MODULE-4: Overvoltage Phenomenon and Insulation Coordination in Electric Power Systems

Syllabus

4.1 National Causes for Over voltages - Lightning Phenomenon, Overvoltage due to Switching Surges,
4.2 System Faults and Other Abnormal
4.3 Principles of Insulation Coordination on High Voltage and Extra High Voltage Power Systems

Course Objectives

To discuss overvoltage phenomenon and insulation coordination in electric power systems.

4.1 National Causes for Over voltages - Lightning Phenomenon, Overvoltage due to Switching Surges

a) Causes of Over voltage in Power System

Increase in voltage for the very short time in power system is called as the over voltage. it is also known as the voltage surge or voltage transients. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system, There are two types of causes of over voltage in power system.

1. Over voltage due to external causes
2. Over voltage due to internal causes

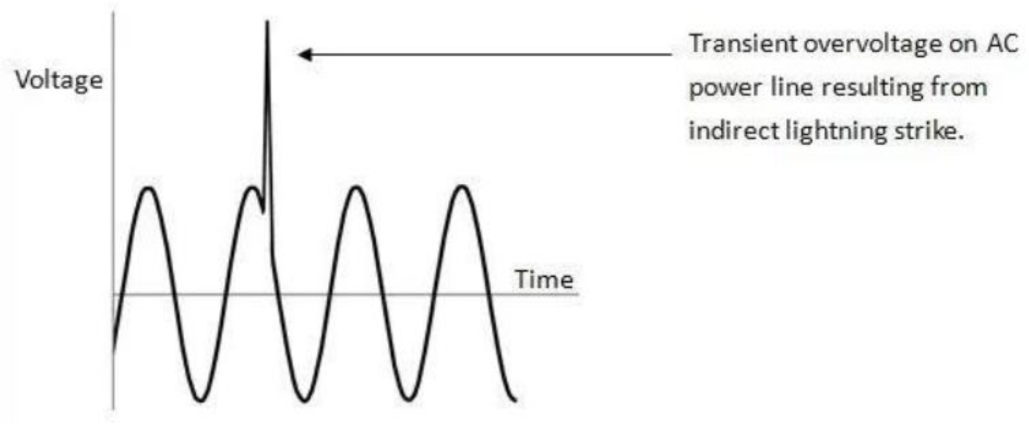
Transient over voltages can be generated at high frequency (load switching and lightning), medium frequency (capacitor energizing), or low frequency.Over voltage due to external causes:
This cause of over voltage in power system is the lightning strokes in the cloud.
Now, how lightning strokes are produced. So when electric charges get accumulated in clouds due to thunder Strom caused due to some bad atmosphere process.
This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line. It may be due to any of the following causes:
A) Direct lightning stroke
B) Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'.
C) Voltages induced due to atmospheric changes along the length of the line.
D) Electrostatically induced voltages due to presence of charged clouds nearby.

E) Electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.

The potential between the clouds and earth breaks down and lightning flash takes place between the cloud and ground when this voltage becomes 5 to 20 million volts or when the potential gradient becomes 5000V to 10000V per cm.

There are two types of lightning strokes.

1. Direct lightning strokes
2. Indirect lightning strokeS



b) LIGHTNING ,SWITCHING AND TEMPORARY OVER VOLTAGE

over-voltage-spike

Over voltages are caused on power systems due to external and internal influencing factors. The voltage stress caused by over voltage can damage the lines and equipment's connected to the system. Over voltages arising on a system can be generally classified into two main categories as below:

External Over voltages

This type of over voltages originates from atmospheric disturbances, mainly due to lightning. This takes the form of a surge and has no direct relationship with the operating voltage of the line. It may be due to any of the following causes:

a) Direct lightning stroke

b) Electromagnetically induced over voltages due to lightning discharge taking place near the line, called 'side stroke'.

c) Voltages induced due to atmospheric changes along the length of the line.

d) Electrostatically induced voltages due to presence of charged clouds nearby.

e) Electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.

Internal Over voltages

These over voltages are caused by changes in the operating conditions of the power system. These can be divided into two groups as below:

1. Switching over voltages or Transient over operation voltages of high frequency:

This is caused when switching operation is carried out under normal conditions or when fault occurs in the network. When an unloaded long line is charged, due to Ferranti Effect the receiving end voltage is increased considerably resulting in over voltage in the system. Similarly when the primary side of the transformers or reactors is switched on, over voltage of transient nature occurs.

2. Temporary over voltages:

These are caused when some major load gets disconnected from the long line under normal or steady state condition.

4.2 System Faults

Over voltage tends to stress the insulation of the electrical equipment's and likely to cause damage to them when it frequently occurs. Over voltage caused by surges can result in spark over and flash over between phase and ground at the weakest point in the network, breakdown of gaseous/solid/ liquid insulation, failure of transformers and rotating machines.

4.2.1 Overvoltage Protection

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.

4.2.3 **Voltage Surge**

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.

4.2.3 Switching Impulse

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 5th or higher harmonics. Actually for frequencies of 5th 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

- Earthing screen.
- Overhead earth wire.
- Lighning arrester or surge dividers.

Earthing Screen

Earthing screen is generally used over electrical substation. 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 earth wire 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 earth wire divert all the lightning strokes to the ground instead of allowing them to strike directly on the transmission conductors.

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 insulator 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.

4.3 Insulation Co-ordination

Insulation Coordination in Power System was introduced to arrange the electrical insulation levels of different components in the electrical power system including transmission network, in such a manner, that the failure of insulator, if occurs, confindes to the place where it would result in the least danmage 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.

For proper understanding the insulation coordination we have to understand first, some basic terminologies of the electrical power system. Let us have a discussion.

Nominal System Voltage

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

Insulation Level

Every electrical equipment has to undergo different abnormal transient over voltage situation 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 and short 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 impulse wave 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.

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 arrestors 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 level voltage 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.

Course Outcome

At the end of the course, student will be able to:

Discuss overvoltage phenomenon and insulation coordination in electric power systems.