand electrical power systems are:

- **To find over-voltages** in a power system due to a fault condition (incorporates transformer non-linearities; provides multiple-run capability to determine best/worst-case scenarios in terms of location of fault, point-on-wave of the fault, and type of fault).

- **To find over-voltages** in a power system due to an event such as a lightning strike (accommodates a nano-second time step).

- **To find the harmonics** generated by virtually any power electronic device or system, including STATCOM's, HVDC transmission links, SVC's, and machine drives (provides accurate models of the power electronic switching devices such as thyristors, GTO's, IGBT's, diodes, etc.; includes detailed analog and digital control system models).

- **To investigate and mitigate** the pulsing effects of diesel generators and wind turbines, as well as other devices on the overall electric power grid.

- **To find** the maximum energy in a surge arrester for a given electrical disturbance.

- **To design** and fine tune control systems to optimize performance.

- **To investigate** the sub-synchronous response (SSR) impact when a machine and multi-mass turbine interact with power electronic equipment or series compensated transmission lines.
- **To model** voltage source converters (VSC) or STATCOMs along with their detailed control systems models.
- **To investigate** power system instabilities created by harmonic resonance or control system interactions.
- **To perform insulation co-ordination studies**.

- **To design** and simulate variable speed drives of many types including cyclo-converters and electric vehicle and ship propulsion system drives.

- **To design** industrial systems, such as compensation controllers, power electronic drives, electric furnaces, and filters.

- **To study** the transient and harmonic impact of distributed generation systems such as wind and micro-turbine systems on the power grid.

- **To study** and mitigate capacitor switching transients.

- **To study** the system impact of transmission line imbalances during contingency periods.

PSCAD is a multi-purpose power system simulator and can thus be used for any scenario where a detailed understanding of the full time domain of analysis is beneficial. This includes the design and modeling of virtually any electrical power system.

7. Write a note on EMTP.

The Electromagnetic Transients Program (EMTP) is a computer program for simulating electromagnetic, electromechanical, and control system transients on multi-phase electric power systems and it's derivatives Alternative Transients Program (ATP).

Studies involving use of the EMTP fall in two general categories.

- One is design, which includes insulation coordination, equipment ratings, protective device specification, control systems design, etc.

- The other is solving operational problems such as unexplained outages or equipment failures.

COMPONENTS

- Uncoupled and coupled linear, lumped R,L,C elements.

- Transmission lines and cables with distributed and frequency-dependent parameters.

- Nonlinear resistances and inductances, hysteretic inductor, time-varying resistance, TACS/MODELS controlled resistance.

- Components with nonlinearities: transformers including saturation and hysteresis, surge arresters (gapless and with gap), arcs.

- Ordinary switches, time-dependent and voltage-dependent switches, statistical switching (Monte-Carlo studies).

- Valves (diodes, thyristors, triacs), TACS/MODELS controlled switches.

- Analytical sources: step, ramp, sinusoidal, exponential surge functions, TACS/MODELS defined sources.

- Rotating machines: 3-phase synchronous machine, universal machine model.

- User-defined electrical components that include MODELS interaction

Typical Applications

EMTP is used world-wide for switching and lightning surge analysis, insulation coordination and shaft torsional oscillation studies, protective relay modeling, harmonic and power quality studies, HVDC and FACTS modeling. Typical EMTP studies are:

- Lightning overvoltage studies
- Switching transients and faults
- Statistical and systematic overvoltage studies
- Very fast transients in GIS and groundings
- Machine modeling

- Transient stability, motor startup
- Shaft torsional oscillations
- Transformer and shunt reactor/capacitor switching
- Ferroresonance
- Power electronic applications
- Circuit breaker duty (electric arc), current chopping
- FACTS devices: STATCOM, SVC, UPFC, TCSC modeling
- Harmonic analysis, network resonances
- Protective device testing

Some Additional Information

Noise- Electrical noise, or noise, is unwanted electrical signals that produce undesirable effects in the circuits in which they occur.

Common Mode Noise- Common Mode Noise present equally and in phase in each current carrying wire with respect to a ground plane or a circuit. Common mode noise can be caused by radiated emission from a source of EMI. Common mode noise can also couple from one circuit to another by inductive or capacitive means. Lightning discharges may also produce common mode noise in power wiring.

Ground loop- Potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential.