UNIT 1

OVER VOLTAGE IN ELECTRICAL POWER SYSTEM

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.

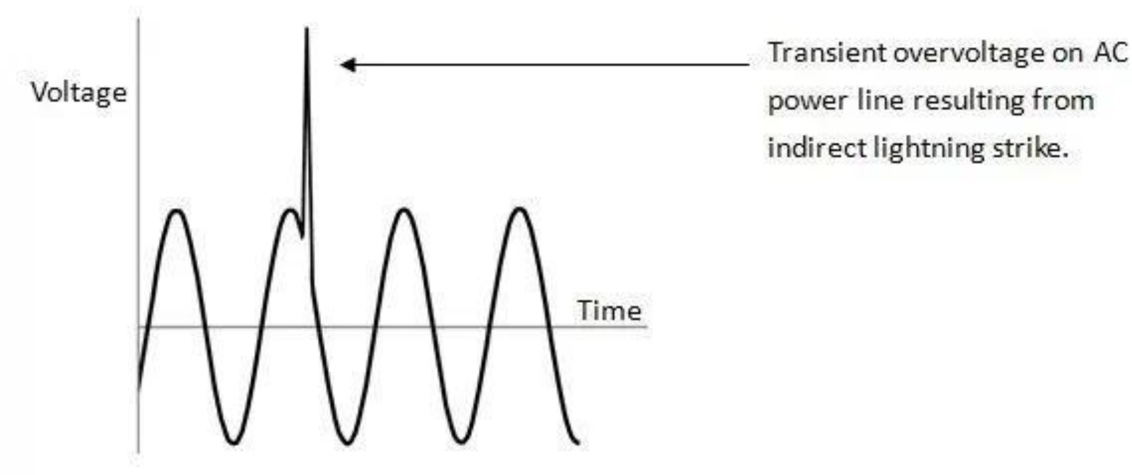
E) Electrostatically induced over voltages due to the frictional effects of small particles like dust or dry snow in the atmosphere or due to change in the altitude of the line.

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



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.

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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.

EFFECTS OF OVER VOLTAGES ON POWER SYSTEMS

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.

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.

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.

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.

INSULATION COORDINATION

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

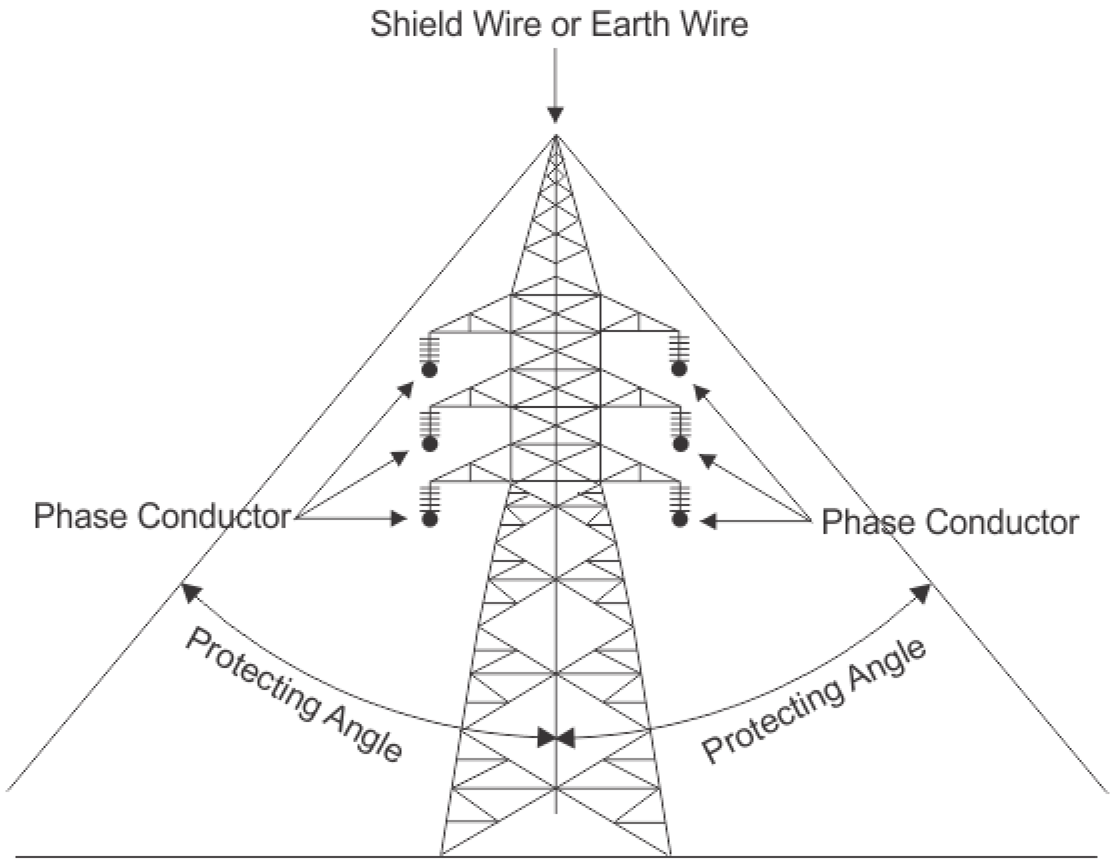
During switching operation there may be uni-polar voltage appears in the system. The wave form of which may be periodically damped or oscillating one. Switching impulse wave form has steep front and long damped oscillating tale.

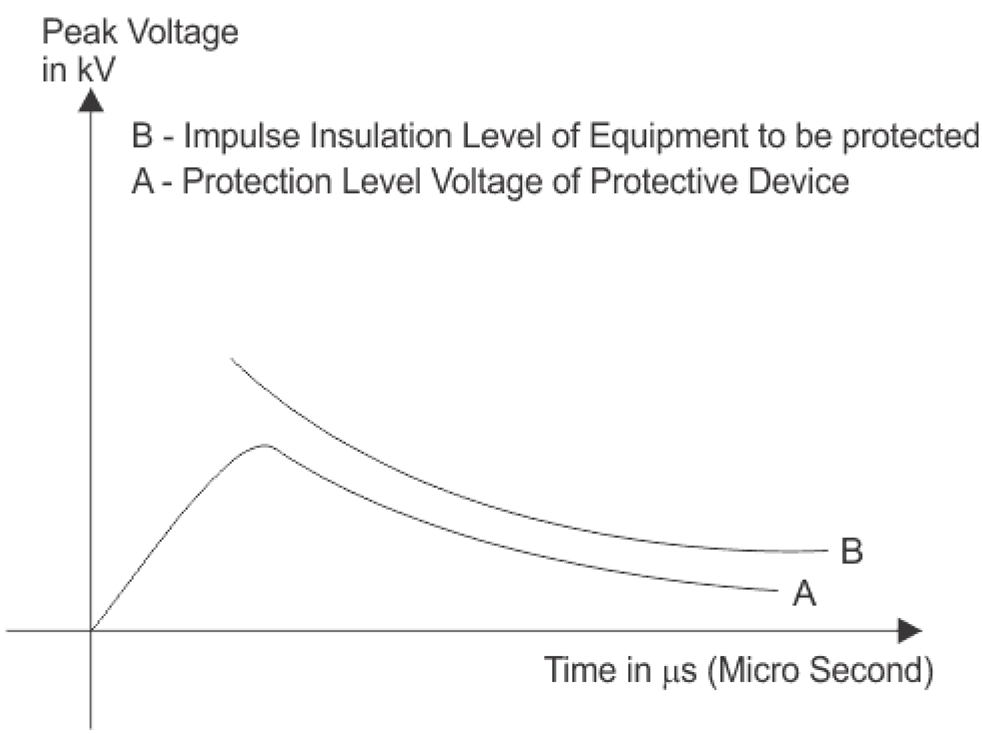
Short Duration Power Frequency Withstand Voltage

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.





Voltage - Time Curved 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 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.

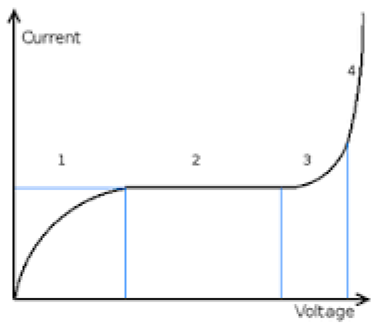
Generally, the impulse insulation level is established at 15 to 25 % above the protective level voltage of protective devices.

UNIT 2

ELECTRICAL BREAKDOWN IN GASES,SOLIDS AND LIQUIDS

GASEOUS BREAKDOWN IN UNIFORM AND NON UNIFORM FIELDS

Gases. Electrical breakdown occurs within a gas when the dielectric strength of the gas is exceeded. ... The voltage that leads to electrical breakdown of a gas is approximated by Paschen's Law. Partial discharge in air causes the "fresh air" smell of ozone during thunderstorms or around high-voltage equipment



UNIFORM AND NON UNIFORM FIELDS

Electric fields are represented by drawing field lines that represent the direction of the field, as well as the strength of the field. More field lines represents a higher field strength. In a non-uniform electric field, the field lines tend to be curved and are more concentrated near the charges. In a uniform electric field, since the field strength does not vary, the field lines are parallel to each other and equally spaced. Uniform fields are created by setting up a potential difference between two conducting plates placed at a certain distance from one another. The field is considered to be uniform at the center of the plates, but varies close to the edge of the plates. The strength of the field depends on the potential difference applied to the plates and the distance by which they are separated. A higher potential difference or voltage results in a stronger electric field. The greater the distance between the plates, the weaker the field becomes. The electric field is therefore calculated as a ratio of the voltage between the plates to the distance they are separated by THEM.

CORONA DISCHARGE

A corona discharge is an electrical discharge brought on by the ionization of a fluid such as air surrounding a conductor that is electrically charged. Spontaneous corona discharges occur naturally in high-voltage systems unless care is taken to limit the electric field strength. A corona will occur when the strength (potential gradient) of the electric field around a conductor is high enough to form a conductive region, but not high enough to cause electrical breakdown or arcing to nearby objects. It is often seen as a bluish (or other color) glow in the air adjacent to pointed metal conductors carrying high voltages, and emits light by the same property as a gas discharge lamp.

In many high voltage applications corona is an unwanted side effect. Corona discharge from high voltage electric power transmission lines constitutes an economically significant waste of energy for utilities. In high voltage equipment like televisions, radio transmitters, X-ray machines and particle accelerators the current leakage caused by coronas can constitute an unwanted load on the circuit. In air, coronas generate gases such as ozone (O3) and nitric oxide (NO), and in turn nitrogen dioxide (NO2), and thus nitric acid (HNO3) if water vapor is present. These gases are corrosive and can degrade and embrittle nearby materials, and are also toxic to people. Corona discharges can often be suppressed by improved insulation, corona rings, and making high voltage electrodes in smooth rounded shapes. However, controlled corona discharges are used in a variety of processes such as air filtration, photocopiers and ozone generators.

VACCUM BREAKDOWN

Experiments have been performed in order to get information about the phenomena preceding the electrical breakdown in small vacuum gaps. Most experiments have been made with impulse voltages of different rise times; some complementary results obtained with alternating voltage are also presented. The effect of surface layers on the breakdown voltage and on the pre-breakdown current is discussed. It has been found that the rise time of the voltage affects both the breakdown voltage and the pre-breakdown current. The experiments seem to indicate that breakdown in the underlying circumstances is the result of a discharge in metal vapour, originating from the anode. The vapour is thought to be generated by the heating of the anode by a bombardment of field-emission electrons. The transition of the pre-breakdown current to a sudden discharge may occur when the vapour density passes a critical value.

§ 1. Introduction.

The mechanism of the electrical breakdown

in vacuum has been the subject of many investigations. Generally, field emission of electrons is accepted as the first step in the process. Different explanations have to be given for the breakdown of small gaps (< 1 mm) and for the high-voltage breakdown of large gaps,

since it has been found that the breakdown field strength decreases considerably with increasing gap length. The pre-breakdown current introducing the discharge should therefore be much smaller in large gaps than in small ones. A few hypotheses with regard to the development of the discharge will be briefly mentioned here. Except for assumption e), breakdown is thought to occur as a result of some multiplication process in metallic vapour produced at one of the electrodes:

a) Evaporation of the anode surface is caused by a bombardment by field-emission electrons breakdown mechanisms in solid and composite dielectrics

Solid dielectric materials are used in all kinds of electrical circuits and devices to insulate one current carrying part from another when they operate at different voltages. A good dielectric should have low dielectric loss, high mechanical strength, should be free from gaseous inclusion, and moisture, and be resistant to thermal and chemical deterioration. Solid dielectrics have higher breakdown strength compared to liquids and gases.

Studied of the breakdown of solid dielectrics are of extreme importance in insulation studies. When breakdown occurs, solids get permanently damaged while gases fully and liquids partly recover their dielectric strength after the applied electric field removed.

The mechanism of breakdown is a complex phenomenon in the case of solids, and varies depending on the time of application of voltage as shown in Fig.

4. 1. The various breakdown mechanisms can be classifiedINTRINSIC BREAKDOWN

When voltages are applied only for short durations of the order of 8 10 sthe dielectric strength of a solid dielectric increases very rapidly to an upper limit called the intrinsic electric strength. Experimentally, this highest dielectric strength can be obtained only under the best experimental conditions when all extraneous influences have been isolated and the value depends only on the structure of the material and the temperature. The maximum electrical strength recorder is 15 MV/cm for polyvinyl-alcohol at -1960 C. The maximum strength usually obtainable ranges from 5 MV/cm. Intrinsic breakdown depends upon the presence of free electrons which are capable of migration through the lattice of the dielectric. Usually, a small number of conduction electrons are present in solid dielectrics, along with some structural imperfections and small amounts of impurities. The impurity atoms, or molecules or both act as traps for the conduction electrons up to certain ranges of electric fields and temperatures. When these ranges are exceeded, additional electrons in addition to trapped electrons are released, and these electrons participate in the conduction process. Based on this principle, two types of intrinsic breakdown mechanisms have been proposed.

i) Electronic Breakdown

Intrinsic breakdown occurs in time of the order of 10-8 s and therefore is assumed to be electronic in nature. The initial density of conduction (free) electrons is also assumed to be large, and electron-electron collisions occur. When an electric field is applied, electrons gain energy from the electric field and cross the forbidden energy gap from the valence band to the conduction band. When this process is repeated, more and more electrons become available in the conduction band, eventually leading to breakdown.

ii) Avalanche or Streamer Breakdown

This is similar to breakdown in gases due to cumulative ionization. Conduction electrons gain sufficient energy above a certain critical electric field and cause liberation of electrons from the lattice atoms by collision. Under uniform field conditions, if the electrodes are embedded in the specimen, breakdown will occur when an electron avalanche bridges the electrode gap. An electron within the dielectric, starting from the cathode will drift towards the anode and during this motion gains energy from the field and loses it during collisions. When the energy gained by an electron exceeds the lattice ionization potential, an additional electron will be liberated due to collision of the first electron.

Unit 3

Generation of high voltage and current

Generation of high d.c. voltages is mainly required in research work in the areas of pure and applied physics. Sometimes, high direct voltages are needed in insulation tests on cables and capacitors. Impulse generator charging units also require high d.c. voltages of about 100 to 200 kV. Normally, for the generation of d.c. voltages of up to 100 kV, electronic valve rectifiers are used and the output currents are about 100 mA. The rectifier valves require special construction for cathode and filaments since a high electrostatic field of several kV/cm exist between the anode and the cathode in the nonconduction period. The a.c. supply to the rectifier tubes may be of power frequency or may be of audio frequency from an oscillator. The latter is used when a ripple of very small magnitude is required without the use of costly filters to smoothen the ripple. Half and Full Wave Rectifier Circuits

Rectifier circuits for producing high d.c. voltages from a.c. sources may be

(a) halfwave,

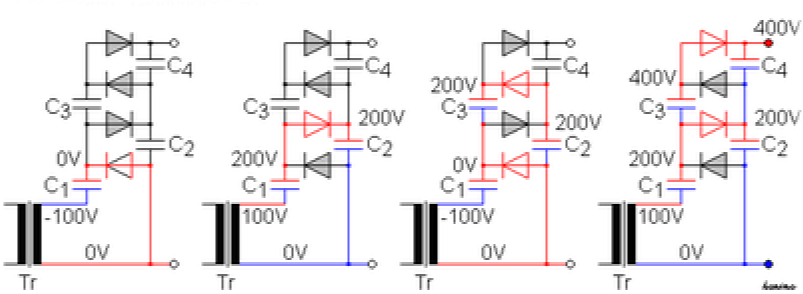
(b) full wave, or

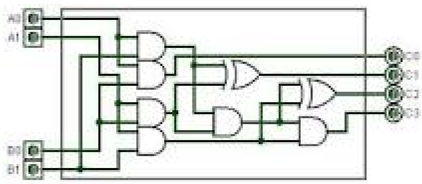
(c) voltage doubler type rectifiers.

The rectifier may be an electron tube or a solid state device. Nowadays single electron tubesare available for peak inverse voltages up to 250 kV, and semiconductor or solid state diodesup to 20 kV. For higher voltages, several units are to be used in series. When a number ofunits are used in series, transient voltage distribution along each unit becomes non-uniformand special care should be taken to make the distribution uniform. Commonly used half waveand full wave rectifiers

Multiplier Circuits

A binary multiplier is an electronic circuit used in digital electronics, such as a computer, to multiply two binary numbers. It is built using binary adders. A variety of computer arithmetic techniques can be used to implement a digital multiplier.





Assuming that the peak voltage of the AC source is +Us, and that the C values are sufficiently high to allow, when charged, that a current flows with no significant change in voltage, then the (simplified) working of the cascade is as follows:

Illustration of the described operation, with +us = 100v

Negative peak (−us): the c1 capacitor is charged through diode d1 to us v (potential difference between left and right plate of the capacitor is us)

Positive peak (+us): the potential of c1 adds with that of the source, thus charging c2 to 2us through d2

Negative peak: potential of c1 has dropped to 0 v thus allowing c3 to be charged through d3 to 2us.

Positive peak: potential of c2 rises to 2us (analogously to step 2), also charging c4 to 2us. The output voltage (the sum of voltages under c2 and c4) rises until 4us is reached.

In reality more cycles are required for c4 to reach the full voltage. Each additional stage of two diodes and two capacitors increases the output voltage by twice the peak ac supply voltage.

Van de graff generator

A Van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate electric charge on a hollow metal globe on the top of an insulated column, creating very high electric potentials. It produces very high voltage direct current (DC) electricity at low current levels. It was invented by American physicist Robert J. Van de Graaff during 1929.[1] The potential difference achieved by modern Van de Graaff generators can be as much as 5 megavolts. A tabletop version can produce on the order of 100,000 volts and can store enough energy to produce a visible spark. Small Van de Graaff machines are produced for entertainment, and for physics education to teach electrostatics; larger ones are displayed in some science museums.

The Van de Graaff generator was developed as a particle accelerator for physics research, its high potential is used to accelerate subatomic particles to great speeds in an evacuated tube. It was the most powerful type of accelerator of the 1930s until the cyclotron was developed. Van de Graaff generators are still used as accelerators to generate energetic particle and x-ray beams for nuclear medicine research. In order to double the voltage, two generators are often used together, one generating positive and the other negative potential; this is termed a tandem Van de Graaff accelerator. For example, the Brookhaven National Laboratory Tandem Van de Graaff achieves about 30 million volts of potential difference.

The voltage produced by an open-air Van de Graaff machine is limited by arcing and corona discharge to about 5 megavolts. Most modern industrial machines are enclosed in a pressurized tank of insulating gas; these can achieve potentials of as much as about 25 megavolts.

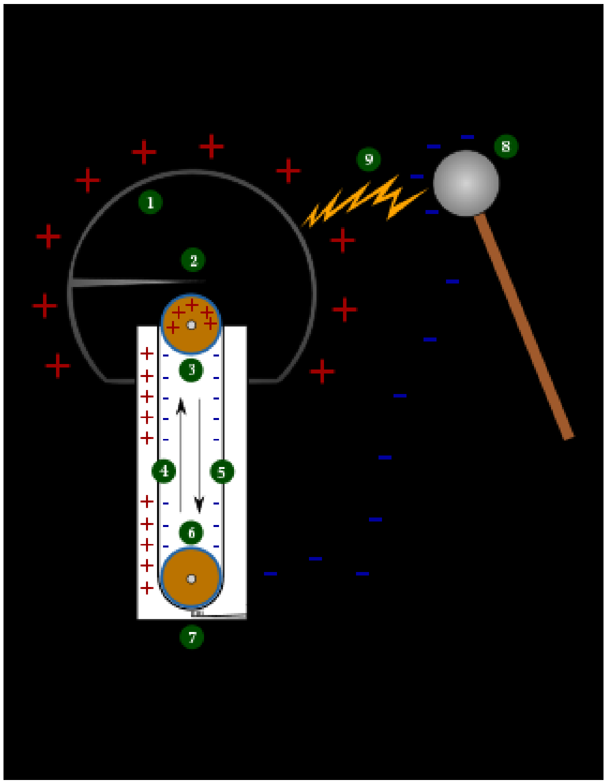
A simple Van de Graaff generator consists of a belt of rubber (or a similar flexible dielectric material) moving over two rollers of differing material, one of which is surrounded by a hollow metal sphere.[2] Two electrodes, (2) and (7), in the form of comb-shaped rows of sharp metal points, are positioned near the bottom of the lower roller and inside the sphere, over the upper roller. Comb (2) is connected to the sphere, and comb (7) to ground. The method of charging is based on the triboelectric effect, such that simple contact of dissimilar materials causes the transfer of some electrons from one material to the other. For example (see the diagram), the rubber of the belt will become negatively charged while the acrylic glass of the upper roller will become positively charged. The belt carries away negative charge on its inner surface while the upper roller accumulates positive charge. Next, the strong electric field surrounding the positive upper roller (3) induces a very high electric field near the points of the nearby comb (2). At the points, the field becomes strong enough to ionize air molecules, and the electrons are attracted to the outside of the belt while positive ions go to the comb. At the comb (2) they are neutralized by electrons that were on the comb, thus leaving the comb and the attached outer shell (1) with fewer net electrons. By the principle illustrated in the Faraday ice pail experiment, i.e. by Gauss's law, the excess positive charge is accumulated on the outer surface of the outer shell (1), leaving no field inside the shell. Electrostatic induction by this method continues, building up very large amounts of charge on the shell.

In the example, the lower roller (6) is metal, which picks negative charge off the inner surface of the belt. The lower comb (7) develops a high electric field at its points that also becomes large enough to ionize air molecules. In this case the electrons are attracted to the comb and positive air ions neutralize negative charge on the outer surface of the belt, or become attached to the belt. The exact balance of charges on the up-going versus down-going sides of the belt will depend on the combination of the materials used. In the example, the upward-moving belt must be more positive than the downward-moving belt. As the belt continues to move, a constant "charging current" travels via the belt, and the sphere continues to accumulate positive charge until the rate that charge is being lost (through leakage and corona discharges) equals the charging current. The larger the sphere and the farther it is from ground, the higher will be its peak potential. In the example, the wand with metal sphere (8) is connected to ground, as is the lower comb (7); electrons are drawn up from ground due to the attraction by the positive sphere, and when the electric field is great enough (see below) the air breaks in the form of an electrical discharge spark (9). Since the material of the belt and rollers can be selected, the accumulated charge on the hollow metal sphere can either be made positive (electron deficient) or negative (excess electrons).

The friction type of generator described above is easier to build for science fair or homemade projects, since it does not require a high-voltage source. Greater potentials can be obtained with alternative designs (not discussed here) for which high voltage sources are used at the upper and/or lower positions of the belt to transfer charge more efficiently onto and off the belt.

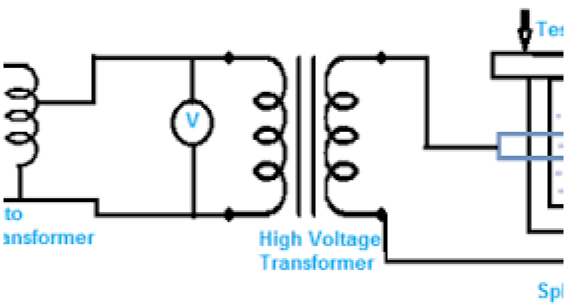
A Van de Graaff generator terminal does not need to be sphere-shaped to work, and in fact, the optimum shape is a sphere with an inward curve around the hole where the belt enters. A rounded terminal minimizes the electric field around it, allowing greater potentials to be achieved without ionization of the air, or other dielectric gas, surrounding. Outside the sphere, the electric field becomes very strong and applying charges directly from the outside would soon be prevented by the field. Since electrically charged conductors do not have any electric field inside, charges can be added continuously from the inside without increasing them to the full potential of the outer shell. Since a Van de Graaff generator can supply the same small current at almost any level of electrical potential, it is an example of a nearly ideal current source.

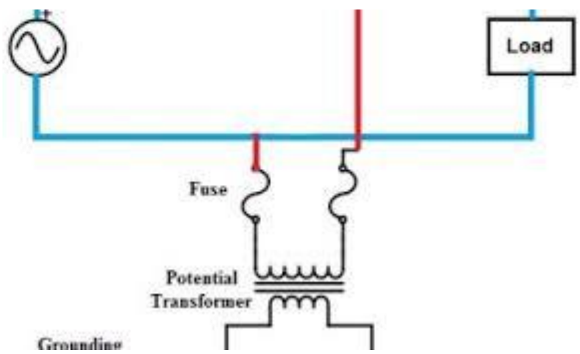
The maximal achievable potential is approximately equal to the sphere radius R multiplied by the electric field Emax at which corona discharges begin to form within the surrounding gas. For air at standard temperature and pressure (STP) the breakdown field is about 30 kV/cm. Therefore, a polished spherical electrode 30 cm in diameter could be expected to develop a maximal voltage



High Alternating Voltage Generator Using Cascade   Transformers

The above Figure shows the cascade transformer units in which the first transformer is at the ground potential along with its tank. The second transformer is kept on insulators and maintained at a potential of V2, the output voltage of the first unit above the ground. The high voltage winding of the first unit is connected to the tank of the second unit. The low voltage winding of this unit is supplied from the excitation winding of the first transformer, which is in series with the high voltage winding of the first transformer at its high voltage end. The rating of the excitation windings is almost identical to that of the primary or the low or the low voltage winding. The high voltage connection from the first transformer winding and the excitation winding terminal are taken through a bushing to the second transformer. In a similar manner, the third transformer is kept on insulators above the ground at a potential of 2V2 and is supplied likewise from the second transformer. The number of stages in this type of arrangement are usually two four, but very often, three stages are adapted to facilitate a three-phase operation so that3V 2 can be obtained between the lines. Supply to the units can be obtained from a motor-generator set or through an induction regulstor for variation of the output voltage. The rating of the primary or the low voltage windings is usually 230 or 400 V for small units up to 100 kVA. For larger outputs the rating of the low voltage winding may be 3.3 kV, 6.6kV or 11 kV.



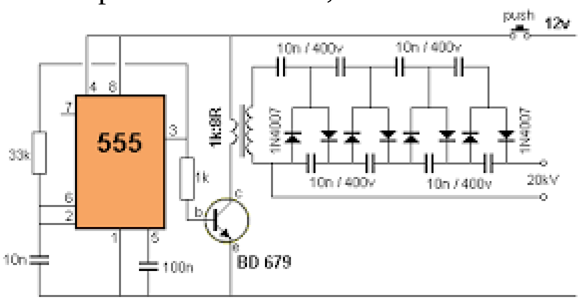


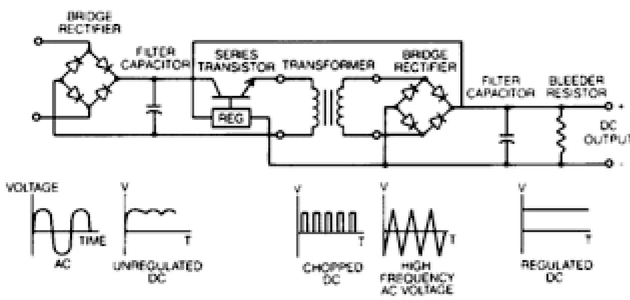
Production Of High Frequency Ac High Voltage

The power systems engineers is interested in high voltages primarily for power transmission, and secondly for testing of his equipment used in power transmission. In this chapter we are interested in generating high voltages for testing of insulation. Thus generation has to be carried out in the testing laboratory. In many testing laboratories, the primary source of power is at low voltage (400 V three phase or 230 V single phase, at 50 Hz). Thus we need to be able to obtain the high voltage from this. Since insulation is usually being tested, the impedances involved are extremely high (order of M_____ _ rents small (less than an ampere). Therefore high voltage testing does not usually require high power. Thus special methods may be used which are not applicable when generating high voltage in high power applications.

Generation of High Alternating Voltages

Single transformer test units are made for high alternating voltages up to about 200 kV. However, for high voltages to reduce the cost (insulation cost increases rapidly with voltage) and make transportation easier, a cascade arrangement of several transformers is used.





Standuard Impulse Wave Shapes

Lighting is a common phenomenon in transmission lines because of their tall height. This lightning stroke on the line conductor causes impulse voltage. The terminal equipment of transmission line such as power transformer then experiences this lightning impulse voltages. Again during all kind of online switching operation in the system, there will be switching impulses occur in the network. The magnitude of the switching impulses may be about 3.5 times the system voltage.

Insulation is one of the most important constituents of a transformer. Any weakness in the insulation may cause failure of transformer. To ensure the effectiveness of the insulation system of a transformer, it must confirms the dielectric test. But the power frequency withstand test alone can not be adequate to demonstrate the dielectric strength of a transformer. That is why impulse test of transformer performed on it. Both lightning impulse test and switching impulse test are included in this category of testing.

Lightning Impulse

The lightning impulse is a pure natural phenomenon. So it is very difficult to predict the actual wave shape of an lightning disturbance. From the data compiled about natural lightning, it may be concluded that the system disturbance due to natural lightning stroke, can be represented by three basic wave shapes.

Full wave

Chopped wave and

Front of wave

Although the actual lightning impulse disturbance may not have exactly these three shapes but by defining these waves one can establish a minimum impulse dielectric strength of a transformer.

If lighting disturbance travels some distance along the transmission line before it reaches the transformer, its wave shape may approach to full wave.

If during traveling, if flash-over occurs at any insulator of the transmission line, after the peak of the wave has been reached, the wave may become in form of chopped wave.

If the lightning stroke directly hits the transformer terminals, the impulse voltage rises rapidly until it is relieved by a flash over. At the instant of flash-over the voltage suddenly collapses and may form the front of wave shape.

The effect of these wave forms on the transformer insulation may be different from each other. We are not going here in detail discussion of what type of impulse voltage wave forms causes what type of failure in transformer. But whatever may be the shape of lightning disturbance voltage wave, all of them can cause insulation failure in transformer. So lighting impulse test of transformer is one of the most important type test of transformer.

Switching Impulse

Through studies and observations reveal that the switching over voltage or switching impulse may have front time of several hundred microseconds and this voltage may be periodically damped out. The IEC - 600060 has adopted for their switching impulse test, a long wave having front time 250 μs and time to half value 2500 μs with tolerances. The purpose of the impulse voltage test is to secure that the transformer insulation withstand the lightning overvoltage which may occur in service. Impulse test The impulse generator design is based on the Marx circuit. The basic circuit diagram is shown on Figure above. The impulse capacitors Cs (12 capacitors of 750 ηF) are charged in parallel through the charging resistors Rc (28 kΩ) (highest permissible charging voltage 200 kV). When the charging voltage has reached the required value, breakdown of the spark gap F1 is initiated by an external triggering pulse. When F1 breaks down, the potential of the following stage (point B and C) rises. Because the series resistors Rs is of low-ohmic value compared with the discharging resistors Rb (4,5 kΩ) and the charging resistor Rc, and since the low-ohmic discharging resistor Ra is separated from the circuit by the auxiliary spark-gap Fal, the potential difference across the spark-gap F2 rises considerably and the breakdown of F2 is initiated.

Thus the spark-gaps are caused to break down in sequence. Consequently the capacitors are discharged in series-connection. The high-ohmic discharge resistors Rb are dimensioned for switching impulses and the low-ohmic resistors Ra for lightning impulses. The resistors Ra are connected in parallel with the resistors Rb, when the auxiliary spark-gaps break down, with a time delay of a few hundred nano-seconds.

The arrangement is necessary in order to secure the functioning of the generator.

The wave shape and the peak value of the impulse voltage are measured by means of an Impulse Analysing System (DIAS 733) which are connected to the voltage divider. The required voltage is obtained by selecting a suitable number of series-connected stages and by adjusted the charging voltage. In order to obtain the necessary discharge energy parallel or series-parallel connections of the generator can be used. In these cases some of the capacitors are connected in parallel during the discharge.

The required impulse shape is obtained by suitable selection of the series and discharge resistors of the generator.

The front time can be calculated approximately from the equation:

For R1 >> R2 and Cg >> C (15.1)

Tt = .R.C.123

and the half time to half value from the equation

T ≈ 0,7.R.C

In practice the testing circuit is dimensioned according to experience.

Performance of Impulse Test

Impulse test The test is performed with standard lightning impulses of negative polarity. The front time (T1) and the time to half-value (T2) are defined in accordance with the standard.

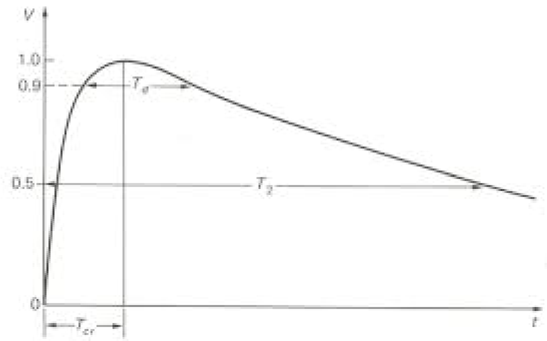
Standard lightning impulse

Front time T1 = 1,2 μs ± 30%

Time to half-value T2 = 50 μs ± 20%

In practice the impulse shape may deviate from the standard impulse when testing low-voltage windings of high rated power and windings of high input capacitance. The impulse test is performed with negative polarity voltages to avoid erratic flash overs in the external insulation and test circuit. Waveform adjustments are necessary for most test objects. Experience gained from results of tests on similar units or eventual pre-calculation can give guidance for selecting components for the wave shaping circuit.

The test sequence consists of one reference impulse (RW) at 75% of full amplitude followed by the specified number of voltage applications at full amplitude (FW) (according to IEC 60076-3 three full impulses). The equipment for voltage and current signal recording consists of digital transient recorder, monitor, computer, plotter and printer. The recordings at the two levels can be compared directly for failure indication. For regulating transformers one phase is tested with the on-load tap changer set for the rated voltage and the two other phases are tested in each of the extreme positions.



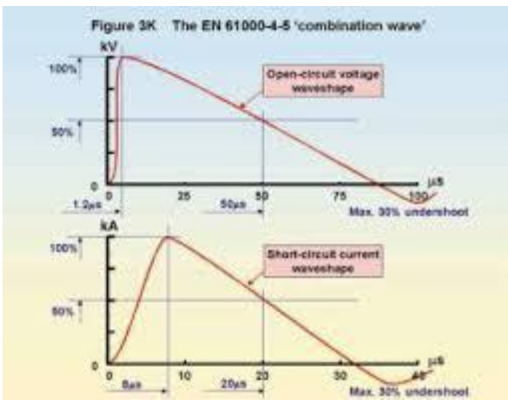


Figure 3K The EN 61000-4-5 'combination wave'

The circuit generates a high-voltage pulse by charging a number of capacitors in parallel, then suddenly connecting them in series. See the circuit above. At first, n capacitors (C) are charged in parallel to a voltage VC by a high-voltage DC power supply through the resistors (RC). The spark gaps used as switches have the voltage VC across them, but the gaps have a breakdown voltage greater than VC, so they all behave as open circuits while the capacitors charge. The last gap isolates the output of the generator from the load; without that gap, the load would prevent the capacitors from charging. To create the output pulse, the first spark gap is caused to break down (triggered); the breakdown effectively shorts the gap, placing the first two capacitors in series, applying a voltage of about 2VC across the second spark gap.[2] Consequently, the second gap breaks down to add the third capacitor to the "stack", and the process continues to sequentially break down all of the gaps. The last gap connects the output of the series "stack" of capacitors to the load. Ideally, the output voltage will be nVC, the number of capacitors times the charging voltage, but in practice the value is less. Note that none of the charging resistors Rc are subjected to more than the charging voltage even when the capacitors have been erected. The charge available is limited to the charge on the capacitors, so the output is a brief pulse as the capacitors discharge through the load (and charging resistors). At some point, the spark gaps stop conducting, and the high-voltage supply begins charging the capacitors again.

The principle of multiplying voltage by charging capacitors in parallel and discharging them in series is also used in the voltage multiplier circuit, used to produce high voltages for laser printers and cathode ray tube television sets, which has similarities to this circuit. The difference is that the voltage multiplier is powered with alternating current and produces a steady DC output voltage, while the Marx generator produces a pulse.

Marx generator used for testing high-voltage power-transmission components at TU Dresden, Germany Marx generator at utility trade fair, Leipzig, East Germany, 1954 Marx generator (standing rectangular structure, left) in high-voltage lab at Jabalpur Engineering College, Jabalpur, India 600 kV 10-stage Marx generator in operation Optimization

To deliver 5 ns rise time pulses, the Marx generator is often built into a coaxial wave guide. The spark gaps are placed as close as possible together for maximum UV light exchange for minimum jitter. DC HV comes from underneath, pulsed HV leaves at the top into the coaxial line. The double line of spheres in the middle are the spark gaps, all other spheres are to avoid corona discharge. Blue=water capacitor. Grey=solid metal. Black= thin wire. The outer conductor also functions as a vessel, so that the gas and the pressure can be optimized.

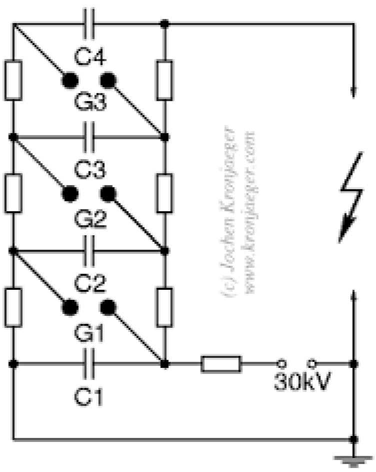
Proper performance depends upon selection of capacitor and the timing of the discharge. Switching times can be improved by doping of the electrodes with radioactive isotopes caesium 137 or nickel 63, and by orienting the spark gaps so that ultraviolet light from a firing spark gap switch illuminates the remaining open spark gaps.[3] Insulation of the high voltages produced is often accomplished by immersing the Marx generator in transformer oil or a high pressure dielectric gas such as sulfur hexafluoride (SF_6).

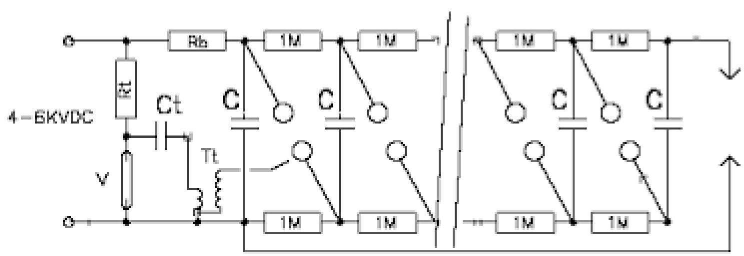
Note that the less resistance there is between the capacitor and the charging power supply, the faster it will charge. Thus, in this design, those closer to the power supply will charge quicker than those farther away. If the generator is allowed to charge long enough, all capacitors will attain the same voltage.

In the ideal case, the closing of the switch closest to the charging power supply applies a voltage 2V to the second switch. This switch will then close, applying a voltage 3V to the third switch. This switch will then close, resulting in a cascade down the generator that produces nV at the generator output (again, only in the ideal case).

The first switch may be allowed to spontaneously break down (sometimes called a self break) during charging if the absolute timing of the output pulse is unimportant. However, it is usually intentionally triggered once all the capacitors in the Marx bank have reached full charge, either by reducing the gap distance, by pulsing an additional trigger electrode (such as a Trigatron), by ionising the air in the gap using a pulsed laser, or by reducing the air pressure within the gap.

The charging resistors, Rc, need to be properly sized for both charging and discharging. They are sometimes replaced with inductors for improved efficiency and faster charging. In many generators the resistors are made from plastic or glass tubing filled with dilute copper sulfate solution. These liquid resistors overcome many of the problems experienced by more-conventional solid resistive materials, which have a tendency to lower their resistance over time under high voltage conditions.





generation of switching surgesSwitching surge generators of different types are needed for the study of the impact of oscillating switching surge in power systems. This chapter deals with the details of the various types of switching impulse voltage generators, that is, standard switching impulse voltage generator, unipolar-damped OSS generator and damped OSS generator. To generate the oscillating switching impulse voltage, Marx type impulse generator is used. The impulses are, alternatively UDOSS or DOSS, and the frequency and decay rate can be controlled by varying the resistances, capacitances and inductance of the impulse generator circuit.

Generation of standard switching surges

A 3 MV, 50_ kJ impulse voltage generator has been used to obtain the standard switching surges (250/2500µs). It is a fifteen stage Marx type impulse voltage generator, out of which five stages are used to get a maximum output voltage of 1000000 volts. Each stage has two 0.33µF capacitors in series and it employs a resistive wave shaping circuit. The Marx generator capacitors are charged using a voltage doubler circuit. The de voltage to the circuit can be varied smoothly from 0 to100 kV using a motor driven auto-transformer in the input side of the rectifier circuit.

A 500 kV, 6.25 kJ impulse voltage generator is also used to obtain the standard switching surge (250/2500 µs). It is a ten stage Marx type generator with a capacitance of 0.5 µF per stage and a resistive wave shaping circuit. The Marx circuit is fed from a voltage doubler circuit. The de voltage can be varied smoothly from Oto 50 kV by an auto-transformer in the input side of the rectifier circuit.

. The following components of Marx impulse voltage generator are designed · .·::·<t-:-'·'. ;i ·g· the simulation of impulse voltage generator described in chapter 2.

a) For 3 million volt generator

i. Wave front resistor (Rf) of magnitude 7.0 kn. It consists of five tubular resistors connected in series.

ii. Wave tail resistors (Rt) consist of five tubular resistors connected in series having a total magnitude of 114.1 kn.

iii. The load capacitor (CL) consists of four 0.1 µF capacitors connected in series

b) For 500 kV generator

i. Wave fornt resistor (Rf) of magnitude 15 kn. This consisted of a number of tubular resistors connected in series.

ii. The wave tail resistors (Rt) consists of tubular resistors, connected in series and having a resistance of 79 kn.

iii. The load capacitor (CL) consists of two capacitors of 9.0 nF and 1.07 nF connected in parallel.

GENERATION OF IMPULSE CURRENTS

Lightning discharges involve both high voltage impulses and high current impulses on transmission lines. Protective gear like surge diverters have to discharge the lightning currents without damage. Therefore, generation of impulse current waveforms of high magnitude find application in testing work as well as in basic research on nonlinear resistors, electric are studies, and studies relating to electric plasmas in high current discharges.

Definition of Impulse Current Waveforms

The waveshape used in testing surge diverters are 4/10 and 8/20 µ s, the figures respectively representing the nominal wave front and wave tail times the tolerances allowed on these times are ±10%only. Apart from the standard impulse current, waves, rectangular waves of long duration are also used for testing. The waveshape should be nominally rectangular in shape. The rectangular waves generally have durations of the order of 5.0 ms, with rise and fall times of the order 0f 0.5 to 5.0 ms, with rise and fall times of the waves being less than ±10%of their total duration. The tolerance allowed on the peak value is +20% and -0% (the peak value may be more than the specified value but not less). The duration of the wave is at least defined as the total time of the wave during which the current is least 10% of its peak value.

Circuits for Producing Impulse Current Waves

For producing impulse currents of large value, a bank of capacitors connected in parallel are charged to a specified value and are discharged through a series R-L circuit as shown in Fig. C represents a bank of capacitors connected in parallel which are charged from a d.c. source to a voltage up to 200 kV. R represents the dynamic resistance of the rest object and the resistance of the circuit and the shunt. L is an air cored high current inductor, usually a spiral tube of a few turns. If the capacitor is charged to a voltage V and discharged when the spark gap is triggered, the current i m will be given by the equation The circuit is usually under damped, so that The time taken for the current i m to rise from zero to the first peak value is The duration for one half cycle of the damped oscillatory wave t2 is, Generation of High Impulse Currents For producing large values of impulse currents, a number of capacitors are charged in parallel and discharge in parallel into the circuit. In order to minimize the effective inductance, the capacitors are subdivided into smaller units. If there are n1 groups of capacitors, each consisting of n2 units and if L0 is the inductance of the common discharge path, L1 is that of each group and L2 is that of each unit, then the effective inductance L is given by Also, the arrangement of capacitors into a horse-shoe layout minimizes the effective load inductance.

The essential parts of an impulse current generator are:

(i) a.d.c charging unit giving a variable voltage to the capacitor bank,

(ii) capacitors of high value (0.5 to 5 µF) each with very low self inductance, capable of

giving high short circuit currents

Tripping and control of impulse generators

1. TRIPPING AND CONTROL OF IMPULSE GENERATORS • In large impulse generators, the spark gaps are generally sphere gaps or gaps formed by hemispherical electrodes. • The gaps are arranged such that sparking of one gap results in automatic sparking of other gaps as overvoltage is impressed on the other. • A simple method of controlled tripping consists of making the first gap a three electrode gap and firing it from a controlled source. Refer to given diagram.

2. Tripping of an impulse generator with a three electrode a gap

3. TRIPPING AND CONTROL OF IMPULSE GENERATORS • The first stage of the impulse generator is fitted with a three electrode gap, and the central electrode is maintained at a potential in between that of the top and the bottom electrodes with the resistors R1 and RL. • The tripping is initiated by applying a pulse to the thyraton G by closing the switch S. • C produces an exponentially decaying pulse of positive polarity. • The Thyraton conducts on receiving the pulse from the switch S and produces a negative pulse through the capacitance C1 at central electrode. • Voltage between central electrode and the top electrode of the three electrode gap goes above its sparking potential and gap contacts.

4. TRIPPING CIRCUIT USING A TRIGATRON • This requires much smaller voltage for operation compared to the three electrode gap. • Nowadays a trigatron shown below is used. Trigatron gap

5. TRIPPING CIRCUIT USING A TRIGATRON • A trigatron gap consists of a high voltage spherical electrode, an earthed main electrode of spherical shape, and a trigger electrode through the main electrode. • The trigatron is connected to a pulse circuit as shown below.

6. TRIPPING CIRCUIT USING A TRIGATRON • Tripping of the impulse generator is effected by a trip pulse which produces a spark between the trigger electrode and the earthed sphere. • Due to space charge effects and distortion of the field in the main gap, spark over of the main gap occurs and it is polarity sensitive.

7. TRIPPING CIRCUIT USING A TRIGATRON • Tripping of the impulse generator is effected by a trip pulse which produces a spark between the trigger electrode and the earthed sphere. • Due to space charge effects and distortion of the field in the main gap, spark over of the main gap occurs and it is polarity sensitive.

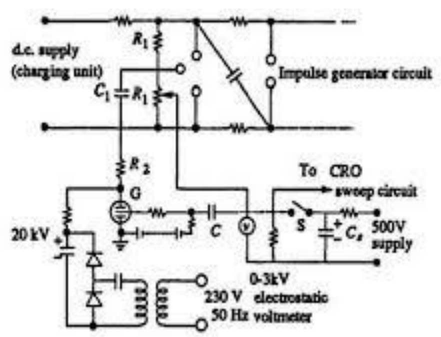


Figure: 3.25 Tripping of an impulse generator with a three electrode gap

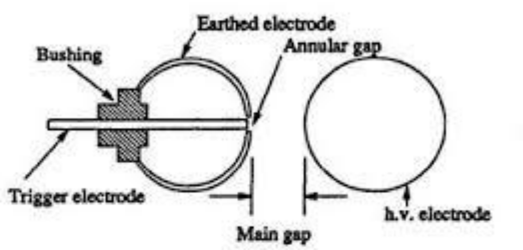
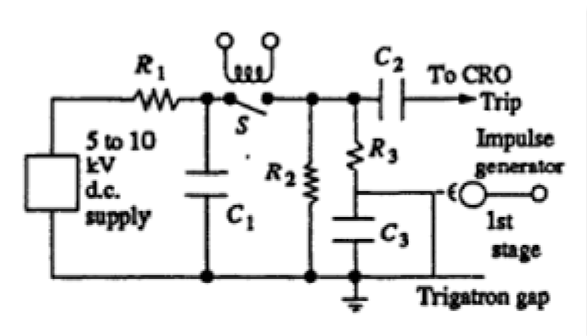


Figure:3.26 (a) Trigatron gap

An impulse generator is an electrical apparatus which produces very short high-voltage or high-current surges. Such devices can be classified into two types: impulse voltage generators and impulse current generators. High impulse voltages are used to test the strength of electric power equipment against lightning and switching surges. Also, steep-front impulse voltages are sometimes used in nuclear physics experiments. High impulse currents are needed not only for tests on equipment such as lightning arresters and fuses but also for many other technical applications such as lasers, thermonuclear fusion, and plasma devices.

HIGH VOLTAGE IMPULSE GENERATOR
Capacitor Bank, Diode Bank,
Resistance Bank, Sphere Gap Assembly
HV Transformer



R1
S
C2
To CRO
Trip
5 to 10
kV
d.c.
supply
C1
R2
R3
Impulse
generator
C3
1st
stage
Trigatron gap

UNIT 4

HVDC TRANSMISSION SYSTEM

High Voltage Measurement High voltages can be measured in a variety of ways. Direct measurement of high voltages is possible up to about 200 kV, and several forms of voltmeters have been devised which can be connected directly across the test circuit. High Voltages are also measured by stepping down the voltage by using transformers and potential dividers. The sparkover of sphere gaps and other gaps are also used, especially in the calibration of meters in high voltage measurements. Transient voltages may be recorded through potential dividers and oscilloscopes. Lightning surges may be recorded using the Klydonograph. 6.1 Direct Measurement of High Voltages 6.1.1 Electrostatic Voltmeters One of the direct methods of measuring high voltages is by means of electro-static voltmeters. For voltages above 10 kV, generally the attracted disc type of electrostatic voltmeter is used. When two parallel conducting plates (cross section area A and spacing x) are charged q and have a potential difference V, then the energy stored in the is given by It is thus seen that the force of attraction is proportional to the square of the potential difference applied, so that the meter reads the square value (or can be marked to read the rms value). Electrostatic voltmeters of the attracted disc type may be connected across the high voltage circuit directly to measure up to about 200 kV, without the use of any potential divider or other reduction method. [The force in these electrostatic instruments can be used to measure both a.c. and d.c. voltages]. N x V F = - A x A = - d x d C so that x A for uniform field Capacitance C = N d x d C Force F = V Energy stored W = C V so that change d W = V d C = F d x 2 2 2 1 2 2 2 1 2 2 2 1 2 1 ε ε ε ∴ ∴ 92_ _ High Voltage Engineering - J R Lucas 2001 Abraham Voltmeter The Abraham voltmeter is the most commonly used electrostatic meter in high voltage testing equipment. In this instrument, there are two mushroom shaped hollow metal discs. As shown in figure 6.1 the right hand electrode forms the high voltage plate, while the centre portion of the left hand disc is cut away and encloses a small disc which is movable and is geared to the pointer of the instrument. The range of the instrument can be altered by setting the right hand disc at pre-marked distances. The two large discs form adequate protection for the working parts of the instrument against external electrostatic disturbances. These instruments are made to cover ranges from 3 kV to 500 kV. Owing to the difficulty of designing electrostatic voltmeters for the measurement of extra high voltages which will be free from errors due to corona effects, within the instrument, and to the external electrostatic fields, a number of special methods have been devised for the purpose.

Sphere Gaps

A spark gap will have a very repeatable breakdown voltages for a given atmospheric conditions. For mostly mechanical reasons, uniform field gaps (using, for example Rogowski or Bruce profile electrodes) are not used as much as sphere gaps where the spheres are quite a bit larger than the gap. There isn't a convenient analytical expression for the breakdown voltage as a function of sphere diameter and gap, as there is for a uniform field gap, however, there is a lot of empirical test data, and sphere gaps are by far and away the most common way of measuring high voltages with a spark gap.

Typical accuracies are 3% for gaps less than half the diameter of the sphere and 5% for the gap larger than the diameter of the sphere. As the gap gets larger, the field between the spheres gets

more and more nonuniform, and as a result the scatter in the data gets larger. A rod gap represents sort of the ultimate in non-uniform gap, and is often quoted at +/- 8% accuracy.
Sphere Gap Breakdown Voltage Table

Mechanical, electrical, and procedural details

A series resistor is usually put between the source and the gap to limit the breakdown current and to provide some damping of the high frequency oscillations. It is typically 100K to 1 Meg for AC or DC voltages, and no more than 500 Ohms for impulse voltages.

For AC peak and DC measurements, the voltage is gradually increased until breakdown occurs. The mean of 5 measurements that fall within ± 3% is used as the value. For impulses, a 50% flashover voltage is calculated from the mean of two measurements, described as follows, which must be within 2% of each other. The first measurement voltage is set so that out of 10(?) impulses, either 2 or 4 flashovers occur. The second measurement is set so that out of the 10 impulses, either 6 or 8 flashovers occur. *(N.B.Presumably, there is some ANSI specification for this process, which will be used to update this section.)*

Sphere gaps can be arranged either vertically, typically with the lower sphere grounded (earthed), or horizontally. The surroundings do have an effect on the breakdown voltage, as they alter the field configuration. Standard clearances are specified for spheres of various sizes in both configurations. These clearances reduce the effect of the surroundings to less than the specified accuracy (e.g. 3%). In the following: **D** is the diameter of the spheres, **S** is the spacing of the gap, S/D <= 0.5. **A** is the height of the lowest point of the HV sphere above the ground. **B** is the radius of clearance from surrounding structions.

D (cm)	A (max)	A (min)	B (min)
<= 6.25	7*D	9*D	14*S
10-15	6*D	8*D	12*S
25	5*D	7*D	10*S
50	4*D	6*D	8*S
100	3.5*D	5*D	7*S
150	3*D	4*D	6*S
200	3*D	4*D	6*S

Actual values (meters)

Sphere Diameter (cm)	A (max) meters	A (min) meters	B (min) for max gap (D/2)

			meters
<= 6.25	7*D	9*D	14*S
10-15	60-75	0.80-1.20	0.60
25	1.25	1.75	1.25
50	2.0	3.0	2.0
100	3.5	500	3.5
150	4.5	600	4.5
200	6.0	800	6.0

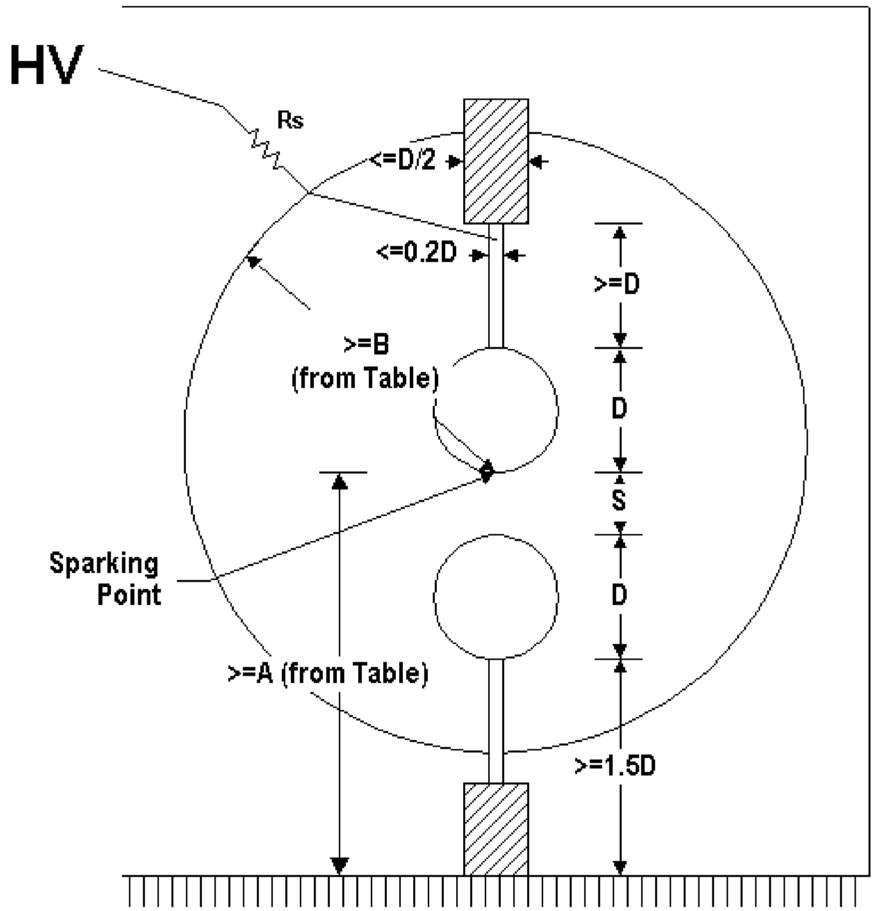
Additional Construction details

The insulator supporting the upper sphere should be less than 0.5 D in diameter. The sphere itself should be supported by a conductive metal shank no more than 0.2 D in diameter and at least D in length (that is, the sparking point should be at least 2D from the lower end of the upper insulator).

The high voltage lead should not pass near the upper electrode. Ideally it should be led away from shank avoiding crossing a plane perpendicular to the shank at least 1 D away from the sphere (i.e. 2 D away from the sparking point, until it is outside of a sphere of radius B from the sparking point.

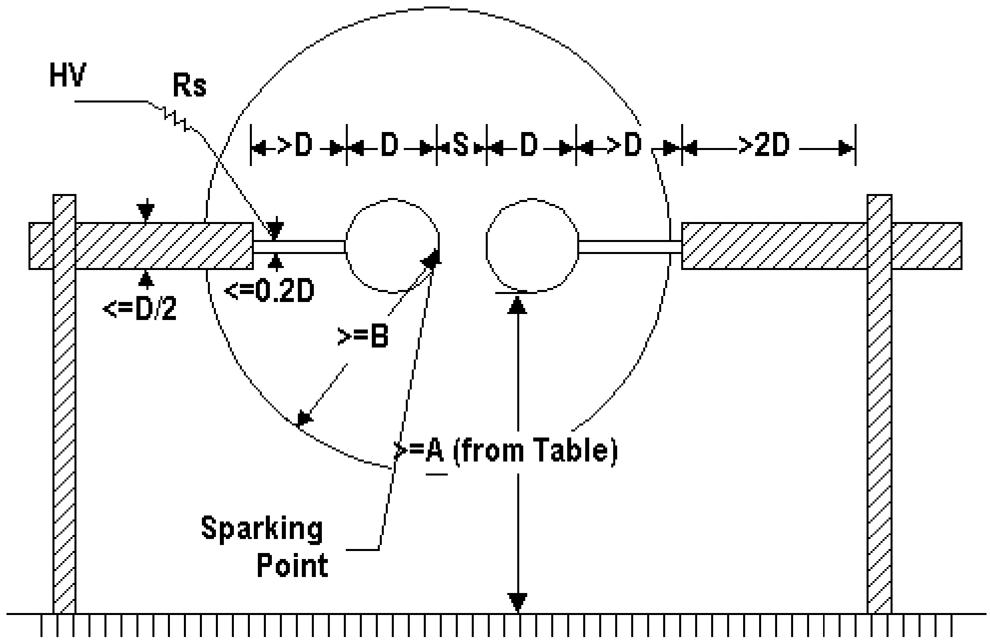
The top of the lower electrode should be at least 1.5D above the (presumably) grounded floor.

Vertical Spark Gap Schematic Diagram



Horizontal gaps are much the same as vertical gaps, except that both electrodes are insulated. The insulators should be longer, at least 2D long (putting the sparking point at least 4D from the supports: 2D for the insulator, 1D for the shank, 1D for the sphere). And, both spheres should be the appropriate clearance from the floor or external objects.

Horizontal Spark Gap Schematic Diagram



- **Impulse Voltage Measurements Using Voltage Dividers**

If the amplitudes of the impulse voltage is not high and is in the range of a few kilovolts, it is possible to measure them even when these are of short duration by using CROS. However, if the voltages to be measured are of high magnitude of the order of megavolts which normally is the case for testing and research purposes, various problems arise. The voltage dividers required are of special design and need a thorough understanding of the interaction present in these voltage dividing systems. The voltage generator G is connected to a test object—T through a lead L.

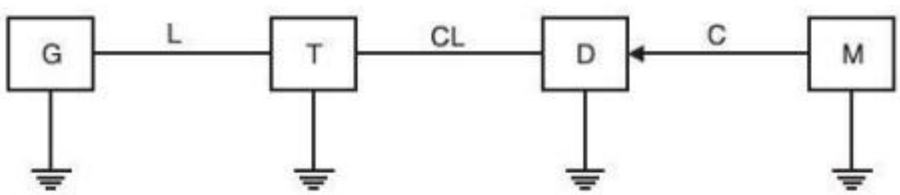


Figure: 4.7 Basic voltage testing circuit

These three elements form a voltage generating system. The lead L consists of a lead wire and a resistance to damp oscillation or to limit short-circuit currents if of the test object fails. The

measuring system starts at the terminals of the test object and consists of a connecting lead CL to the voltage divider D. The output of the divider is fed to the measuring instrument (CRO etc.) M. The appropriate ground return should assure low voltage drops for even highly transient phenomena and keep the ground potential of zero as far as possible.
It is to be noted that the test object is a predominantly capacitive element and thus this forms an Oscillatory circuit with the inductance of the load. These oscillations are likely to be excited by any steep voltage rise from the generator output, but will only partly be detected by the voltage divider. A resistor in series with the connecting leads damps out these oscillations. The voltage divider should always be connected outside the generator circuit towards the load circuit (Test object) for accurate measurement. In case it is connected within the generator circuit and the test object discharges (chopped wave) the whole generator including voltage divider will be discharged by this short circuit at the test object and thus the voltage divider is loaded by the voltage drop across the lead L. As a result, the voltage measurement will be wrong. Yet for another reason, the voltage divider should be located away from the generator circuit. The dividers cannot be shielded against external fields. All objects in the vicinity of the divider which may acquire transient potentials during a test will disturb the field distribution and thus the divider performance. Therefore, the connecting lead CL is an integral part of the potential divider circuit. In order to avoid electromagnetic interference between the measuring instrument M and C the high voltage test area, the length of the delay cable should be adequately chosen. Very short length of the cable can be used only if the measuring instrument has high level of electromagnetic compatibility (EMC). For any type of voltage to be measured, the cable should be co-axial type. The outer conductor provides a shield against the electrostatic field and thus prevents the penetration of this field to the inner conductor. Even though, the transient magnetic fields will penetrate into the cable, no appreciable voltage is induced due to the symmetrical arrangement. Ordinary coaxial cables with braided shields may well be used for d.c. and a.c. voltages. However, for impulse voltage measurement double shielded cables with predominantly two insulated braided shields will be used for better accuracy.

During disruption of test object, very heavy transient current flow and hence the potential of the Ground may rise to dangerously high values if proper earthling is not provided. For this, large metal sheets of highly conducting material such as copper or aluminum are used. Most of the modern high voltage laboratories provide such ground return along with a Faraday Cage for a complete shielding of the laboratory. Expanded metal sheets give similar performance. At least metal tapes of large width should be used to reduce the impedance.

Voltages dividers for a.c., d.c. or impulse voltages may consist of resistors or capacitors or a convenient combination of these elements. Inductors are normally not used as voltage dividing elements as pure inductances of proper magnitudes without stray capacitance cannot be built and also these inductances would otherwise form oscillatory circuit with the inherent capacitance of the test object and this may lead to inaccuracy in measurement and high voltages in the measuring circuit. The height of a voltage divider depends upon the flash over voltage and this follows from the rated maximum voltage applied.

Now, the potential distribution may not be uniform and hence the height also depends upon the design of the high voltage electrode, the top electrode. For voltages in the megavolt range, the height of the divider becomes large. As a thumb rule following clearances between top electrode and ground may be assumed 2.5 to 3 meters/MV for d.c. voltages.2 to 2.5 m/MV for lightning impulse voltages. More than 5 m/MV rms for a.c. voltages. More than 4 m/MV for switching impulse voltage.The potential divider is most simply represented by two impedances Z1 and Z2 connected in series and the sample voltage required for measurement is taken from across Z2, FIG. 4.8.If the voltage to be measured is V1 and sampled voltage V2, then

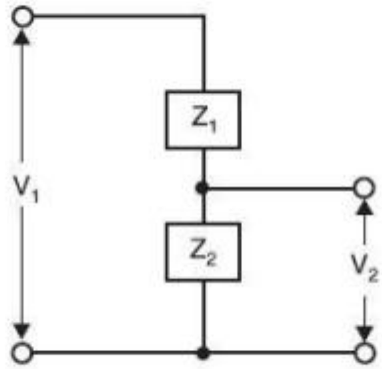


Figure: 4.8 Basic diagram of a potential divider circuit

$$V2 = \frac{Z2}{Z1+Z2} V1 \qquad \rightarrow (4.8)$$

If the impedances are pure resistances

$$V2 = \frac{R2}{R1+R2} V1 \qquad \rightarrow (4.9)$$

If the impedances are pure resistances

$$V2 = \frac{C1}{C1+C2} V1 \qquad \rightarrow (4.10)$$

The voltage V_2 is normally only a few hundred volts and hence the value of Z_2 is so chosen that V_2 across it gives sufficient deflection on a CRO. Therefore, most of the voltage drop is available across the impedance Z_1 and since the voltage to be measured is in megavolt the length of Z_1 is large which result in inaccurate measurements because of the stray capacitances associated with long length voltage dividers (especially with impulse voltage measurements) unless special precautions are taken. On the low voltage side of the potential dividers where a screened cable of finite length has to be employed for connection to the oscillograph other errors and distortion of wave shape can also occur.

Measurement of ac and dc impulse current

Measurement of High Voltages and Currents

The devices and instruments for measurement of high voltages and currents differ vastly from the low voltage and low current devices.

MEASUREMENT OF HIGH DIRECT CURRENT VOLTAGES

High voltages can be measured in a variety of ways. Direct measurement of high voltages is possible up to about 200 kV, and several forms of voltmeters have been devised which can be connected directly across the test circuit. High Voltages are also measured by stepping down the voltage by using transformers and potential dividers. The sparkover of sphere gaps and other gaps are also used, especially in the calibration of meters in high voltage measurements. Transient voltages may be recorded through potential dividers and oscilloscopes. Lightning surges may be recorded using the Klydonograph.

Direct Measurement of High Voltages

1 Electrostatic Voltmeters

Principle is used in electrostatic voltmeter?

If the electric field is produced by the voltage V between a pair of parallel plate disc electrodes, the force F on an area A of the electrode, for which the field gradient E is the same across the area and perpendicular to the surface. One of the direct methods of measuring high voltages is by means of electro-static voltmeters. For voltages above 10 kV, generally the attracted disc type of electrostatic voltmeter is used. When two parallel conducting plates (cross section area A and spacing x) are charged q and have a potential difference V, then the energy stored in the is given by It is thus seen that the force of attraction is proportional to the square of the potential difference applied, so that the meter reads the square value (or can be marked to read the rms value). Electrostatic voltmeters of the attracted disc type may be connected across the high voltage circuit directly to measure up to about 200 kV, without the use of any potential divider or other reduction method. [The force in these electrostatic instruments can be used to measure both a.c. and d.c. voltages.

2 Sphere gaps

The sphere gap method of measuring high voltage is the most reliable and is used as the standard for calibration purposes. The breakdown strength of a gas depends on the ionisation of the gas molecules, and on the density of the gas. As such, the breakdown voltage varies with the gap spacing; and for a uniform field gap, a high consistency could be obtained, so that the sphere gap i very useful as a measuring device. By precise experiments, the breakdown voltage variation with gap spacing, for different diameters and distances, have been calculated and represented in charts. In the measuring device, two metal spheres are used, separated by a gas-gap. The potential difference between the spheres is raised until a spark passes between them. The breakdown strength of a gas depends on the size of the spheres, their distance apart and a number of other factors. A spark gap may be used for the determination of the peak value of a voltage wave, and for the checking and calibrating of voltmeters and other voltage measuring devices. The density of the gas (generally air) affects the sparkover voltage for a given gap setting. Thus the correction for any air density change must be made. The air density correction factor The spark over voltage for a given gap setting under the standard conditions (760 torr pressure and at 20oC) must be multiplied by the correction factor to obtain the actual sparkover voltage. The breakdown voltage of the sphere gap is almost independent of humidity of the atmosphere, but the presence of dew on the surface lowers the breakdown voltage and hence invalidates the calibrations. The breakdown voltage characteristic has been determined for similar pairs of spheres (diameters 62.5 mm, 125 mm, 250 mm, 500 mm, 1 m and 2 m) When the gap distance is increased, the uniform field between the spheres becomes distorted, and accuracy falls.

The limits of accuracy are dependant on the ratio of the spacing d to the sphere diameter D, as The breakdown voltage characteristic is also dependant on the polarity of the high voltage sphere in the case of asymmetrical gaps (i.e. gaps where one electrode is at high voltage and the other at a low voltage or earth potential). If both electrodes are at equal high voltage of opposite polarity (i.e. + ½ V and - ½ V), as in a symmetrical gap, then the polarity has no effect. In the case of the asymmetrical gap, there are two breakdown characteristics; one for the positive high voltage and the other for the negative high voltage. Since the breakdown is caused by the flow of electrons, when the high voltage electrode is positive, a higher voltage is generally necessary for breakdown than when the high voltage electrode is negative. However, when the gaps are very far apart, then the positive and the negative characteristics cross over due to various space charge effects. But this occurs well beyond the useful operating region. Under alternating voltage conditions, breakdown will occur corresponding to the lower curve (i.e. in the negative half cycle under normal gap spacings). Thus under normal conditions, the a.c. characteristic is the same as the negative characteristic. In sphere gaps used in measurement, to obtain high accuracy, the minimum clearance to be maintained between the spheres and the neighbouring bodies and the diameter of shafts are also specified, since these also affect the accuracy (figure 6.5). There is also a tolerance specified for the radius of curvature of the spheres. "The length of any diameter shall not differ from the correct value by more than 1% for spheres of diameter up to 100 cm or more than 2% for larger spheres". Peak values of voltages may be measured from 2 kV up to about 2500 kV by means of spheres. One sphere may be earthed with the other being the hig voltage electrode, or both may be supplied with equal positive and negative voltages with respect to earth (symmetrical gap). When spark gaps are to be calibrated using a standard sphere gap, the two gaps should not be connected in parallel. Equivalent spacing should be determined by comparing each gap in turn with a suitable indicating instrument. Needle gaps may also be used in the measurement of voltages up to about 50 kV, but errors are caused by the variation of the sharpness of the needle gaps, and by the corona forming at the points before the gap actually sparks over. Also the effect of the variation of the humidity of the atmosphere on such gaps is much greater. Usually, a resistance is used in series with the sphere gap, of about 1ohm/V sparkover conditions to about a maximum of 1 A. However for impulse measurements, a series resistance must not be used since this causes a large drop across the resistance. In measuring impulse voltages, since the breakdown does not occur at exactly the same value of voltage each time, what is generally specified is the 50 % breakdown value. A number of impulses of the same value is applied and a record is kept of the number of times breakdown occurs, and a histogram is plotted with the peak value of the impulse voltage and the percentage of breakdown. The factors that are influencing the peak voltage measurement using sphere gap are

(i)Nearby earthed objects

(ii)Atmosphere conditions

(iii)Influence of humidity

(iv)Irradiation

(v)Polarity and rise time of voltage waveform

(vi)Switching surge

3 GENERATING VOLTMETER(GVM)

A generating voltmeter is a variable capacitor voltage generator which generates current proportional to the voltage to be measured. It provides loss free measurement of D.C and A.C voltages. It is driven by a synchronous motor and does not absorb power or energy from the voltage measuring source.

Whenever the source loading is not permitted or when direct connection to the high voltage source is to be avoided, the generating principle is employed for the measurement of high voltages, A generating voltmeter is a variable capacitor electrostatic voltage generator which generates current proportional to the voltage to be measured. Similar to electrostatic voltmeter the generating voltmeter provides loss free measurement of d.c.

UNIT-5

HIGH VOLTAGE TESTING

Electrical Insulator Testing | Cause of Insulator failure

To ensure the desired performance of an electrical insulator, that is for avoiding unwanted **insulator failure**, each insulator has to undergo numbers of **insulator test**. Before going through **testing of insulator** we will try to understand different causes of **insulator failure**. Because insulator testing ensures the quality of electrical insulatorand chances for **failure of insulation** depend upon the quality of insulator.

Causes of Insulator Failure

There are different causes due to which **failure of insulation** in electrical power system may occur. Let's have a look on them one by one-

Cracking of Insulator

The porcelain insulator mainly consists of three different materials. The main porcelain body, steel fitting arrangement and cement to fix the steel part with porcelain. Due to changing climate conditions, these different materials in the insulator expand and contract in different rate. These unequal expansion and contraction of porcelain, steel and cement are the chief cause of cracking of insulator.

Defective Insulation Material

If the insulation material used for insulator is defective anywhere, the insulator may have a high chance of being puncher from that place.

Porosity in The Insulation Materials

If the porcelain insulator is manufactured at low temperatures, it will make it porous, and due to this reason it will absorb moisture from air thus its insulation will decrease and leakage current will start to flow through the insulator which will lead to **insulator failure**.

Improper Glazing on Insulator Surface

If the surface of porcelain insulator is not properly glazed, moisture can stick over it. This moisture along with deposited dust on the insulator surface, produces a conducting path. As a result the flash over distance of the insulator is reduced. As the flash over distance is reduced, the chance of failure of insulator due to flash over becomes more.

Flash Over Across Insulator

If flash over occurs, the insulator may be over heated which may ultimately results into shuttering of it.

Mechanical Stresses on Insulator

If an insulator has any weak portion due to manufacturing defect, it may break from that weak portion when mechanical stress is applied on it by its conductor. These are the main causes of insulator failure. Now we will discuss the different **insulator test**procedures to ensure minimum chance of failure of insulation.

Insulator Testing

According to the British Standard, the electrical insulator must undergo the following tests

1. Flashover tests of insulator,

2. Performance tests and

3. Routine tests Let's have a discussion one by one-

Flashover Test

There are mainly three types of flashover test performed on an insulator and these are -

Power Frequency Dry Flashover Test of Insulator

1. First the insulator to be tested is mounted in the manner in which it would be used practically.

2. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator.

3. Now the power frequency voltage is applied and gradually increased up to the specified value. This specified value is below the minimum flashover voltage.

4. This voltage is maintained for one minute and observe that there should not be any flash-over or puncher occurred. The insulator must be capable of sustaining the specified minimum voltage for one minute without flash over.

Power Frequency Wet Flashover Test or Rain Test of Insulator

1. In this test also the insulator to be tested is mounted in the manner in which it would be used practically.

2. Then terminals of variable power frequency voltage source are connected to the both

electrodes of the insulator.
3. After that the insulator is sprayed with water at an angle of 45o in such a manner that its precipitation should not be more 5.08 mm per minute. The resistance of the water used for spraying must be between 9 kΩ 10 11 kΩ per cm3 at normal atmospheric pressure and temperature. In this way we create artificial raining condition.
4. Now the power frequency voltage is applied and gradually increased up to the specified value.
5. This voltage is maintained for either one minute or 30 second as specified and observe that there should not be any flash-over or puncher occurred. The insulator must be capable of sustaining the specified minimum power frequency voltage for specified period without flash over in the said wet condition.

Power Frequency Flashover Voltage test of Insulator

1. The insulator is kept in similar manner of previous test.
2. In this test the applied voltage is gradually increased in similar to that of previous tests.
3. But in that case the voltage when the surroundings air breaks down, is noted.

Impulse Frequency Flashover Voltage Test of Insulator

The overhead outdoor insulator must be capable of sustaining high voltage surges caused by lightning etc. So this must be tested against the high voltage surges.

1. The insulator is kept in similar manner of previous test.
2. Then several hundred thousands Hz very high impulse voltage generator is connected to the insulator.
3. Such a voltage is applied to the insulator and the spark over voltage is noted.

The ratio of this noted voltage to the voltage reading collected from power frequency flashover voltage test is known as impulse ratio of insulator.

This ratio should be approximately 1.4 for pin type insulator and 1.3 for suspension type insulators.

Performance Test of Insulator

Now we will discuss performance test of insulator one by one-

Temperature Cycle Test of Insulator

1. The insulator is first heated in water at 70oC for one hour.

2. Then this insulator immediately cooled in water at 7oC for another one hour. 3. This cycle is repeated for three times. 4. After completion of these three temperature cycles, the insulator is

dried and the glazing of insulator is thoroughly observed.

After this test there should not be any damaged or deterioration in the glaze of the insulator surface.

Puncture Voltage Test of Insulator

1. The insulator is first suspended in an insulating oil.
2. Then voltage of 1.3 times of flash over voltage, is applied to the insulator.

A good insulator should not puncture under this condition.

Porosity Test of Insulator

1. The insulator is first broken into pieces.

2. Then These broken pieces of insulator are immersed in a 0.5 % alcohol solution of fuchsine dye under pressure of about 140.7 kg ⁄ cm2 for 24 hours. 3. After that the sample are removed and examine. The presence of a slight porosity in the material is indicated by a deep penetration of the dye into it.

Mechanical Strength Test of Insulator

1. The insulator is applied by 2½ times the maximum working strength for about one minute.

The insulator must be capable of sustaining this much mechanical stress for one minute without any damage in it.

Routine Test of Insulator

Each of the insulator must undergo the following routine test before they are recommended for using at site.

TESTING ON BUSHING

A transformer bushing is an insulating structure that facilitates the passage of an energized, current-carrying conductor through the grounded tank of the transformer. The conductor may be built in to the bushing, i.e., a bottom-connected bushing, or the bushing may be built with the provision for a separate conductor to be drawn through its centre, a.k.a., a draw-lead or draw-rod bushing.

The two principal types of bushing construction are solid or bulk type and capacitance-graded (sometimes called condenser type). The bushings used for the low voltage winding(s) of a transformer are often solid type with a porcelain or epoxy insulator. Capacitance-graded bushings, designed for higher voltage ratings, are used for a transformer’s high voltage winding.

Unlike a solid type construction, in a capacitance-graded transformer bushing, conducting layers are inserted at predetermined radial intervals within the insulation that separates the centre conductor from the insulator (housing) of the bushing. These multiple conductive inserts create capacitive elements linking the centre conductor of the bushing to ground. Their purpose is to control the voltage field around the center conductor so that the voltage distributes more uniformly across the surrounding insulation system in the bushing.

In solid type bushings, electrical grade mineral oil is often used between the conductor and the insulator, which may be contained within the bushing or shared with the transformer. Typical insulation used in a capacitance-graded bushing is oil-impregnated paper (OIP), resin-impregnated paper (RIP), and resin bonded paper (RBP). Capacitance-graded bushings also use mineral oil, usually contained within the bushing.

Transformer bushing failures are often credited as one of the top causes of transformer failures so the condition of the bushings is of high interest to transformer asset owners. Typical bushing failure modes include moisture ingress, electrical flashover, lightning strike, short-circuited capacitance-graded layer(s), bushing misapplication, corrosive sulphur, broken connection between ground sleeve and flange, and a broken tap connection. The following electrical field tests provide information about the integrity of the bushings.

Bushing diagnosis

- **Tan delta/Power factor/dissipation factor/capacitance (@ line frequency)**; Tan delta/power factor/dissipation factor assesses the integrity of the insulation system of the bushing. C1 and C2 tests should be performed on a capacitance-graded bushing. A C1 power factor/dissipation factor test checks the health of the bushing’s main core insulation, while the C2 measurement is used to assess the bushing tap compartment’s insulation plus the outermost main core insulating wraps and surrounding filler material. Often, C2 serves as early detection for moisture ingress or other contaminants that collect around the flange area because of a deteriorated or faulty top terminal gasket, for example.
- **Capacitance**, which is measured concurrently, assesses the physical integrity of the bushing. An increase in C1 capacitance for example may indicate short-circuited capacitance-graded layers in the bushing, a diagnosis which warrants the bushing’s immediate replacement.

- **Tan delta/power factor/dissipation factor tip-up**; Tan delta/power factor/dissipation factor tip-up (which checks to see whether power factor/dissipation factor changes when the test voltage changes) may be useful in the detection of loose connections or localized defects; may be effective in detecting aging effects when combined with DFR. Ask us how…
- **Variable frequency power factor/dissipation factor (VFPF)**; This test is a collection of power factor/dissipation factor measurements performed across a subset of the frequencies included in a DFR measurement (e.g., 15 – 500 Hz). Conductive contaminants are easily seen at low frequencies (15 Hz and below) while problems such as top terminal looseness and PD inducing type issues may be detected at higher frequencies (500 Hz).
- **Hot collar test**; A hot collar test is used routinely for solid type bushings without taps and is effective in revealing deterioration, contamination, low compound or liquid levels, and voids in the compound (if applicable). It may also be effective as a supplementary test to C1 and C2 tests on capacitance-graded bushings with taps.
- **Dielectric frequency response (DFR)**; In bushing diagnostics, a pronounced temperature dependence (i.e., increased power factor/dissipation factor at high temperatures) is a strong indicator of bushing insulation deterioration. DFR measurements provide the capability of performing individual temperature correction of measured 50/ 60 Hz power factor/dissipation factor at various temperatures to values at a reference temperature (20^{o}C). Comparing this measured temperature dependence with the bushing manufacturer's data for temperature correction will tell if the bushing is good or not. DFR measurements can be used for moisture assessment of bushings.

Bushings are an integral component of high voltage machines. A bushing is used to bring high voltage conductors through the grounded tank or body of the electrical equipment without excessive potential gradients between the conductor and the edge of the hole in the body. The bushing extends into the surface of the oil at one end and the other end is carried above the tank to a height sufficient to prevent breakdown due to surface leakage.

Following tests are carried out on bushings:

(i) Power Factor Test

The bushing is installed as in service or immersed in oil. The high voltage terminal of the bushing is connected to high voltage terminal of the Schering Bridge and the tank or earth portion of the bushing is connected to the detector of the bridge. The capacitance and p.f. of the bushing is measured at different voltages as specified in the relevant specification and the capacitance and p.f. should be within the range specified.

(ii) Impulse Withstand Test

The bushing is subjected to impulse waves of either polarity or magnitude as specified in the standard specification. Five consecutive full waves of standard wave form (1/50 μ sec.) are applied and if two of them cause flash over, the bushing is said to be defective. If only one flash

(iii) Chopped Wave and Switching Surge Test

Chopped wave and switching surge of appropriate duration tests are carried out on high voltage bushings. The procedure is identical to the one given in (ii) above.

(iv) Partial Discharge Test

In order to determine whether there is deterioration or not of the insulation used in the bushing, this test is carried out. The shape of the discharge is an indication of nature and severity of the defect in the bushing. This is considered to be a routine test for High voltage bushings.

(v) Visible Discharge Test at Power Frequency

The test is carried out to ascertain whether the given bushing will give rise to ratio interference or not during operation. The test is carried out in a dark room. The voltage as specified is applied to the bushing (IS 2099). No discharge other than that from the grading rings or arcing horns should be visible.

(vi) Power Frequency Flash Over or Puncture Test

(Under Oil): The bushing is either immersed fully in oil or is installed as in service condition. This test is carried out to ascertain that the internal breakdown strength of the bushing is 15% more than the power frequency momentary dry withstand test value.

TESTING OF ISOLATORS AND CIRCUIT BREAKERS

A **circuit breaker** is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current, typically resulting from an overload or short circuit. Its basic function is to interrupt current flow after a fault is detected. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices that protect low-current circuits or individual household appliance, up to large switchgear designed to protect high voltage circuits feeding an entire city. The generic function of a circuit breaker, RCD or a fuse, as an automatic means of removing power from a faulty system is often abbreviated to ADS (Automatic Disconnection of Supply).

All circuit breaker systems have common features in their operation, but details vary substantially depending on the voltage class, current rating and type of the circuit breaker.

The circuit breaker must firstly detect a fault condition. In small mains and low voltage circuit breakers, this is usually done within the device itself. Typically, the heating and/or magnetic effects of electric current are employed. Circuit breakers for large currents or high voltages are usually arranged with protective relay pilot devices to sense a fault condition and to operate the opening mechanism. These typically require a separate power source, such as a battery, although some high-voltage circuit breakers are self-contained with current transformers, protective relays, and an internal control power source.

Once a fault is detected, the circuit breaker contacts must open to interrupt the circuit; This is commonly done using mechanically stored energy contained within the breaker, such as a spring or compressed air to separate the contacts. Circuit breakers may also use the higher current caused by the fault to separate the contacts, such as thermal expansion or a magnetic field. Small circuit breakers typically have a manual control lever to switch off the load or reset a tripped breaker, while larger units use solenoids to trip the mechanism, and electric motors to restore energy to the springs.

The circuit breaker contacts must carry the load current without excessive heating, and must also withstand the heat of the arc produced when interrupting (opening) the circuit. Contacts are made of copper or copper alloys, silver alloys and other highly conductive materials. Service life of the contacts is limited by the erosion of contact material due to arcing while interrupting the current. Miniature and molded-case circuit breakers are usually discarded when the contacts have worn, but power circuit breakers and high-voltage circuit breakers have replaceable contacts.

When a high current or voltage is interrupted, an arc is generated. The length of the arc is generally proportional to the voltage while the intensity (or heat) is proportional to the current. This arc must be contained, cooled and extinguished in a controlled way, so that the gap between the contacts can again withstand the voltage in the circuit. Different circuit breakers use vacuum, air, insulating gas, or oil as the medium the arc forms in. Different techniques are used to extinguish the arc including:

- Lengthening or deflecting the arc
- Intensive cooling (in jet chambers)
- Division into partial arcs
- Zero point quenching (contacts open at the zero current time crossing of the AC waveform, effectively breaking no load current at the time of opening. The zero crossing occurs at twice the line frequency; i.e., 100 times per second for 50 Hz and 120 times per second for 60 Hz AC.)
- Connecting capacitors in parallel with contacts in DC circuits.

Finally, once the fault condition has been cleared, the contacts must again be closed to restore power to the interrupted circuit.

Short-circuit[edit]

Circuit breakers are rated both by the normal current that they are expected to carry, and the maximum short-circuit current that they can safely interrupt. This latter figure is the **ampere interrupting capacity** (**AIC**) of the breaker.

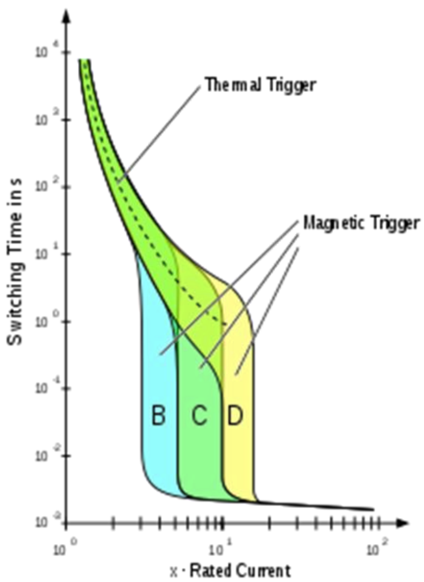
Under short-circuit conditions, the calculated maximum prospective short circuit current may be many times the normal, rated current of the circuit. When electrical contacts open to interrupt a large current, there is a tendency for an arc to form between the opened contacts, which would allow the current to continue. This condition can create conductive ionized gases and molten or vaporized metal, which can cause further continuation of the arc, or creation of additional short circuits, potentially resulting in the explosion of the circuit breaker and the equipment that it is installed in. Therefore, circuit breakers must incorporate various features to divide and extinguish the arc.

The maximum short-circuit current that a breaker can interrupt is determined by testing. Application of a breaker in a circuit with a prospective short-circuit current higher than the breaker's interrupting capacity rating may result in failure of the breaker to safely interrupt a fault. In a worst-case scenario the breaker may successfully interrupt the fault, only to explode when reset.

Typical domestic panel circuit breakers are rated to interrupt 10 kA (10000 A) short-circuit current.

Miniature circuit breakers used to protect control circuits or small appliances may not have sufficient interrupting capacity to use at a panel board; these circuit breakers are called "supplemental circuit protectors" to distinguish them from distribution-type circuit breakers.

Standard current ratings



Time till trip versus current as multiple of nominal current

Circuit breakers are manufactured in standard sizes, using a system of preferred numbers to cover a range of ratings. Miniature circuit breakers have a fixed trip setting; changing the operating current value requires changing the whole circuit breaker. Larger circuit breakers can have adjustable trip settings, allowing standardized elements to be applied but with a setting intended to improve protection. For example, a circuit breaker with a 400 ampere "frame size" might have its overcurrent detection set to operate at only 300 amperes, to protect a feeder cable.

International Standards, IEC 60898-1 and European Standard EN 60898-1, define the *rated current* I_n of a circuit breaker for low voltage distribution applications as the maximum current that the breaker is designed to carry continuously (at an ambient air temperature of 30 °C). The commonly available preferred values for the rated current are 6 A, 10 A, 13 A, 16 A, 20 A, 25 A, 32 A, 40 A, 50 A, 63 A, 80 A, 100 A,[5] and 125 A (similar to the R10 Renard series, but using 6, 13, and 32 instead of 6.3, 12.5, and 31.5 – it includes the 13 A current limit of British BS 1363 sockets). The circuit breaker is labeled with the rated current in amperes, but excluding the unit symbol, A. Instead, the ampere figure is preceded by a letter, *B*, *C*, or *D*, which indicates the *instantaneous tripping current* — that is, the minimum value of current that causes the circuit breaker to trip without intentional time delay (i.e., in less than 100 ms), expressed in terms of I_n

CABLE TESTING

Whether installing new cable, or troubleshooting existing cable, cable testing plays an important role in the process. Common tests for datacom cabling include length, wiremap, attenuation, NEXT, DC loop resistance, and return loss.

As networks evolve, so do the requirements of the cabling infrastructure to support them. New standards are continuously being developed to provide guidelines for cabling professionals when installing, testing, troubleshooting, and certifying either copper and fiber. Whether it's 10BASE-T, 100BASE-TX or 1000BASE-T, there are specific requirements and potential pitfalls in implementing these technologies. With 10GBASE-T, it becomes even more critical to keep current with the latest proliferations in cabling and cable testing.

Cable testing provides a level of assurance that the installed cabling links provide the desired transmission capability to support the data communication desired by the users.

Types of Cable Testers

Cable test instruments are designed with a variety of focused features for particular field tasks. They vary in price, performance, and application. Depending on the task the field test instrument performs, it can be classified into one of the three hierarchical groups: certification, qualification, or verification. While some features overlap between test tools, each group answers a unique testing need and provides a different level of operational assurance.

Levels of Cable Testing

Certification – guarantees cabling system compliance to industry standards

Certification instruments are the only tools that provide "Pass" or "Fail" information in accordance with industry standards. In North America, the prevalent industry standards organization dealing with the transmission capabilities of structured cabling is the Telecommunications Industry Association (TIA). In international markets, the Electro-technical commission of the International Organization for Standards (ISO/IEC) creates and maintains standards for telecommunication cabling.

Certification test tools determine whether a link is compliant with a category (TIA) or class (ISO); for example, category 6 or class E. These standards are independent of specific network technologies. This makes them more "future proof" because new network technologies can emerge that base their designs on these standards and would therefore be supported by the certified installed cabling. Certification is the final step required by many structured cabling manufacturers to grant their warranties for a new cabling installation. The DSX CableAnalyzer™ Series has become the premier certification tester in the market for professional data communication installers, as well as network infrastructure staffs.

Versiv Kit Configurator

How will you be using your Versiv?

Take a Tour

Qualification – determines if an existing cabling link can support certain network speeds and technologies

Qualification testers meet the needs of network technicians who do not install new cabling, but need to troubleshoot operating networks. Qualification testers perform tests that decide whether an existing cabling link will support the requirements for "Fast Ethernet" (100BASE-TX), Voice over Internet Protocol (VoIP), or Gigabit Ethernet. These test tools furthermore allow the network technician to quickly isolate cabling problems from network protocol or addressing problems. Qualification test tools, such as CableIQ™ Qualification Tester, include all the capabilities of verification test tools but they are more powerful in that they perform an assessment of the cabling bandwidth and identify defects that affect the bandwidth. Qualification testers do not execute the battery of tests prescribed by the standards to be considered a "certification tool."

Verification – verifies that cable is connected correctly

Verification test tools perform basic continuity functions, they assure that all wires in a cabling link are connected to the proper termination points and not to any other conductors. In twisted pair cabling, it is critical to maintain the proper pairing of the wires. Better verification test tools also verify wire pairing and detect installation defects like “split pairs”. Verification test tools may also assist in troubleshooting by providing a toner to locate a cabling link. Verification tools sometimes include additional features such as a Time Domain Reflectometer (TDR) to determine length of a cable or distance to a break or short circuit. These test tools do not provide any information on bandwidth or suitability for high-speed data communication.

TESTING OF TRANSFORMER

Testing of Transformers The structure of the circuit equivalent of a practical transformer is developed earlier. The performance parameters of interest can be obtained by solving that circuit for any load conditions. The equivalent circuit parameters are available to the designer of the transformers from the various expressions that he uses for designing the transformers. But for a user these are not available most of the times. Also when a transformer is rewound with different primary and secondary windings the equivalent circuit also changes. In order to get the equivalent circuit parameters test methods are heavily depended upon. From the analysis of the equivalent circuit one can determine the electrical parameters. But if the temperature rise of the transformer is required, then test method is the most dependable one. There are several tests that can be done on the transformer; however a few common ones are discussed here.

The actual loss under load condition will be in error to that extent. Many external means of removal of heat from the transformer in the form of different cooling methods give rise to different values for temperature rise of insulation. Hence these permit different levels of loading for the same transformer. Hence the only sure way of ascertaining the rating is by conducting a load test. It is rather easy to load a transformer of small ratings. As the rating increases it becomes difficult to find a load that can absorb the requisite power and a source to feed the necessary current. As the transformers come in varied transformation ratios, in many cases it becomes extremely difficult to get suitable load impedance. Further, the temperature rise of the transformer is due to the losses that take place ‘inside’ the transformer. The efficiency of the transformer is above 99% even in modest sizes which means 1 percent of power handled by the transformer actually goes to heat up the machine. The remaining 99% of the power has to be dissipated in a load impedance external to the machine. This is very wasteful in terms of energy also. (If the load is of unity power factor) Thus the actual loading of the transformer is seldom resorted to. Equivalent loss methods of loading and ‘Phantom’ loading are commonly used in the case of transformers. The load is applied and held constant till the temperature rise of transformer reaches a steady value. If the final steady temperature rise is lower than the maximum permissible value, then load can be increased else it is decreased. That load current which gives the maximum permissible temperature rise is declared as the nominal or rated load current and the volt amperes are computed using the same.