MAILAM ENGINEERING COLLEGE
Mailam(po),Villupuram(dt.) Pin: 604 304
(Approved by AICTE, New Delhi, Affiliated to Anna University Chennai & Accredited by TCS)
Department of Electrical & Electronics Engineering

SUB CODE / NAME: EE6701/ HIGH VOLTAGE ENGINEERING
YEAR / SEC : IV / A & B

SYLLABUS

UNIT I OVER VOLTAGES IN ELECTRICAL POWER SYSTEMS
Causes of over voltages and its effects on power system – Lightning, switching surges and temporary overvoltages, Corona and its effects – Reflection and Refraction of Travelling waves- Protection against overvoltages.

UNIT II DIELECTRIC BREAKDOWN
Gaseous breakdown in uniform and non-uniform fields – Corona discharges – Vacuum breakdown – Conduction and breakdown in pure and commercial liquids, Maintenance of oil Quality – Breakdown mechanisms in solid and composite dielectrics.

UNIT III GENERATION OF HIGH VOLTAGES AND HIGH CURRENTS
Generation of High DC, AC, impulse voltages and currents - Triggering and control of impulse generators.

UNIT IV MEASUREMENT OF HIGH VOLTAGES AND HIGH CURRENTS
High Resistance with series ammeter – Dividers, Resistance, Capacitance and Mixed dividers - Peak Voltmeter, Generating Voltmeters - Capacitance Voltage Transformers, Electrostatic Voltmeters – Sphere Gaps - High current shunts- Digital techniques in high voltage measurement.

UNIT V HIGH VOLTAGE TESTING & INSULATION COORDINATION
High voltage testing of electrical power apparatus as per International and Indian standards – Power frequency, impulse voltage and DC testing of Insulators, circuit breakers, bushing, isolators and transformers- Insulation Coordination.

TEXT BOOKS:
1. S.Naidu and V. Kamaraju, 'High Voltage Engineering', Tata McGraw Hill, Fifth Edition, 2013.
2. E. Kuffel and W.S. Zaengl, J.Kuffel, 'High voltage Engineering fundamentals', Newnes Second Edition Elsevier , New Delhi, 2005.
3. Subir Ray,' An Introduction to High Voltage Engineering' PHI Learning Private Limited, New Delhi, Second Edition, 2013.

REFERENCES:
1. L.L. Alston, 'High VoltageTechnology', Oxford University Press, First Indian Edition, 2011.
2. C.L.Wadhwa, 'High voltage Engineering', New Age International Publishers, Third Edition, 2010.

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EE6701/ HIGH VOLTAGE ENGINEERING

UNIT-1

TWO MARKS

1) Why protection of transmission line important? **(APR-MAY2011,18)**

It is essential for electrical power engineers to reduce the number of outages and preserve the continuity of service and electric supply.

2) What are the causes of over voltages in electric Power system? **(Dec-11, Dec-14)(OR)What are the various abnormalities in power system?(May 2015)**

- Lightning over voltages
- Switching overvoltages

3) How does switching over voltage originate? **(Dec-2008)**

Switching over voltages originate in the system itself by connection and disconnection of circuit breaker contact or due to initiation or interruption of faults.

4) What is Isokeraunic level or thunderstorm days? **(May-2011, Nov-16,17)**
Isokeraunic level is defined as the number of days in a year when thunder is heard or recorded in particular location.

5) What are the factors that influence the lightning induced voltage on transmission lines? (Nov 2015)

- The ground conductivity
- The leader stroke current
- Corona

6) How is transmission lines classified?

- Lines with no loss or ideal lines
- Line without distortion or distortion less lines
- Line with small losses
- Lines with infinite and finite length defined by all the four parameters

7) What are the principles observed in the lattice diagram?

- All waves travel downhill, i.e., into the positive time.
- The position of the wave at any instant is given by means of the time scale at the left of the lattice diagram
- The total potential at any instant of time is the super position of all the waves which arrive at that point until that instant of time, displaced in position from each other by time intervals equal to the time difference of their arrival/
- Attenuation is included so that the amount by which a wave is reduced is taken care

- The previous history of the wave, if desired can be easily traced. If the computation is to be carried out at a point where the operations cannot be directly placed on the lattice diagram, the arms can be numbered and the quantity can be tabulated and computed.

8) What are the components of switching surges?

Switching surges may include high natural frequencies of the system, damped normal frequency voltage Component or the restriking and recovery voltage of the system with successive reflected waves from terminations.

9) How does switching surges cause damage to circuit breaker? **May-2008**

In circuit breaking operation, switching surges with a high rate of rise of voltage may cause repeated restriking of the arc between the contact of a circuit breaker, thereby causing destruction of the circuit breaker contacts.

10) What are the factors of origin of switching surges? **(NOV-DEC-2012)**

- Open and closing the switch gears
- High natural frequency of the system
- Damped normal frequency voltage components
- Restriking and recovery voltage with successive reflective wave form terminations
- Repeated restriking of the arc between the contacts off

11) Give the factor for over voltages generation in EHV system.

Over voltages are generated in EHV system when there is sudden release of internal energy stored either in the electrostatic form in the electromagnetic form.

12) Give the situation that give rise to switching over voltages of short duration and lower magnitude?

- Single pole closing of circuit breaker
- Interruption of fault current when the L-G or L-L fault is cleared
- Resistance switching used in circuit breakers
- Switching lines terminated by transformer
- Series capacitor compensated lines

13) What are the different method by which switching over voltages of short duration and long magnitude be calculated?

- Mathematical modeling of a system using digital computer
- Scale modeling using transient network analyzers
- By conducting field tests to determine the expected maximum amplitude of the over

voltages and their duration at different points on the line.

14) What are the different measures to control or reduce over voltages?

- One step or multi step energization of lines by preinsertion or resistors
- Phase controlled closing or circuit breakers with proper sensors
- Drainage or trapped charges on long lines before the reclosing of the lines
- Limiting the over voltages by using surge diverter.

15) What are the causes for power frequency and its harmonic over voltages? **(DEC-2013,17)**

- Sudden loss of loads
- Disconnection of inductive loads or connection of capacitive loads
- Ferranti effect, unsymmetrical faults
- Saturation in transformers

16) How are the over voltage of power frequency harmonics and voltage with frequency measure the Operating frequency caused?
These are caused during tap changing operations, by magnetic or Ferro resonance phenomena in large power transformers and by resonating over voltages due to series capacitors with shunt reactors or transformers.

17) What are the methods to control over voltages due to switching?

- Energization of transmission lines in one or more steps by inserting resistance and withdrawing then afterwards
- Phase controlled closing of circuit breakers
- Drainage of trapped charges before reclosing
- Use of shunt reactors
- Limiting switching surges by suitable surge diverters.

18) Give the factor by which over voltages due to lightning strokes can be minimized or avoided in practice.

- Shielding the over head lines by using ground wires above the phase wires
- Using the ground rods and counter poise wires
- Including protective devices like expulsion gaps, protector tubes on the lines and surge diverters at the line terminations and substations

19) . Where is surge arrester placed in substation?

Surge arresters are devices used at substations and at line terminations to discharge the lightning over voltages and short duration switching surges. These are usually mounted at the line end at the nearest point to the substation. They have a flash over voltage lower than that of any other insulation or apparatus at the substation.

20) Define attenuation and distortion?

- The decrease in the magnitude of the wave as it propagates along the line is called attenuation.
- The elongation or change of wave shape that occurs is called distortion.

21)Define lightning phenomenon? **NOV-DEC 2012**

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

22) What is counterpoise wire/give it is uses? **NOV-DEC 2012**

Counter- Poise Wires are buried in the ground at a depth of 0.5 to 1m, running parallel to the transmission line conductors and connected to the tower legs. Wire length may be 50 to 100 m long.

23) Mention the different kinds of over voltages?(**MAY-JUNE 2013**)

Different kinds of over voltages

External or Lightning voltage

Internal overvoltage's

Switching surges

Insulation Failure

Arcing ground

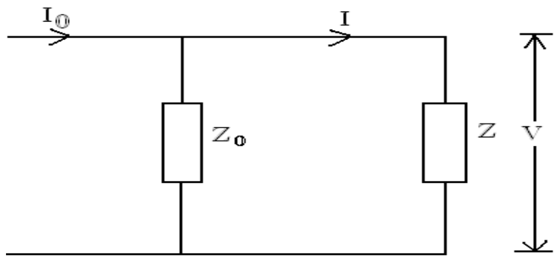
Resonance

Harmonics

24) What is stepped leader stroke? (**MAY-JUNE 2013**)

A lightning stroke begins with a faint predischarge, called the leader, which goes from the cloud to the ground. The leader establishes a path for the highly luminous return stroke (what you really see) which propagates from the ground up to the cloud. The first stroke of a flash is usually preceded by a "stepped leader", so called because it appears to progress in discrete steps (about 100 segments, each 50 m long) from cloud to ground.

25) Draw the mathematical model for lightning discharges**.(May-2014,18)**



$$I_o - lightingstrokecurrent$$
$$Z_o - sourceimpedance$$
$$Z - objectimpedance\ (surgeimpedance)$$
$$V = IZ$$
$$= I_0 \left(\frac{Z_0}{Z_0 + z}\right) Z$$
$$= I_0 \left(\frac{Z}{1 + \frac{Z}{Z_0}}\right)$$

26) Classify the lightning strokes.**(May-2014)**

Direct lightning strokes
In direct lightning strokes

27) What is Bewley Lattice Diagram?**(Dec-14)**

This is a graphical representation of the time-space relation,which shows the position and direction of motion at any instant of incident,reflected and transmitted current or voltage surges.in the Lattice Diagram, the horizontal axes represent the distance travelled along the system and vertical axis represent the time taken to travel. At each instant of change in impedance, the reflected and transmitted values (current or voltage) can be calculated my multiplying incident wave values with reflected and transmitted coefficients.

28)Why the simple spark gap cannot offer full protection against over voltage?(NOV 2015)

- The major disadvantagethat it does not satisfy one of the basic requirements of a lightning arrester *i.e.*, it doesnot interrupt the power frequency follow current. This means that every operation of the spark gap resultsin a*L-G* fault and the breakers must operate to de-energize the circuit to clear the flashover. The spark gap, therefore, is generally used as back up protection.
- The spark over voltage depends on atmospheric condition
- without series resistance with spark gap creates step voltage when current zero.

29.What are the characteristics of lightning strokes?(May 2015)

The characteristics of lightning are include the amplitude of current, rate of rise, probability of distribution of current and wave shapes of lightning voltage and current.

1. The lightning strokes are predominantly of negative polarity. However the surges on transmission lines can be negative as well as positive polarity depending on whether they are caused by direct lightning strokes or by induction.

2.The percentage of positive to total surges reported are :strokes to transmission line 18% distribution lightning arrester surges 37%,station lightning arrester 12%.

3.The total duration of lightning strokes may be about one second or so.

4.The peak current in the stroke may be from 1 KA to 200 KA.

5.Time to first peak is between 0 and 10 µS. The time to half wave on the tail between 5 and 90 µS

6.Field data indicates that very high stroke current do not coincide with very short time to crest. About 50 % of stroke currents have a rate of rise exceeding 7.5 KA/ µS and 10 % exceed 25 KA/ µS.

30. what is back flashover? Nov-16.

When a direct lightning stroke occurs on a tower, the tower has to carry huge impulse currents. If the tower footing resistance is considerable, the potential of the tower rises to a large value, steeply with respect to the line and consequently a flashover may take place along the insulator strings. This is known as back flashover.

31.Define Corona Critical Disruptive Voltage.May-2017

Critical Disruptive Voltage is defined as the minimum phase to neutral voltage required for the Corona discharge to start.

32.What are the different method employed for protection of overhead lines against lightning? May-17

i.Shielding the overhead lines by using ground wires above the phase wires.

ii.Using ground rods and counter-poise wire

iii.Protected device like expulsion gap, protector tubes on the line and surge diverters at line termination and substations.

PART-B

1) Explain briefly internal Causes of over voltage and its effect on power system? Dec-2008

The over voltage causes may be broadly divided in to two main categories:

i) INTERNAL OVER VOLTAGES CAUSES
   - Switching surges.
   - Insulation Failure.
   - Arcing Ground.
   - Resonance.

ii) EXTERNALOVER VOLTAGES CAUSES

- Lightning.

INTERNAL CAUSES OF OVER VOLTAGE:

Internal causes of over voltage on the power system are primarily due to oscillations set up by the sudden changes in the circuit conditions.

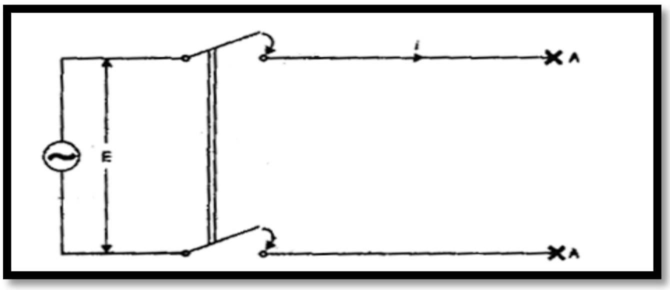
a) Switching surges:

The over voltage, produced on the power system due to switching operations are known as switching surges. the few causes will be discussed here.

- Case of open line
- Case of loaded line
- Current chopping

i)Case of open line:

- During switching operations of unloaded line, travelling waves are set up to produce over voltage on the line. When the unloaded line is connected to the voltage source a voltage wave is setup which travels along the line.



- On reaching the terminal point A it's reflected back to the supply end without change of sign. This causes voltage doubling. If E RMS is the supply voltage, then the instantaneous voltage that the lines have to with stand will be $2\sqrt{2}$ E.This over voltage is of temporary in nature.

ii) Case of loaded Line:

- Over voltage will also be produce during switching operations of a loaded line. suppose a loaded line is suddenly interrupted across the switch the voltage range is 2ZI

  Where

  I-Instantaneous value of current at the time of opening of line
  Z-Natural impedance of the line.

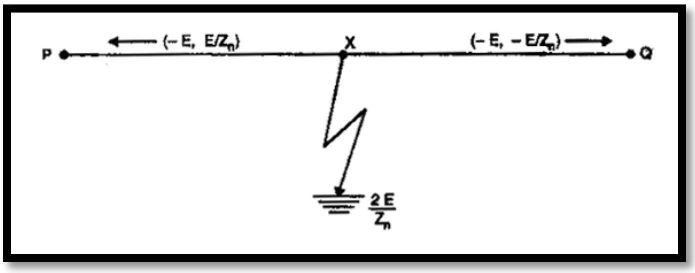
iii) Current chopping:

- Current chopping results in the production of high voltage transients across the contacts of the air-blast circuit breaker. when breaking low currents with air-blast breaker, the powerful de-ionizing effects of air-blast causes the current to fall abruptly to zero will before the nature current zero is reached

- This phenomenon is called current chopping and produces high voltage across breaker contacts this current chopping are prevented by resistance switching.

b) Insulation Failure:

- The most case of insulation failure in a power system is grounding of conductor (insulation failure between line and earth) which may cause over voltage in the system.



- Suppose a line at potential E is earthed at point X.the earthling of the line cause two equal voltage of-E to travel along XQ and XP containing currents.-E/Z_n and + E/Z_n respectively. Both these current pass through X to earth. So that current to earth is $2E/Z_n$.

c) Arcing ground:

- The phenomenon of intermittent is taking place inline-to-ground fault of a three phase system with consequent productions transients is known as arcing ground.

d) Resonance:

- Resonance in an electrical system occurs when inductive reactance of the circuit becomes equal to the capacitive reactance. Under resonance the impedance of the circuit and the power factor is unity.

2) ***Explain briefly various charge formation theory and also explain briefly lightning mechanism?***

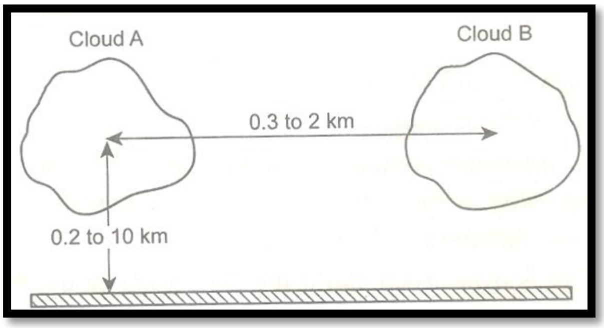
NOV-DEC 2012,17, NOV-DEC 2013,MAY-17,18

Lightning Phenomenon:

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

Charge formation in the clouds:

During thunderstorms, positive and negative charges become separated by the heavy air currents with ice crystals in the upper part and rain in the lower part of the cloud. this charge separation depends on the height of the clouds which range from 0.2 to 10 k.m with their charge centers probably at a distance of about 0.35 to 2 K.m as shown in fig.



Charge inside the clouds - 1 to 100 coulomb

Potential of the cloud - 10^7 to10^8 Volt

Energy associated with the cloud - 250kwhr

The upper region of the clouds are usually positively charged where as lower region of the clouds are negative charged except the local region near the base and head which is positive as shown in fig.

Fair weather conditions - Max.gradient=1V/Cm.

Bad weather conditions - Maximum gradient reached.

At the ground level due to charged cloud - 300V/Cm.

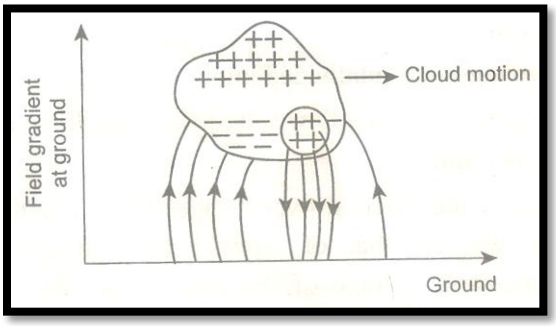
Charge Distribution Theory:

- Willson's theory of charge separations
- Simpson's theory
- Reynold and mason theory

i) Will son's theory:

Willson's theory based on the following assumption

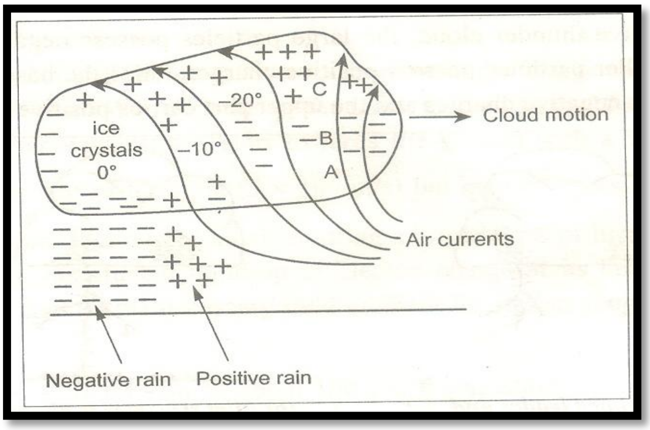
- ✓ Large Number of ions present in the atmosphere.
- ✓ Many of the these ions attach themselves to small dust particles and water particles
- ✓ Electric field exists in the earth atmosphere during fair weather which is directed downwards towards the earth.
- ✓ Subsequently the lower part of the drop attracts negative charges from the atmosphere and leaving positive charges in the air.



- ✓ Thus this theory says since large negatively charged drops settle on the base of the cloud and smaller positively charged settle on the upper direction of the clouds.

ii)Simpson's Theory:

The Simpson's theory explained with help of following regions shown in below figure.



Below Region A:

Air current travels above 800Cm/Sec and no rain drops fall through.

In Region A:

Air velocity is high enough to break the falling rain drops causing a positive charge sprays in the cloud and negative charge in the air.

The spray is blown upwards but as the velocity of air decreases, the positively charged water drops recombine with the large drops and fall again.

In Region B:

It becomes negatively charged by the air current.

In Region C:

The temperature is low (below freezing point) and only ice crystals exist. the impact of air on these crystals makes them negatively charged.

iii) Reynold and Mason Theory:

Thunder clouds are developed at heights of 1to 2 k.m above the ground level. And may extend upto 12 to 14 km above the ground

Air currents, moisture, specific temperature range are required for thunder clouds and charge formations.

The air current controlled by the temperature gradient move upwards carry moisture and water droplets below -40°C (above 12 Km).

The water droplets in the cloud are blown up by air currents and get super cooled over a range of height and temperature. When such freezing occurs the crystals grow in to large masses. Due to weight and gravitational force it falls downwards.

3. Discuss about the mechanism of lightning Strokes: **May-2008, May-2012 ,NOV-DEC 2013,16,17.**

The cloud and the ground form two plates of capacitor and dielectric medium is air. Since the lower part of the cloud is negatively charged the earth is positively charged by inductions.

Lightning discharge will require for break down the Air

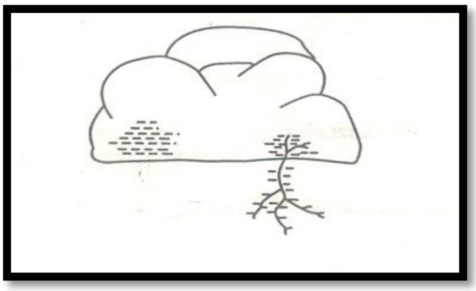
- ✓ Electric field required is 30 kv/Cm (peak)
- ✓ Electric field required is 10 Kv/cm(If the moisture content of the air is large)

Type of lightning streamer:

- ✓ Pilot streamer
- ✓ Stepped Leader
- ✓ Return Stroke
- ✓ Second Charge center
- ✓ Dart leader
- ✓ Heavy return Streamer

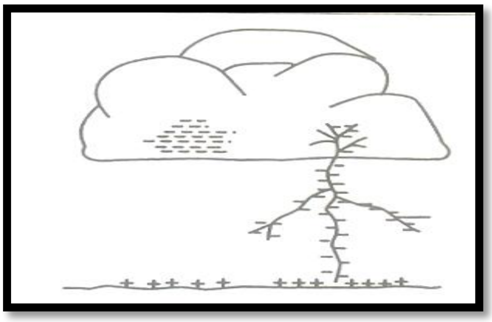
Pilot Streamer:

After the gradient of approximately 10Kv.cm is set up in the clouds the air surrounding gets ionized.In this condition a streamer starts from clouds towards earth. The current in the streamer is 100 A. and speed is 0.16m/μ Sec.This streamer is known as pilot streamer. This leads to the lighting phenomenon.



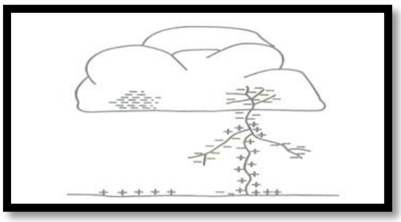
Stepped Leader:

Depending upon the state of ionization of the air surrounding the streamer it’s branched to several paths and this is known as stepped leader.



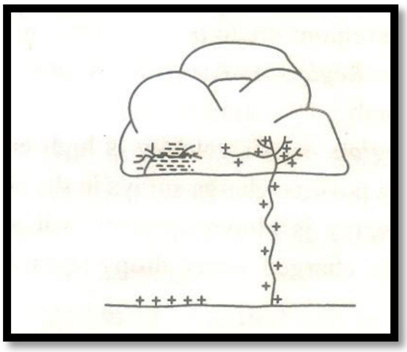
Return Stroke:

Once stepped layer contact with earth a power return stroke moves very fast up towards the clouds through the already ionized path by the leader.



Second charge center:

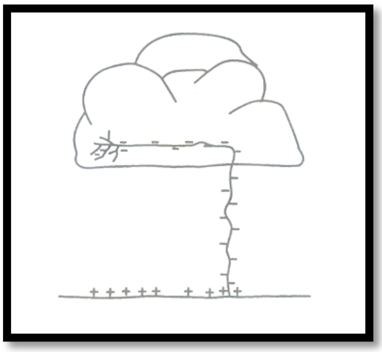
Negative charge of the cloud is being neutralized by the positive induced charge on the earth. this instant gives rise to lighting flash which we observes with our naked eyes. There may be another cell of charges in the cloud near the neutralize charged cell



Dart Leader:

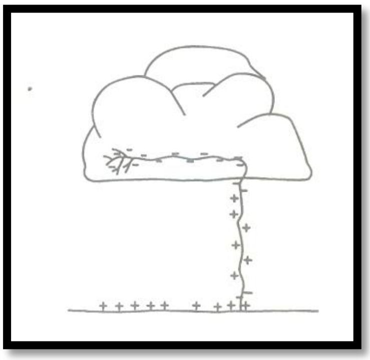
This charged cell will try to neutralize through this ionized path. This streamer is known as dart leader.

The velocity of dart leaderisabout3 % of the velocity of light. The effect of the dart leader is much more severe that of the return stroke.



Heavy return stroke:

The second charge center is discharging to ground through the dart leader. positive streamers are going up from ground. This is called heavy return stroke. This begins to discharge negative charge under the cloud and the second charge center in the cloud.



Rate of charging of thunder clouds

Let λ - conductivity of the medium
E - Electric field intensity
V - Velocity of separation of charges.
ρ - Charge density. Electric field intensity E is given by

$$\frac{dE}{dt} + \lambda E = \rho v$$

Solution of the equations is

$$E = \int \rho v dt + c$$

Multiply $e^{\lambda t}$ on both sides

$$Ee^{\lambda t} = \int \rho v e^{\lambda t} dt + c$$

$$Ee^{\lambda t} = \frac{\rho v}{\lambda} e^{\lambda t} + c$$

$$E = \frac{\rho v}{\lambda} + ce^{-\lambda t}$$

…………………………………………………(1)

To find c, substitute E=0;t=0; in equation (1)

$$0 = \frac{\rho v}{\lambda} + c$$

$$c = -\frac{\rho v}{\lambda}$$

$$\therefore E = \frac{\rho v}{\lambda} - \frac{\rho v}{\lambda} e^{\lambda t}$$

$$E = \frac{\rho v}{\lambda}\left(1 - e^{-\lambda t}\right)$$

Let Q_s = separated charges; Q_g=generated charge

$$\rho = \frac{charge}{Area} = \frac{Q_g}{Ah}$$

Where A-cloud area ,h-height of the charged region.

$$E = \frac{Q_s}{A\varepsilon 0}$$

Where $\varepsilon 0 - permittivittyofthemedium$

$$A = \frac{Q_s}{\varepsilon 0 E}$$

$$Q_{g=}\rho Ah = \rho \frac{Q_s}{\varepsilon 0 E} h$$

$$= \frac{\rho Q_s h}{\varepsilon o \frac{\rho v}{\lambda}\left(1 - e^{-\lambda t}\right)}$$

$$Q_g = \frac{Q_s \boldsymbol{h}}{\varepsilon o \frac{v}{\lambda}\left(1 - e^{-\lambda t}\right)}$$

4) Write shorts on Switching Surges and temporary overvoltage?(NOV-DEC 2011),(NOV-DEC 2013)(NOV **2015)**

For transmission voltages (400 Kv and above) the advantages generated due to switching is same as that of the magnitude of lightning over voltages. This over voltages exists for a long time so it's dangerous to the system.

Switching over voltages increases as the system voltage increases. In extra high voltage line, switching over voltages determine the insulation levels of the lines and their dimensional and cost.

Source (or) Origin of switching surges:

- Open and closing the switch gears
- High natural frequency of the system
- Damped normal frequency voltage components
- Restriking and recovery voltage with successive reflective wave form terminations
- Repeated restriking of the arc between the contacts off

Characteristics of switching surges:

Switching surges arise from any one of the following sources.

- De energizing of lines, cables, and shunt capacitor bank etc.
- Disconnection of unloaded transformer, reactors etc
- Opening and closing of protective devices connected to lines and reactive loads
- Switch off the loads suddenly
- Short circuit due to insulation failure, line to ground contact, line to line contact, L-L-G contacts, three phase to ground contacts etc
- Clearing of the faults
- Arcing ground.

Shape of switching surges:

Irregular

Power frequency with its harmonics

Relative magnitude-2.4 p.u for transformer energizing

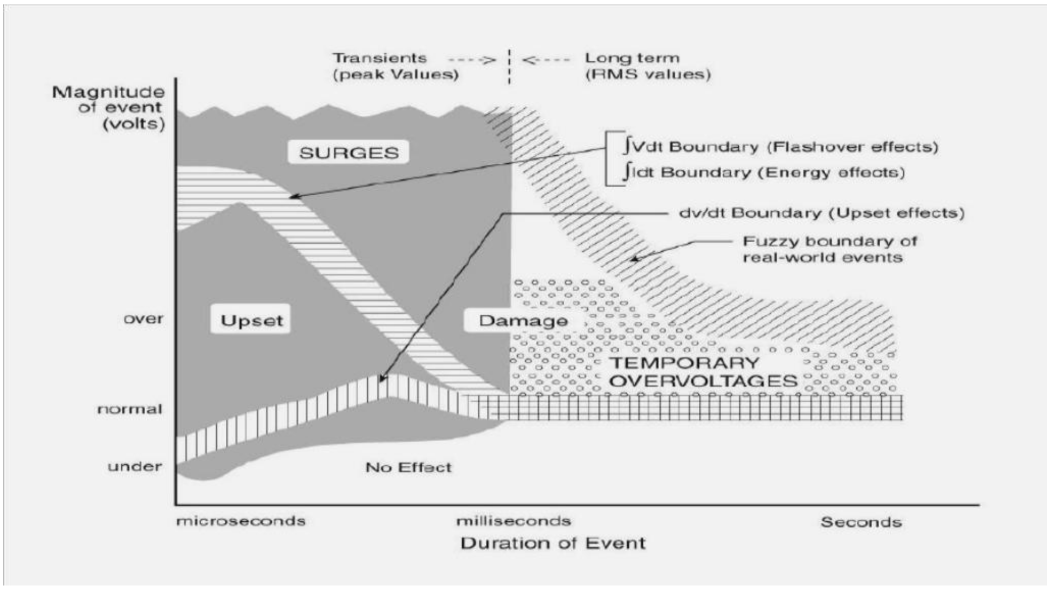
1.4 to 2.0 p.u for switching transmission line.

Switching overvoltage in EHV and UHV system

Switching over voltages in EHV and UHV systems are generated when a sudden release of internal energy stored due to electrostatic or electromagnetic form. This may happen due to

- Interruption of low inductive currents by high speed circuit breakers
- Interruption of small capacitive currents by switching off the unloaded line
- Ferro-resonance conditions
- Energization of long EHV or UHV lines
- Interruption of fault current when the fault is cleared
- Single pole closing circuit breakers
- Switching operations of series capacitor connected to line for compensation
- Sparking of the lightning arrester located at receiving end of line.

Temporary over voltage



Temporary over voltages represent a threat to equipment as well as to any surge protective devices that may have been provided for the mitigation of surges.
The scope of this Guide includes temporary over voltages only as a threat to the survival of SPDs(surge protection devices), and therefore includes considerations on the selection of suitable SPDs.
Following considerations are necessary to reach the goal of practical surge immunity:

Desired protection
Hardware integrity
Process immunity
Specific equipment sensitivities
The power environment
Surge characteristics
Electrical system
Performance of surge protective devices
Protection
Lifetime
The test environment
Cost effectiveness

<u>Measure to control overvoltage due to switching and power frequency</u> **NOV-DEC 2013(NOV 2015)**

In EHV or UHV lines we should control the switching voltages less than 2.5 p.u the following measures are taken to reduce over voltage.

- One or multi-step energization of lines by inserting resistors.
- Phase controlled closing of circuit breaker with proper sensors.
- Drain the trapped charges before reclosing of the lines
- Using shunt reactors
- By using lightning arresters or surge diverters

<u>One or multistep energization of lines by inserting resisters</u>

- During switching of circuit breaker, inserting a series resistance in series with circuit breaker contacts and short circuiting this resistance after a few cycles
- By using inserting resistance the transients due to switching reduces. If the resistance is inserted for a long time, successive reflections takes place and the over voltage reaches high value. therefore using the pre-inserting resistor limit the over voltage

Phase controlled closing of circuit breakers

- Life of the circuit breaker only depends on the no. Of. Time open and close of the contacts. Over voltage can be avoided by closing three phase exactly at the same instant by using phase controlled technique.

Drain and trapped charges before reclosing the lines

- If transmission line is suddenly closed or switched off the electric charge will be stored on capacitor and line conductors.
- These charges are drained by line insulator or through potential transformer.
- But the effective method is connecting temporary inserting to ground before re closure and removing before closure of switching or circuit breaker.

Using shunt reactors:

- Shunt reactors are used to limit voltage rise due to Ferranti effect in EHV lines and reduce surges due to sudden switching.
- But it will give oscillation with the capacitance of the system using connecting resistors are in series with reactors suppress the oscillation and limit over voltage.

5) Write short notes on Power frequency over voltage in power system? (NOV-DEC 2012, MAY-2013)OR

What are the causes for switching and power frequency over voltage ?how are they controlled in power system? NOV-DEC 2013,MAY-2014,MAY-17

In the lines (400 Kv and above) power frequency over voltages occurs arecaused during tap changing operations in transformer.

- Causes for power frequency over voltages;
- Sudden load rejection
- Disconnection of inductive loads
- Ferranti effect
- Unsymmetrical faults
- Saturation in transformer etc.
- Tap changing operations.

Sudden load rejections:

When sudden load rejection in the system cause the speeding up of generator prime movers hence the system frequency will raise.

The speed governing system will respond by reducing the mechanical power generated by the turbines. But initially both the frequency and voltage increases.

The approximate voltage rise is given by

$$v = \frac{f}{fo}E'\left[\left(1 - \frac{f}{fo}\right)\frac{x_s}{x_c}\right]$$

Where

x_s - Reactance of the generator
x_c - Capacitive reactance
E' - Voltage generated before over operating and load rejections.
f - Increased frequency.
fo - normal frequency.

Disconnection of inductive loads or connection of capacitive loads:

- For improving voltage in transmission lines, inductive loads disconnected or capacitive loads are added due to these switching operations, power frequency over voltages may occur.

Ferranti effect:

- The receiving end voltage greater than the sending end voltage during light load or no load operation. Due to Ferranti effect the power frequency over voltage may occurs. Shunt reactors are used to limit voltage rise due to Ferranti effect in EHV lines.

Un symmetrical faults:

- Unsymmetrical faults are single line to ground fault, line to line fault, double line to ground fault. Consider a single line to ground fault occurs at phase ‘a’ v_a=0

Voltage at healthy phases b and c increases for solidly grounded system

$$\frac{X_o}{X_1} \leq 3 \; and \; \frac{R_o}{X_1} \leq 1$$

Where

X_o - zero sequence reactance
R_o - Zero sequence resistance
X_1 - Positive sequence reactance
Rise in voltage $\ngtr 1.4\, p.u$

Saturation transformer:

- When voltage applied to the transformer is more than the rated value or saturation value magnetizing currents increases rapidly. This current produces harmonics due to harmonics produces over voltages.

Tap changing transformer:

- Tap changing operations are required when the voltages changes due to load variations so during these operations power frequency over voltages occurs.

***6)(i)Explain the various methods of Protection against over voltages in OHT lines?*(NOV-DEC-2011, MAY-2013,DEC-2013, 16,17)**

What are the requirements of ground wire for protecting power conductor against direct lightning stroke? Explain how they are achieved in practice.(MAY-JUNE-2014,18)

Types of faults that may occur in power lines

Symmetrical faults

- Three fault(LLLG)

Unsymmetrical faults

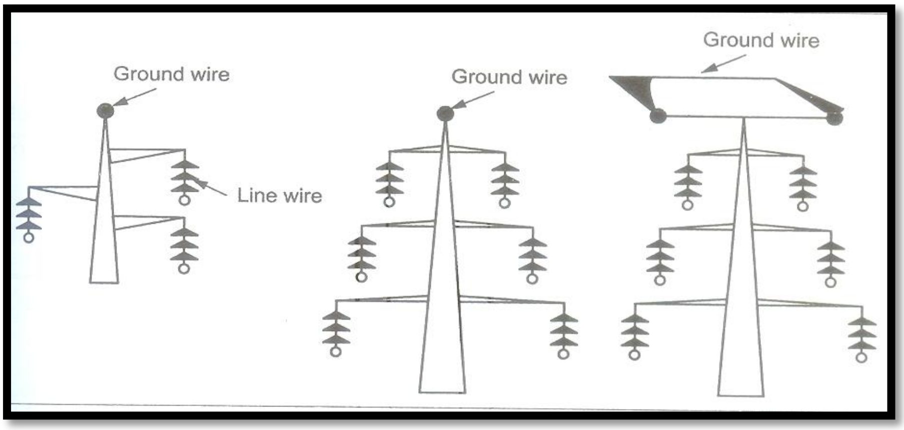
- L-G fault
- L-L fault
- L-L-G fault

Protection of equipments in the power system from over voltages due to lightning can done by:

- Using ground wires above the phase wires.
- Using ground rods.
- Using counter-poise wires.
- Using protective devices like rod gap, expulsion type and valve type surge arrester, etc.

Ground wires:

Ground wire is a conductor run parallel to the main conductor of the transmission line, supported on the same tower and earthed at every equally and regularly spaced towers. The different arrangement of ground wires is as shown in below fig.

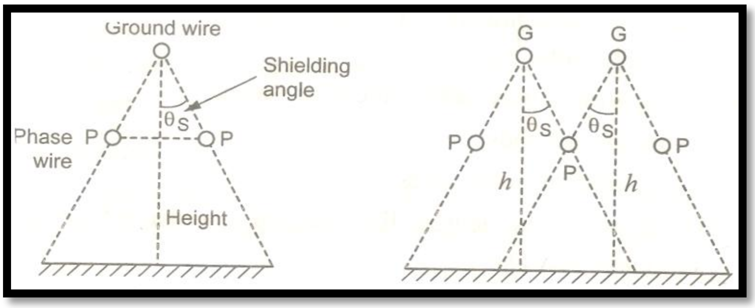


Important considerations of ground wires are:

- Ground wire selection should be based on mechanical considerations rather than electrical considerations.
- It should have high strength and non – corrosive.
- Ground resistance, insulation and clearances between the ground wire and the lines are important in the design.

Shielding angle or Protection angle θ_s **:**

The angle between the vertical line drawn through the vertical of tower and a line through the ground wire and the shielded conductor is as shown below.



Protection of Line Using Ground Wire

Assuming positively charged cloud is present above the line , it induces a negative charge near the line conductors and ground wire. Ground Wire is earthed at regular intervals , so that the negative charges drained to the Earth. As the ground wire is nearer to the line conductor , the induced charged on it will be much less and the potential rise is small.

A single ground wire reduces the induced voltage to one half of that without ground wire. For two ground wires, the reduction is one third of that without ground wire.

Effective protection depends on :

- h (height)
- $\theta_{s\text{ (shielding angle)}} = 30°$

Material used : Galvanized stranded steel conductors.

Uses

- It is used for direct stroke protection of lines for voltage of 110 KV and above.
- To protect lines from attenuation of travelling waves set up in the lines.

Using ground rods

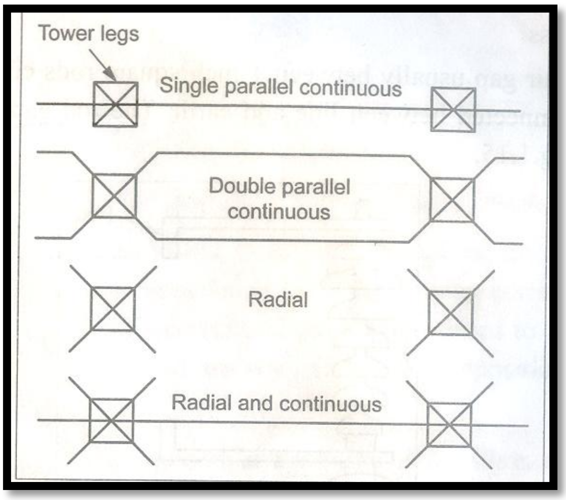
Ground rods are used to reduce the tower footing resistance. These are buried into the ground surrounding the tower structure.
Ground rods are a number of rods about 15 mm diameter and 3 m long driven into the ground. The tower footing resistance can be varied by :

- Varying the space of the rod.
- Varying the number of rods.
- Varying the depth to which they are driven.

Material used: Galvanized iron or copper bearing steel.

Using Counter – Poise Wires

Counter- Poise Wires are buried in the ground at a depth of 0.5 to 1m, running parallel to the transmission line conductors and connected to the tower legs. Wire length may be 50 to 100 m long. The arrangement of counter – poise is as shown.



- ✓ When the lightning stroke, incident on the tower, discharges first through the tower to the ground and discharges through the counter – poise. For proper operation.
- ✓ Leakage resistance of counter poise< Surge impedance
- ✓ If lightning strikes a tower, current is injected and potential rises and flash over of insulator disc takes which results in a L.G faults. So the tower footing resistance value should be low.

Material used: Galvanized steel wire.

6)(ii)Basic Requirements of a Lightning Arrester or Surge Diverter and Explain its operation with V-I characteristics(MAY-2014)

Using Protective Devices

Protective devices are used to protect the power system components against the travelling waves caused by lightning.

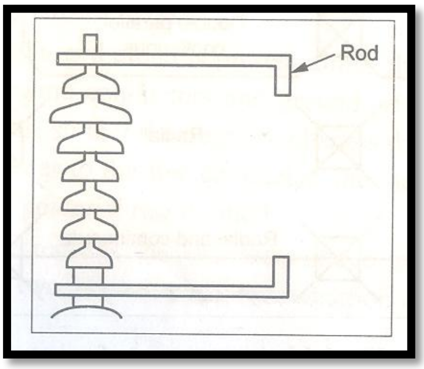
The basic Requirements of a Lightning Arrester are :

- ➢ It should not pass any current to the system component which is to be protected at abnormal conditions.
- ➢ It should break down as quickly as possible when abnormal condition occurs.
- ➢ It should discharge the surge current without damaging it.
- ➢ It should interrupt the power frequency follow current after the surge is discharge to ground.

Rod Gap(Nov 2015) 6 mark

Rod Gap is used to protect the system from lightning or thunderstorm activity is less.

A plain air gap usually between 1 inch square rods cut at right angles at the ends, connected between line and earth. The rod gap arrangement is shown.



Advantages

- Simple in construction.
- Cheap.
- Rugged construction.

Disadvantages

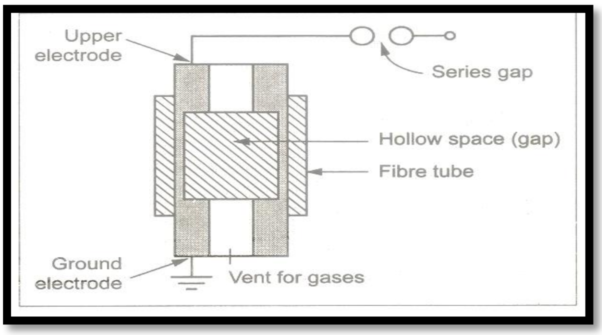
- It does not interrupt the power frequency follow current.
- Every operation of the rod gap results in L –G fault and the breakers must operate to isolate the faulty section.

Uses

- It is used as back – up protection.

Expulsion Type Lightning Arrester (Protector Tube)-MAY-17

- It is a device consists of a spark gap together with an arc quenching device which extinguishes the current arc when the gaps break over due to over voltages. The expulsion type lightning arrester is shown below.



- When lightning incidents, the series gap and the gap in the tube spark and provide low impedance path for power current to flow. The voltage across the terminals of the arrester drops to a low value after spark over occurs and arrester exerts little opposition to the flow of follow current.

The arc struck in the tube volatizes some of the fiber and emitting gas. This gas rushes out through the vent and is interruption takes place at zero current.

Advantages

- Cheap
- To protect small rural transformers where value type arresters are expensive.

Disadvantages

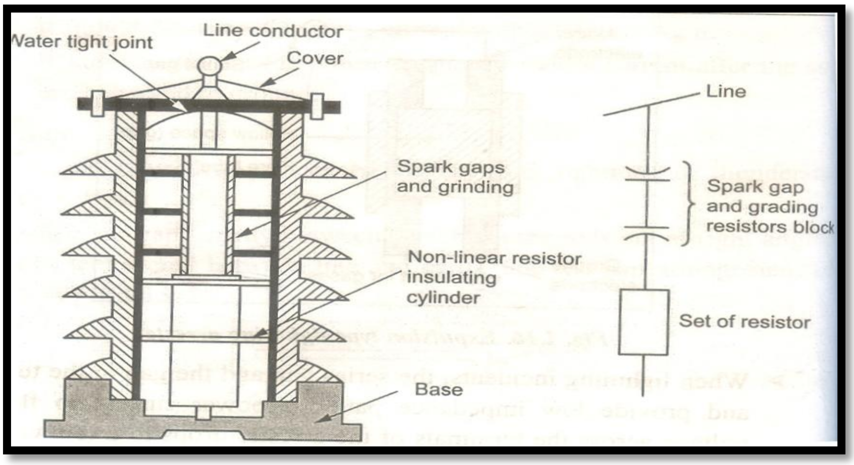
- It is not suitable for protection of expensive station equipment because of poor volt – time characteristics.

Uses

- To protect transmission line insulators(transmission line type)
- To protect distribution transformer(distribution type)

Value Type Lightning Arrester (Non – Linear Type)

Value Type Lightning Arresters are used to protect substations and at line terminations to discharge the lightning over voltages and short duration switching surges. A value type arrester is shown below.



A number of non – linear resistor elements made of silicon carbide and stacked one over the other into two or three sections. They are separated by spark gaps. Spark gaps and resistors are protected by water tight housing. Non – linear resistor possess low resistance to high currents and high resistance to low currents.

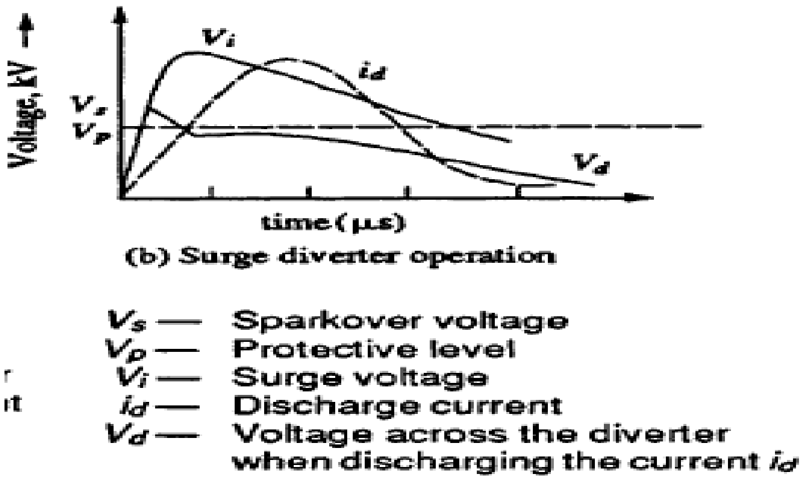
Volt – ampere characteristics is given by ,

$$I = K V^n$$

Where

I=discharge current
N=valve lies between 2 and 6
K=constant
V=applied voltage across the elements.

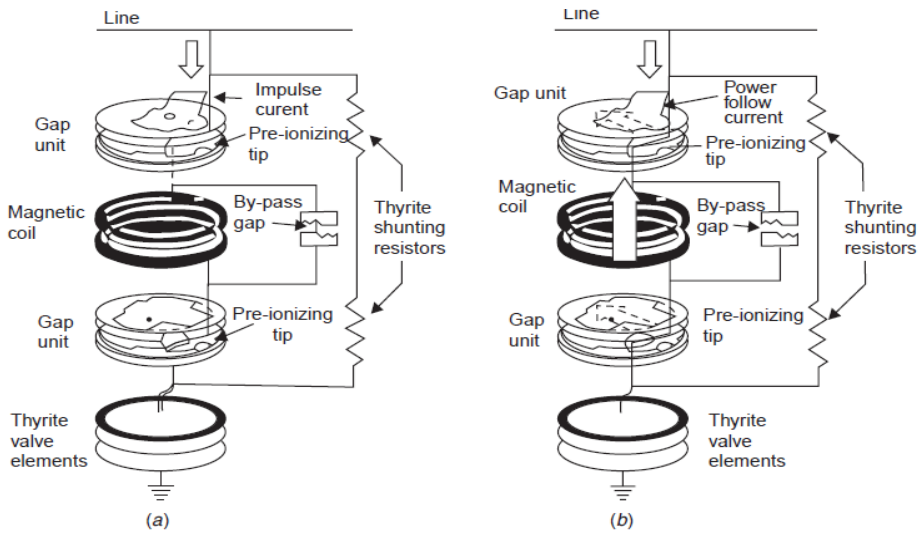
As over voltage occurs due to lighting the resistance of the non-linear element decreases series gap sparks and the arrester discharges. If the current is more, number of series resistance can be added.



(b) Surge diverter operation

operation:

- When a surge voltage is applied to the surge arrester, it breaks down giving the discharge current i_d and maintains a voltage V_d across it. Thus it provides a protection to the protected above the protective level V_p.
- In heavy duty surge arrester the gaps are arranged that the arc burns in the magnetic field of the coils excited by power frequency follow on current.
- During lightning discharges, a high voltage is induced in the coil by steep front of surges and sparking occurs in the auxiliary gap.
- For power frequency follow on currents the auxiliary gap is extinguished, as sufficient voltage will not be present across the auxillary gap to maintain an arc.
- The main gap arcs occur in the magnetic field of coils.
- The magnetic field aided by the horn shaped main gap electrodes, elongate the arc and quenches it rapidly. The follow on current is limited by the voltage drop across the arc and the resistance element.



Schematic diagram of valve-type arrester indicating path of (a) Surge current, (b) Follow current.

Merits:

- To protect station equipment rated 400 KV and above.
- To protect motors and generators
- To protect distribution transformer.

7) Explain step by step procedure to draw (OR) constructing Bewley's lattice diagram?(MAY-2014)

Obtain the expression of reflected and transmission of travelling waves at transmission points (Dec-2014)

Bewley lattice diagram from which the motion of reflected and transmitted waves and their positions at every instant can be obtained. It overcomes the difficulty of keeping track of the multiplicity of successive reflections at the various junctions.

Procedure to draw lattice diagram:

- When a voltage surge of magnitude unity reaches a junction between two sections with surge impedance Z_1 and Z_2
- Then a part 'a' is reflected and a part 'b' is reflected back. In traversing the second line, on reaching the termination at the end of second line, its amplitude=α.b
- Set the ends of the lines at intervals equal to the time of transit of each line.
- If a suitable time scale is chosen, then the diagonals on the lattice diagram show the passage of the waves.

Properties of Bewley Diagram:

- The following are the properties of Bewley lattice diagram,
- All waves travel downhill, because time always increases.
- The positions of any wave at any time can be deduced directly from the diagram.

- The total potential at any instant of time is the superposition of all waves which arrive at the point until the instant of time, displaced in position from each other by time intervals equal to the time difference of their arrival.
- Attenuation is included so that the wave arriving at the far end of the line corresponding to the value entering multiplied by the attenuation factor

<u>Open ended transmission line of surge impedance Z:</u>

$$Z_1 = Z, Z_2 = \infty$$

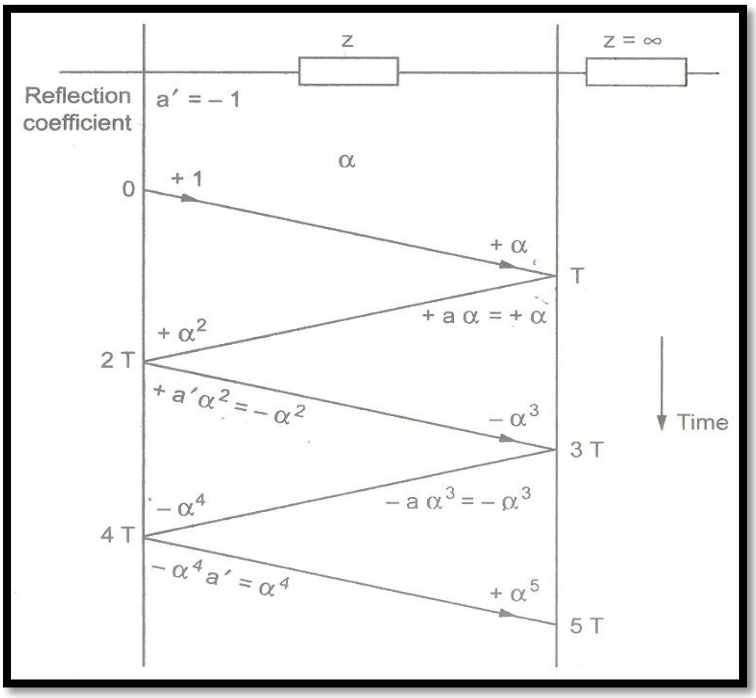
Reflection coefficient at the receiving end

$$a = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{1 - \frac{Z_1}{Z_2}}{1 + \frac{Z_1}{Z_2}}$$

$$= \frac{1 - \frac{Z}{\infty}}{1 - \frac{Z}{\infty}} = 1$$

Reflection coefficient at the sending end

$$a' = \frac{0 - Z}{0 + Z} = 1$$



<u>Procedure:</u>

- Assume T is the time taken for a wave to travel from one end to the end of line and α is the attenuation factor. Assume amplitude s unity.
- At time t=0, the magnitude is +1.the wave is attenuated and reaches at T with magnitude +1× $\alpha = +\alpha$

- At time T, the wave is reflected and the amplitude is $+\alpha \times a = +\alpha$ and the wave is again attunated and reaches at 2T with magnitude$+\alpha^2$
- At time 2T,the wave is reflected and the amplitude is $+\alpha^2 \times -a = -\alpha^2$ and the wave is again attenuated and reaches at 3T with magnitude $-\alpha^3$
- At time 3T, the wave is reflected and the amplitude is $-\alpha^3 \times a = -\alpha^3$ and the wave is attenuated and reaches at 4T with magnitude$-\alpha^4$ and so on.
- Voltage at the receving end

$$= 2[\alpha - \alpha^3 + \alpha^5 + \cdots + \alpha^{2n-1}]u(t)$$

$$= 2\alpha \frac{[1 - \alpha^{4(n+1)}]}{[1 + \alpha^2]} \times u(t)$$

At t=∞, $V_\infty = \frac{2\alpha}{1+\alpha^2}.u(t)$

8. A long transmission line is energized by a unit step voltage 1.0 V at the sending end and is open circuited at the receiving end. Construct the Bewley lattice diagram and obtain the value of the voltage at the receiving end after a long time. Take the attenuation factor a = 0.8.(Dec-2014)(Nov 2015,April/May-18)

Solution: Let the time of travel of the wave = 1 unit

At the receiving end

Reflection coefficient γ= (∞ - Z)/ (∞ + Z) =1.0

Transmission coefficient = 1 + γ = 2.0

At the sending end

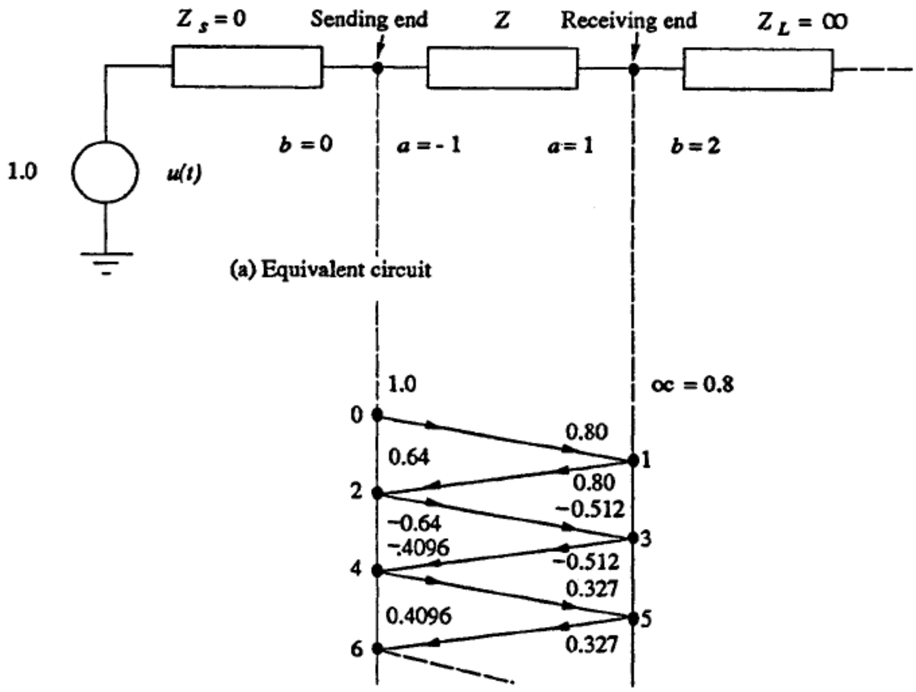
Reflection coefficient γ = (0 - Z)/(0+ Z) = - 1.0

Transmission coefficient = 1+γ = O

Since the source impedance Z_S= 0 and Z_2, the open receiving end impedance is ∞ (infinity), as shown in the lattice diagram of Fig Below.

From the lattice diagram, the wave magnitudes are tabulated as shown below:

At the receiving end	At the Sending end	Time unit
1 1 $1+\alpha^2$ 1 $1-\alpha^4$ 1 $1+\alpha^6$	0 1 2 3 4 5 6	0 α 2α $2\alpha-\alpha^3$ $2\alpha-2\alpha^3$ $2\alpha - 2\alpha^3+\alpha^5$ $2\alpha - 2\alpha^3+2\alpha^5$



The voltage at the receiving end after *4n* units of time is

$V=2(\alpha-\alpha^3+\alpha^5-+\ldots..)u(t)$

$= 2\alpha[(l-\alpha^{4(n+1)})/(l+\alpha^2)]u(t)$

Voltage at the receiving end after a long time (i.e. $t=\infty$) is $Vu(t)=[2\alpha /(1+\alpha^2)]u(t)$

Substituting $\alpha = 0.8$, we get $V\infty = 0.9756\ u(t)$

9. Draw the mathematical model for lightning discharge and explain.(or)Briefly describe a method of recording the occurrence of lightning in an over head transmission line?Nov-16,17

Mathematical Model for Lightning

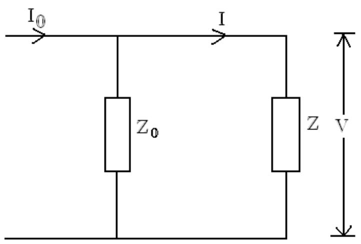
During the charge formation process, the cloud may be considered to be a nonconductor.

Hence, various potentials may be assumed at different parts of the cloud. If the charging process is continued, it is probable that the gradient at certain parts of the charged region exceeds the breakdown strength of the air or moist air in the cloud.

Hence, local breakdown takes place within the cloud. This local discharge may finally lead to a situation wherein a large reservoir of charges involving a considerable mass of cloud hangs over the ground, with the air between the cloud and the ground as a dielectric.

When a streamer discharge occurs to ground by first a leader stroke, followed by main strokes with considerable currents flowing, the lightning stroke may be thought to be a current source of value $I_0$with a source impedance Z_0 discharging to earth.

If the stroke strikes an object of impedance Z, the voltage built across it maybe taken as,



$$V = IZ$$
$$= I_0 \frac{ZZ_0}{Z+Z_0}$$
$$= I_0 \frac{Z}{1+\frac{Z}{Z_0}}$$

$$I_o - lightingstrokecurrent$$
$$Z_o - sourceimpedance$$
$$Z - objectimpedance\ (surgeimpedance)$$
$$V = IZ$$
$$= I_0 \left(\frac{Z_0}{Z_0 + z}\right) Z$$
$$= I_0 \left(\frac{Z}{1 + \frac{Z}{Z_0}}\right)$$
$$Surgeimpedance = 1000\Omega to\ 3000\Omega oflighting.$$
$$Surgeimpedanceoftransmissionline < 500\Omega$$
$$Surgeimpedanceofgroundwire = 100\Omega to\ 150\Omega$$
$$Surgeimpedanceoftower = 10\Omega to\ 50\Omega$$

The source impedance of the lightning channels are not known exactly, but it is estimated to be about 1000 to 3000 Ω.

- The objects of interest to electrical engineers, namely, transmission line, etc. have surge impedances less than 500Ω (overhead lines 300 to 500Ω, ground wires 100 to 150Ω, towers 10 to 50Ω, etc.).
- Therefore, the value Z/Z_0 will usually be less than 0.1 and hence can be neglected. Hence, the voltage rise of lines, etc. may be taken to be approximately $V = I_0 Z$.
- where I_0 is the lightning stroke current and Z the line surge impedance.
- If a lightning stroke current as low as 10,000 A strikes a line of 400 Ωsurge impedance, it may cause an overvoltage of 4000 kV.
- This is a heavy overvoltage and causes immediate flashover of the line conductor through its insulator strings.

- In case a direct stroke occurs over the top of an unshielded transmission line, the current wave tries to divide into two branches and travel on either side of the line.
- Hence, the effective surge impedance of the line as seen by the wave is $Z_0/2$and taking the above example, the overvoltage caused may be only 10,000 x (400/2) = 2000 kV.
- If this line were to be a 132 kV line with an eleven 10 inch disc insulator string, the flashover of the insulator string will take place, as the impulse flashover voltage of the string is about 950 kV for a 2 μ sec front impulse wave.

- The incidence of lightning strikes on transmission lines and sub-stations is related to the degree of thunderstorm activity.
- It is based on the level of ‘Thunderstorm days’ (TD) known as "Isokeraunic Level" defined as the number of days in a year when thunder is heard or recorded in a particular location.
- But this indication does not often distinguish between the ground strikes and the cloud-to-cloud strikes. If a measure of ground flashover density *(Ng)* is obtained, then the number of ground flashovers can be computed from the TD level.
- From the past records and the past experience, it is found that *Ng* = (0.1 to 0.2) TD/strokes/km^2-year.
- It is reported that TD is between *5* and I5 in Britain, Europe and Pacific west of North America, and is in the range of 30 to 50 in Central and Eastern states of U.S.A.
- A much higher level is reported from South Africa and South America. No literature is available for the different regions in India, but a value of 30 to 50 may be taken for the coastal areas and for the central parts of India

10)Explain corona and its effect?April/May-18

Definition

If the field is uniform , then an increase in voltage(A.C.) directly leads to breakdown without any preliminary discharge. However in non-uniform geometry, the increase in a.c. voltage will cause a luminous discharge with the production of hissing noise at points with highest electric field intensity. This form of discharge is termed as Corona discharge and is accompanied by the formation of ozone , as is indicated by the characteristic order of this gas.

If the voltage is d.c., then the appearance will be different . The positive wire will be having a uniform glow and negative wire has a more patchy glow often accompanied by streamers.

An important point in connection with corona that it is accompanied by a loss of power and this means that there is a flow of current to the wire. The current waveform is non-sinusoidal and the non-sinusoidal drop of volts caused by it may be more important than loss of power. It gives rise to **radio interference.**

Attenuation due to corona:

- The effect of corona is to reduce the crest of the voltage wave underpropagation, limiting the peak value to the critical corona voltage.
- Hence, the excess voltage above the critical voltage will cause power loss byionizing the surrounding air.

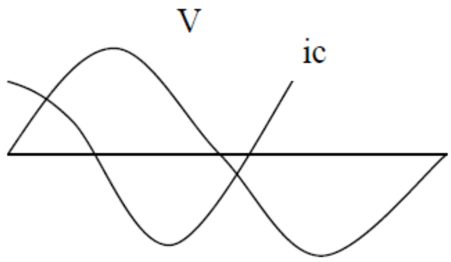
Practical Importance of Corona:

1.)Under normal conditions the loss of power due to corona is of no good importance , and consequently corona calculations do not enter directly into transmission line design. The basis of such design is entirely financially the most economical line being the most acceptable.

2.)The non-sinusoidal coronal current causes a non-sinusoidal drop of volts and these may cause some interference with neighbouring communication circuits due to electromagnetic and electrostatic induction .The current contains large third harmonic.

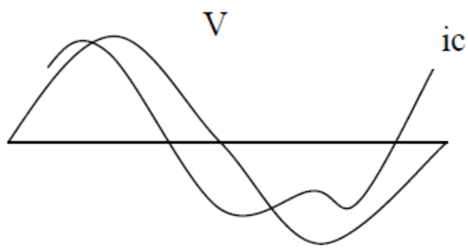
3.)Average corona loss on several lines from 345 KV to 750 KV gave 1 to 20 KW/Km in fair weather the higher values referring to higher voltages . In foul-weather the losses can go upto 300 KW/Km.

4)When a line is energized and no corona is present , the current is a pure sine wave and capacitive.



(a)

without corona voltage and current



(b)

with corona voltage and current

5)An advantage of corona is that it reduces transients , since charges induced on the line by lightning or other causes will be partially dissipated as a corona loss . In this way it acts as a safety value.

6)Audible noise: generation and characteristics.

When corona is present on the conductors EHV lines generate audible noise which is especially high during foul weather . The noise is in broad band , which extends from a very low frequency to about 20 KHz.

Corona discharges generatepositive and negative ions which are alternatively attracted and repelled by the periodicreversal of polarity of the ac excitation .

Their movement gives rise to sound pressurewaves at frequencies of twice the power frequency and its multiples in addition to thebroadband spectrum which is the result of random motions of the ions as shown in Fig.

below.

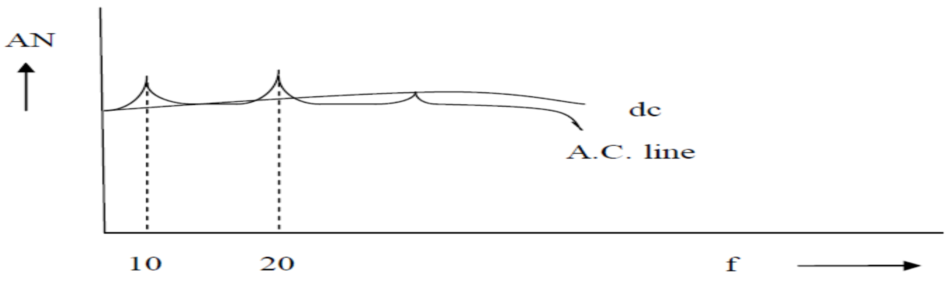


Fig.1.9 Audible noise spectra from ac and dc transmission lines

The audible noise generated by a line is a function of the following factors:
1. The surface voltage gradient on conductor.
2. The number of sub conductors in the bundle.
3. Conductor diameter.
4. Atmospheric conditions.
5. The lateral distance(aerial distance) from the line conductors to the point where noise is to be evaluated.

6) Radio interference:

There are in general two types of corona discharge from transmission line conductors
1. Pulse less or glow corona
2. Pulse type or streamer corona.

Both give rise to energy loss, but only the pulse type of ma gives interference to radio broadcast in the range of 5MHz to 1.6MHz. Besides thin, sparked discharges from broken insulators and loose guy wires interfere with TV reception in the 80-200MHz range. Corona on conductors also causes interference to carrier communication and signaling in the frequency range 30kHz to 500kHz.

11. Derive the expressions for reflection coefficient and refraction coefficient and explain the behavior of travelling waves at short circuited line ?

Whenever there is an abrupt change in the parameters of a transmission line such as an open circuit or a termination, the travelling wave undergoes a transition, of the wave is reflected or sent back and only a portion is transmitted forward.

Atthe transition point (or) junction, the voltage or current wave may attain a value which say vary from zero to twice its initial value.

The incoming wave is called the incident wave and the other waves are called reflected and transmitted (refracted waves at :3. transition point). Such waves are formed according to the Kirchoffs laws.

The current and voltage at any point on the line is written by

$$v = \frac{Coshpx + \frac{Z_0}{Z_t} Sinhpx}{Coshpx + \frac{Z_r}{Z_t} Sinhpx} E(x)$$

$$I = \frac{1}{Z_0}\left[\frac{Coshpx + \frac{Z_0}{Z_t} Sinhpx}{Coshpx + \frac{Z_r}{Z_t} Sinhpx}\right] E(x)$$

General differential solution of above equation

$$V(x) = Ae^{px} + Be^{-px}$$

$$I(x) = \frac{1}{Z_0}(Ae^{px} - Be^{-px})$$

The incident voltage and current consists of reflection and refraction waves.

$V(x)=V_1+V_2$

$I(x)=I_1+I_2$

$I_1= \frac{V_1}{Z_0}=\frac{Ae^{px}}{Z_0}$---------Forward travelling wave

$I_2=\frac{-V_2}{Z_0}=\frac{-Be^{-px}}{Z_0}$--------Backward travelling Wave

The Voltage expression can be written as

$$V = \left[\frac{e^{px}(1+\frac{Z_0}{Z_t}) + e^{-px}\frac{Z_0}{Z_t}(1-\frac{Z_0}{Z_t})}{e^{pL}(1+\frac{Z_0}{Z_t}) + e^{-pL}\frac{Z_0}{Z_t}(1-\frac{Z_0}{Z_t})}\right]E(x)$$

$Z_0 - Sourceimpedance$
$Z_t - Lineterminatingimpedance$
Take x=0 from terminal and x=L at source end
At x=0

The above expression is changed as

$$V = \left[\frac{(1+\frac{Z_0}{Z_t}) + 0)}{e^{pL}(1+\frac{Z_0}{Z_t}) + e^{-pL}\frac{Z_0}{Z_t}(1-\frac{Z_0}{Z_t})}\right]E(x)$$

$$V = \left[\frac{(1+\frac{Z_0}{Z_t})E(x)}{D}\right]$$

Where D is a denominator

The total voltage across Z_t=V= V_i+V_r

V_i-Incident voltage

V_r -reflected voltage

V -refracted voltage

$K_r = \frac{\text{reflected voltage}}{\text{Incident voltage}} = \frac{1+\frac{Z_0}{Z_t}}{1-\frac{Z_0}{Z_t}}$

K_r - reflection co efficient

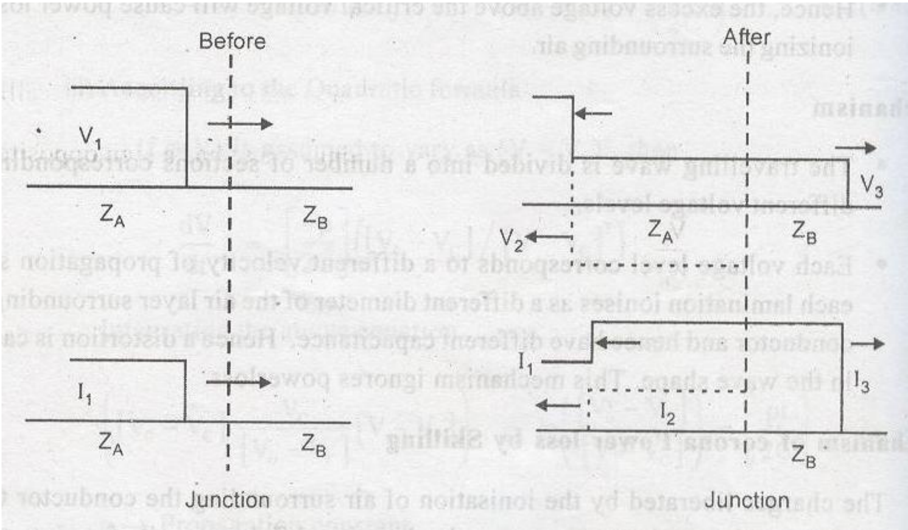
$K_r = \frac{Z_t - Z_0}{Z_t + Z_0}$

Refracted coefficient(or)Transmission coefficient

$K_t = \frac{\text{Total voltage at junction}}{\text{Incident voltage at junction}}$

$= (1 + \frac{Z_0}{Z_t}) + (1 - \frac{Z_0}{Z_t})$

$= \frac{(1+\frac{Z_0}{Z_t})+(1-\frac{Z_0}{Z_t})}{1-\frac{Z_0}{Z_t}} = \frac{2Z_t}{Z_t+Z_0}$



Case (ii):

When a wave travelling on a transmission line reaches a point where the line is joined to a second line of different characteristic impedance.(ie) when line is divided into n other lines

For the refracted wave

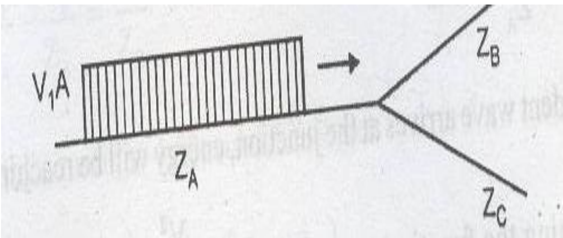
$$I_{3B} = \frac{V_{3B}}{Z_B}$$

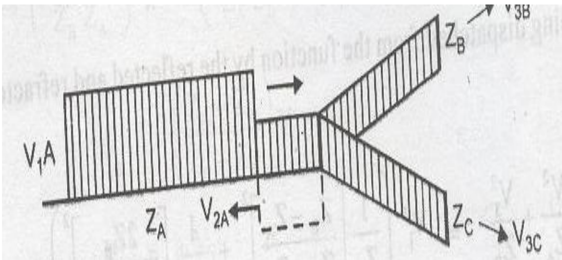
$$I_{3c} = \frac{V_{3c}}{Z_c}, \ldots\ldots I_{3N} = \frac{V_{3N}}{Z_N}$$

For the reflected wave $\quad I_{2A} = \frac{-V_{2A}}{Z_{Ac}}$

For continuity of voltage $\quad V_{1A} + V_{2A} = V_{3B} = V_{3c} = V_{3D\ldots.} = V_{3N}$

and for continuity of current $I_{1A} + I_{2A} = I_{3B} = I_{3c} = I_{3D....} = I_{3N}$



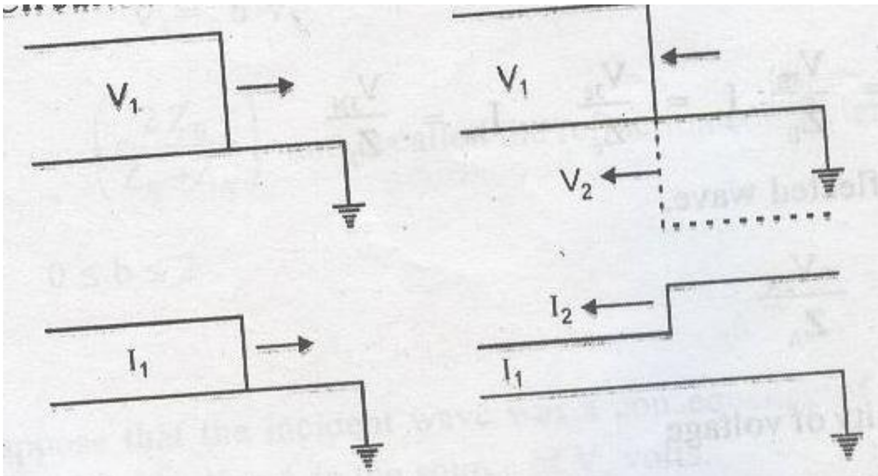


12. Explain the behaviour of travelling waves at line terminations?

Reflection and transmission of a travelling wave at junction points of unequal impedances in a transmission line are of great importance in transmission system.

Depending upon the type of impedance at transition points, the travelling wave is modifiedand sometimes voltage rise or build-up of voltage can occur. The following cases are practical importance.

Case (i) Short Circuited line:



When a travelling wave of voltage reaches a short circuit, the reflected voltagemust precisely cancel out the incident wave so that the refracted wave is zero.

Let,

V_1 — Incident voltage wave

I_1 — Incident current wave

Then Reflected voltage, $V_2 = -V_1$

Reflected current $I_2 = I_1$

The reflected wave of voltage is same as the incident wave as it returns, whilethe reflected current wave augments the incident current wave, doubling the currentflowing in the line.

Let take

Incident Voltage wave = V_1

Incident current wave = $I_1 = \frac{V_1}{Z_A}$

Surge impedances, $Z_A = Z$

$Z_B = 0$

Coefficient of reflection $a = (\frac{Z_B - Z_A}{Z_A + Z_B})$

$a = -1$

Reflected Voltage wave $V_2 = V_1$

Reflected Wave $I_2 = \frac{-V_2}{Z_A} = \frac{-(-V_1)}{Z_A}$

$I_2 = \frac{V_1}{Z_A} = I_1$

$I_2 = I_1$

The total current at the junction point

$= I_1 + I_2 = 2I$

Thus the current at the junction point rises to double the value of the incidentcurrent wave. .

When fed by a voltage source:

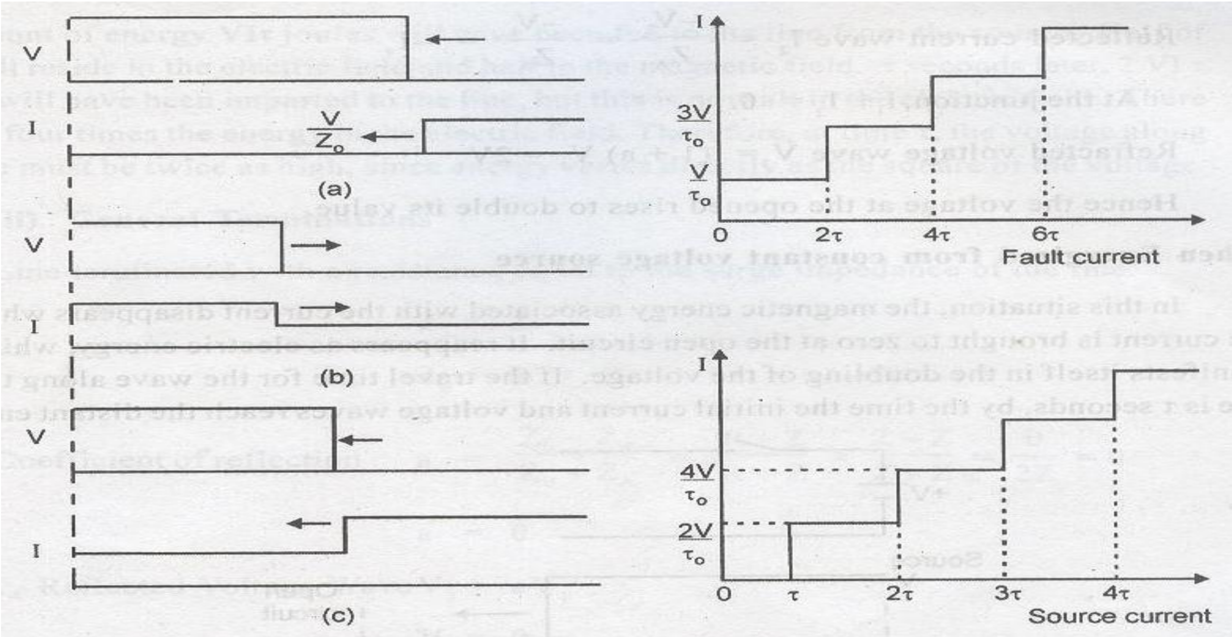
When a short circuit is applied to a transmission line fed by a voltage source,(zero impedance and constant voltage V, neglect the line resistance), the fault current will increase indefinitely at a rate of E, where I_L is the inductance to the point of faultL meters away. This is approximately true as long as travelling wave phenomena areinvolved.

Our specification of the problem implies certain boundary conditions. These are that at the short circuit the voltage is always zero, but at the source it is V at all times.

To satisfy the first of these conditions,When the short circuit is applied,a wave of voltage —V travels toward the source, reducing the line voltage to zero.

When this wave reaches the source, the boundary condition there demands theinitiation of a new wave of voltage +V, which because of its direction, is associated V with current Z.

This is shown in figure (b). These waves in due course reach the short circuit, where upon the cycle repeats figure (c), so that short circuit current as seen at the fault or at the source increases in discrete steps as shown in figure (d) and 2V figure (e)



Case (ii) Open Circuit:

An open circuit at the end of a transmission line demands that the current at thatpoint be zero at all times. Thus when a current wave of +1 arrives at the open circuit, a current wave of -1 is at once initiated to satisfy the boundary condition. This will travel toward the source with a voltage wave of +V.

Incident Voltage Wave = V_1

Incident Current Wave = I_1

$Z_A = Z$

$Z_B = \infty$

Coefficient of Reflection $a = (\frac{Z_B - Z_A}{Z_A + Z_B}) = \frac{1 - \frac{Z_A}{Z_B}}{1 + \frac{Z_A}{Z_B}} = \frac{1 - \frac{Z}{\alpha}}{1 + \frac{Z_A}{\alpha}} = 1$

Reflected voltage wave $V_2 = aV_1 = V_1$

Reflected current wave $I_2 = \frac{-V_2}{Z_A} = \frac{-V_1}{Z_A} = -1$

$I_1 + I_2 = 0$

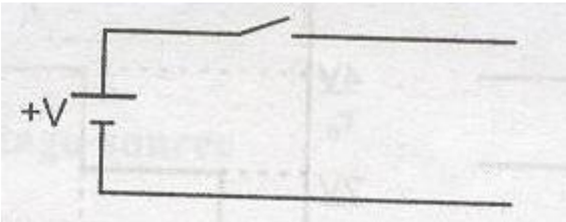
Refracted voltage wave $V_3 = (1 + a)V_1 = 2V_1$

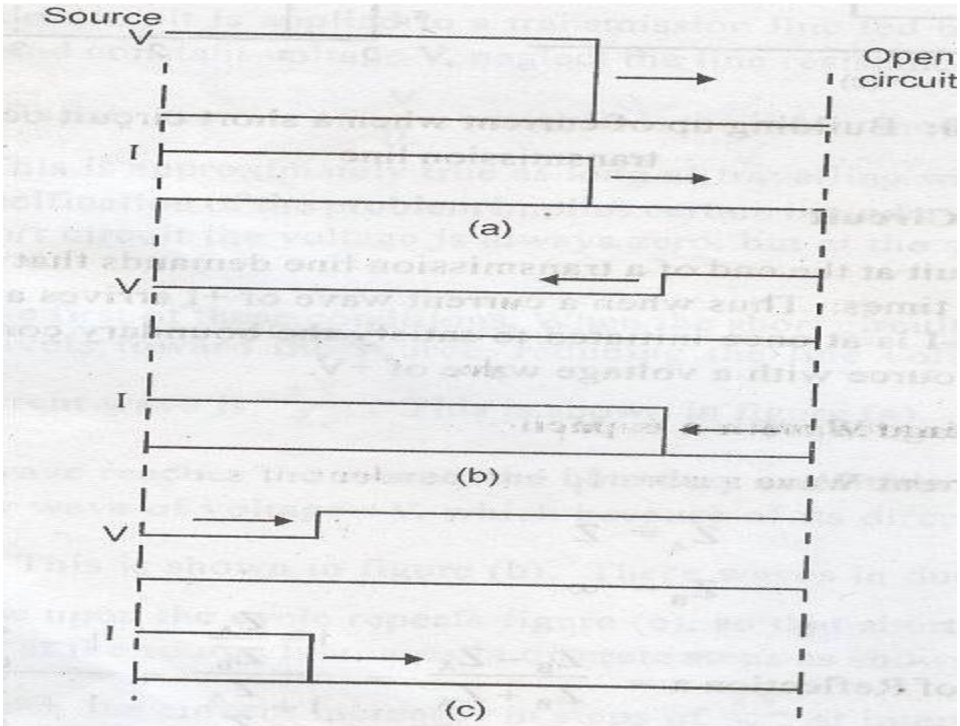
Hence the voltage at the opened rises to double its value.

When energized from constant voltage source:

In this situation, the magnetic energy associated with the current disappears whenthe current is brought to zero at the open circuit.

It reappears as electric energy, whichmanifests itselfin the doubling of the voltage. The travel time for the wave along theline is t seconds, by the time the initial current and voltage waves reach the distant end,





an amount ofenergy joules will have been fed to the line from the source.

Half of this will reside in the electric field and half in the magnetic field 1 seconds later, joules will have been imparted to the line, but this is now all in the electric field.

There is now four times the energy in the electric field. Therefore, at time 1 the voltage along the line must be twice as high, since energy varies directly as the square of the voltage.

Case (ii) General Terminations:

Line terminated with a resistance equal to the surge impedance of the line.

$Z_A = Z$

$Z_B = R = Z$

$$a = (\frac{Z_B - Z_A}{Z_A + Z_B}) = \frac{R - Z}{R + Z} = \frac{Z - Z}{Z + Z} = \frac{0}{2Z} = 0$$

$a = 0$

Reflected Voltage Wave $V_2 = aV_1$

$V_2 = 0$

Reflected Voltage Wave $V_3 = (1 + a)V_1$

$V_3 = V_1$

Thus, there is no reflected wave. There is no discontinuity of the line, and thetravelling wave proceeds without reflection and disappears. Thus there will be noreflections at thejunction, if a transmission line or cable is terminated with a resistanceequal to the surge impedance of the line or cable.

Case (iv) Line terminated with a capacitor:

$Z_A = Z_B$ (behaves as a resistor independent of s.)

$$Z_B = \frac{1}{C_1 s}$$

$$a = \frac{Z_B - Z_A}{Z_B + Z_A}$$

Reflection coefficient $a = \dfrac{(\frac{1}{C_1 s}) - Z_A}{(\frac{1}{C_1 s}) + Z_A}$

Refraction coefficient $b = \dfrac{2Z_B}{Z_B + Z_A} = \dfrac{(\frac{2}{C_1 s})}{(\frac{1}{C_1 s}) + Z_A}$

Thus the laplace transform of the reflected wave

$V_2(s) = aV_1(s)$

$$= \frac{V_1}{s}\left[\frac{(\frac{1}{C_1 s}) - Z_A}{(\frac{1}{C_1 s}) + Z_A}\right]$$

$$= \frac{V_1}{s}\left[\frac{(\frac{1}{C_1 Z_A}) - s}{(\frac{1}{C_1 Z_A}) + s}\right]$$

$$(\frac{1}{C_1 Z_A}) = \alpha$$

$$V_2(S) = \frac{V_1}{S}(\frac{\alpha - S}{\alpha + S})$$

$$= V_1(\frac{\alpha}{S(S+\alpha)} - \frac{1}{S+\alpha})$$

Taking inverse laplace transforms

$$V_2(t) = V_1[1 - e^{-\alpha t} - e^{-\alpha t}]$$

$$V_2(t) = V_1[2 - e^{-\alpha t}]$$

Refracted wave $V_3 = V_1 + V_2$

$$V_3 = V_1(2 - e^{-\alpha t})$$

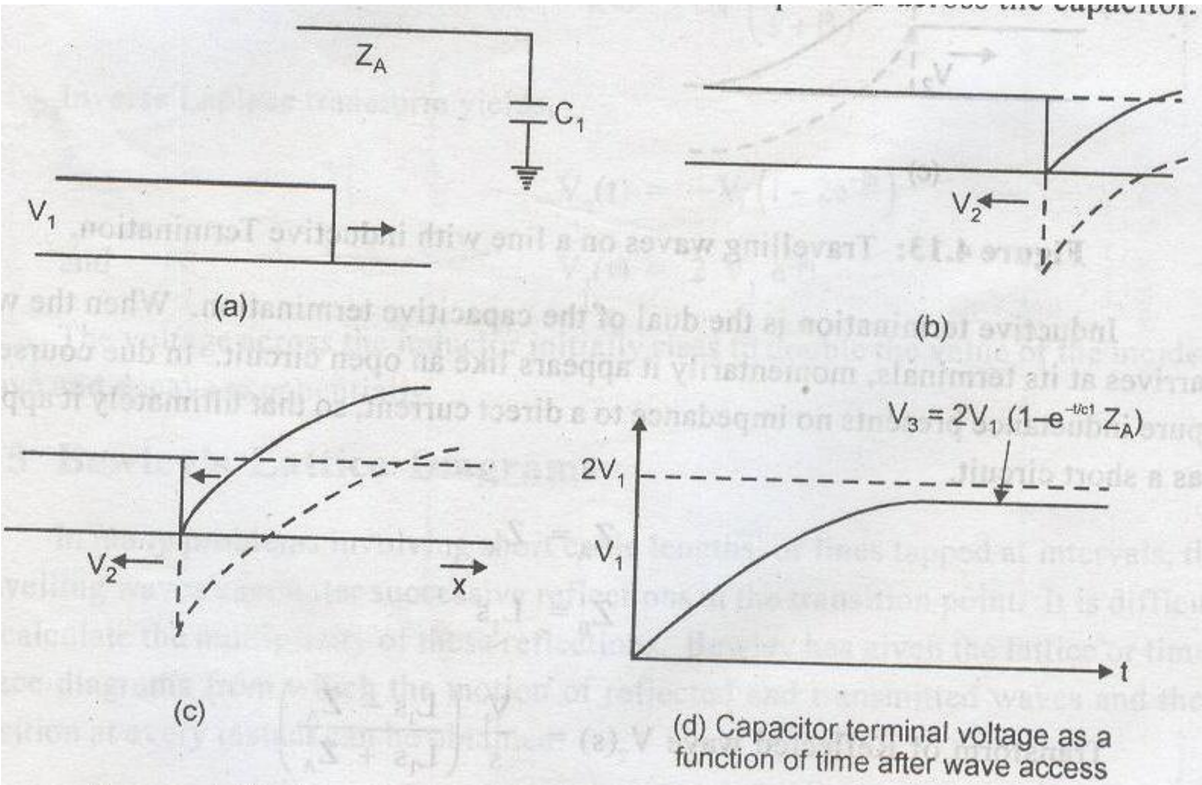
$$V_3(S) = bV_1(S)$$

$$= \frac{V_1}{s}\left[\frac{(\frac{2}{C_1 s})}{\frac{1}{C_1 s + Z_A}}\right]$$

$$= \frac{V_1}{s}\left[\frac{(\frac{2}{C_1 Z_A})}{\frac{1}{C_1 Z_A + s}}\right]$$

$$= V_1\left(\frac{2\alpha}{s[s+\alpha]}\right)$$

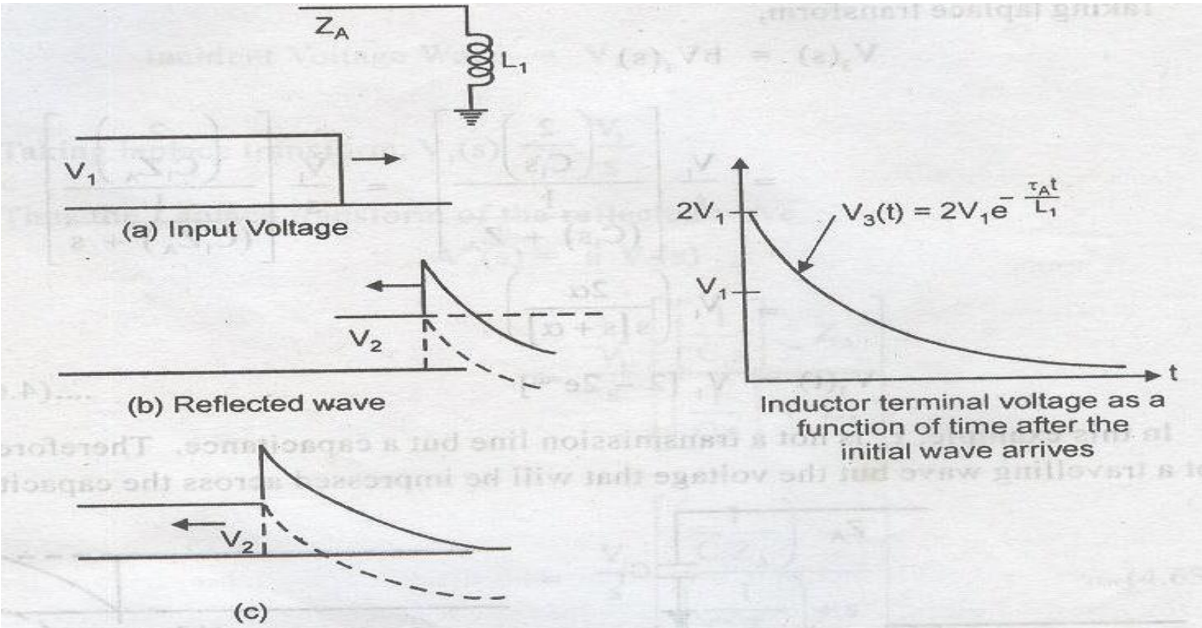
$$V_3(t) = V_1[2 - e^{-\alpha t}]$$



When the incident wave reaches the capacitor C, it cannot instantaneously change its potential. Momentarily, the capacitor behaves like a short circuit, the front of the reflected wave cancels out the incident wave as we observed with a short circuit.

It can be inferred that the steepness of the front is reduced and the wave rises slowly in an exponential manner. The voltage at the junction point finally rises to twice the magnitude of the incident wave.

Case (iv) Transmission line terminated by an inductance L:



Inductive termination is the dual of the capacitive termination. When the wavearrives at its terminals, momentarily it appears like an open circuit. In due course the pure inductance presents no impedance to a direct current, so that ultimately it appears ' as a short circuit.

$Z_A = Z_A$

$Z_B = L_1 s$

Transform of reflected wave $V_2(s) = \frac{V_1}{s}(\frac{L_1 s - Z_A}{L_1 s + Z_A})$

$$= \frac{s - \frac{Z_A}{L_1}}{s + \frac{Z_A}{L_1}} \frac{v_1}{s}$$

Taking partial fraction

$$v_2(s) = -v_1(\frac{1}{s} - \frac{2}{s + \frac{Z_A}{L_1}})$$

$$v_2(t) = -v_1(1 - 2e^{\frac{Z_A}{L_1}t})$$

Transform of refracted wave, $v_3(s) = \frac{v_1}{s}(\frac{2L_1 s}{L_1 s + Z_A})$

$$= \frac{v_1}{s}(\frac{2L_1 s}{L_1(s + \frac{Z_A}{L_1}})$$

$$= \frac{v_1}{1}(\frac{2}{(s + \frac{Z_A}{L_1}})$$

Taking inverse laplace transform we get

$$v_3(t) = 2v_1 e^{\frac{Z_A}{L_1}t}$$

The voltage across the inductor initially rises to double the value of the incident wave and decays exponentially.

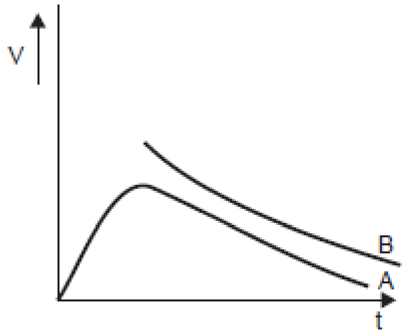
13) Explain Why a steep fronted surge wave form are more vulnerable to insulation?(May 2015)(8 mark)

- For steep fronted travelling waves, the voltages at different points in the sub-station can exceed the protective level by amounts that depend on the distance from the diverter location, the steepness of the wave front and other electrical parameters.
- Hence, it is necessary to decide the number of locations at which surge diverters are to be located and their ratings. It is necessary to keep this number to a minimum. Also, care must be taken regarding switching over-voltages generated due to current chopping which may destroy the transformer or the equipment near the circuit breakers.
- The Basic Impulse Level (BIL) is often determined as simply 1.25 to 1.30 times the protective level offered by the surge diverter. Usually, the next higher BIL value from the standard values is chosen.
- Usually the circuit breaker, the transformer and other equipment are placed at finite distances from the surge diverter and connected through a short distance overhead line or cable. When a surge arises, it suffers multiple reflections between each of the equipment which may give rise to over voltages of considerable magnitude (the travel time is usually less than a microSec).
- It can be shown that when a surge diverter, a breaker and a transformer are in line, the voltage that can build up at a distance *D* from the surge diverter point is given as *V(D) = Vp* + 2S7*, where *Vp* is the spark over voltage/protective level, *S* is the steepness of the wave front, and *T* is the travel time =*DIv*. Here, v is the velocity of the wave travel, assuming that the line extends to a large distance such that no reflections come from the line end.
- The maximum value of *V(D)* is attained when *2T = TQ*, the spark over time of the diverter.
- "Distance effect" is to be suitably allowed for when surge diverters are to be used for SDL also; a margin of 15 to 20% is normally allowed over the protective level.
- Distance effect is negligible for long fronted switching surges.

14)Briefly explain with the aid of suitable diagrams, the statistical method of insulation co-ordination?(16 mark)(May 2015)

- Insulation coordination means the correlation of the insulation of the various equipments in a power
- system to the insulation of the protective devices used for the protection of those equipments againstover-voltages.
- In a power system various equipments like transformers, circuit breakers, bus supports etc. have different breakdown voltages and hence the volt-time characteristics. In order that all the equipments should be properly protected it is desired that the insulation of the various protective devices must be properly coordinated.

- Curve *A* is the volt-time curve of the protective device and *B* the volt-time curve of the equipmentto be protected.
- Thus, any insulation having a withstand voltage strength in excess of the insulation strength of curve *B* is protected by the protective device of curve *A*.



Volt-time curve *A*
(protecting device and) volt-time curve *B* (device to be protected)

The insulation design of EHV and UHV system is based on the following principles.

- The station have transformers and other valuable equipment that have non self restoring insulation.
- The protective levels for lightning surges and switching surges are almost equal and even overlap.
- BIL cannot give protection against switching impulses. So separate SIL needed. So when controlling of switching voltage control device works fail that time surge arrester suppress switching surges.
- The protection level provided by the protective devices like surge arresters is same as for other apparatus difference is surge arrester absorb surge.
- The safety margin is arrived at by considering the risk factor R for the devices used for the protection and the insulation structure to be protected.
- In normal practice the insulation level and the protective safety margin are arrived at by
  i)Selecting the risk of failure(R)
  ii)Statistical safety factor(γ)
  iii)Fixing the withstand voltage and designing the insulation level of any equipment corresponding to 90%,95% of the withstand voltage thus fixed.

Statistical approach

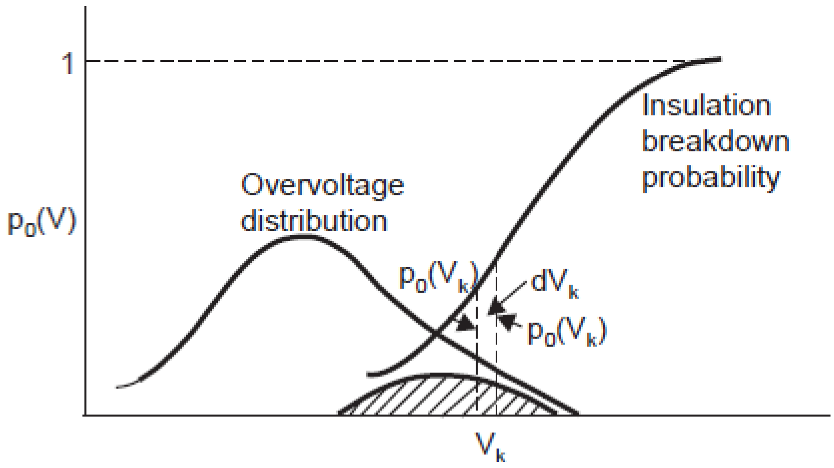
- The statistical methods is a very rigorous experimentation and analysis work so as to find probability of occurence of over-voltages and probability of failure of insulation. It is found that the distribution of breakdown for a given gap follows with some exceptions approximately normal or Gaussian distribution. Similarly the distribution of over voltages on the system also follows the
- Gaussian distribution. In order to coordinate electrical stresses due to over-voltages with the electrical strengths of the dielectric media, it has been found convenient to represent overvoltage distribution in the form of probability density function and the insulation breakdown probability by the cumulative
- Distribution function as shown in Fig.
- Suppose $P0(V\boldsymbol{k})$ is the probability density of an overvoltage Vk and $P0\ (Vk)\ dVk$ the probability of
  occurence of the over voltages having a peak value Vk. To obtain the probability to disruptive discharges due to these overvoltages having a value between Vk and Vk +

dV_k , their probability of occurrence $P_0(V_k)\, dV_k$, shall be multiplied by $P_b(V_k)$ that an impulse of the given type and of value V_k will produce a discharge.
The resultant probability or risk of failure for overvoltage between V_k and $V_k + dV_k$ is thus,

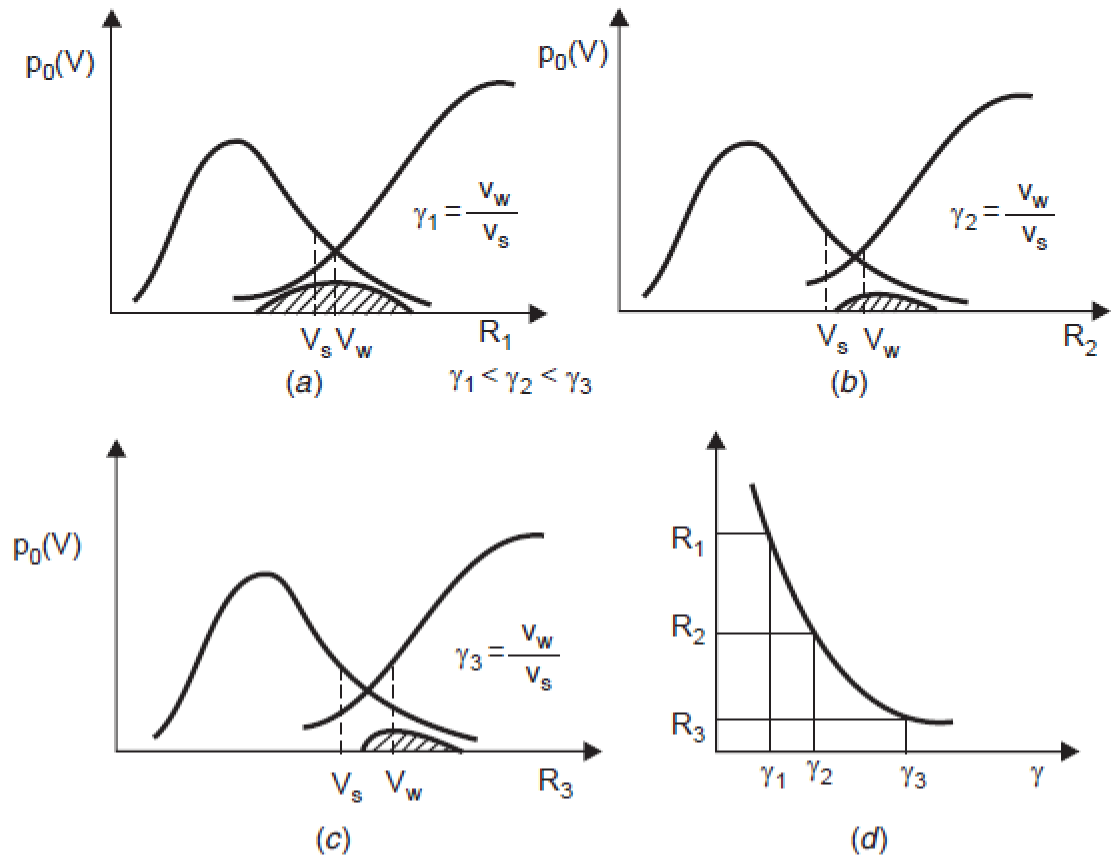
$$dR= P_b(V_k)\, P_0(V_k)\, dV_k$$

- For the total voltage range we obtain the total probability of failure or risk of failure.

$$R=\int_0^{\infty} P_b(V_k)\, P_0(V_k)\, dV_k$$



I Overvoltage distribution and Insulation breakdown probability



Risk of failure as a function of statistical safety factor

UNIVERSITY QUESTIONS
PART-A

1) Why protection of transmission line important? **(APR-MAY2011)**
2) What are the causes of over voltages in electric system? **(NOV-DEC2011,2014)**
3) What is Isokeraunic levelor thunderstorm days? **(May-2011,NOV-16)**
4) What are the factors of origin of switching surges? **(NOV-DEC-2012)**
5)Define lightning phenomenon? **NOV-DEC 2012**
6) What is counterpoise wire/give it is uses? **NOV-DEC 2012**
7) Mention the different kinds of over voltages?(**MAY-JUNE 2013**)
8) What is stepped leader stroke? (**MAY-JUNE 2013**)
9) Draw the mathematical model for lightning discharges.**(May-2014)**
10) Classify the lightning strokes**(May-2014)**
11) What is Bewley Lattice Diagram?**(Dec-14)**
12)What are the factors that influence the lightning induced voltage on transmission line?
13)Why a simple spark gap cannot offer full protection against over voltage?
14) What are the causes of over voltages in electric Power system? **(Dec-11, Dec-14)(OR)**
What are the various abnormalities in power system?(May 2015)
15) What are the factors that influence the lightning induced voltage on transmission lines? (**Nov 2015**)
16)Why the simple spark gap cannot offer full protection against over voltage?(NOV 2015)

17)What are the characteristics of lightning strokes?(**May 2015)**
18)what is back flashover? Nov-16.

PART-B

1) Explain briefly various charge formation theory and also explain briefly lightning mechanism? **(NOV-DEC 2012)**
2). Discuss about the mechanism of lightning Strokes:**(MAY-2008, MAY-2012,NOV-16)**
3) Write shorts on Switching Surges and temporary over voltage? **(NOV-DEC 2011)(NOV 2015)**
4) Write short notes on Power frequency over voltage in power system? **(NOV-DEC 2012, MAY-2013))(NOV 2015)**
5) Explain the various methods of Protection against over voltages? **(NOV-DEC-2011, MAY-2013)**

6)What are the causes for switching and power frequency over voltage ? how are they controlled in power system? **NOV-DEC 2013,MAY-2014,(NOV 2015)**
7)What are the requirements of ground wire for protecting power conductor against direct lightning stroke? Explain how they are achieved in practice**.(MAY-JUNE-2014)**

8)Basic Requirements of a Lightning Arrester or Surge Diverter and Explain its operation with V-I characteristics.**(MAY-2014)(NOV 2015)**
9) Explain step by step procedure to draw (OR) constructing Bewley's lattice diagram?(MAY-2014) (OR)Obtain the expression of reflected and transmission of travelling waves at transmission points **(DEC-14)**

10)A long transmission line is energized by a unit step voltage 1.0 V at the sending end and is open circuited at the receiving end. Construct the Bewley lattice diagram and obtain the value of the voltage at the receiving end after a long time. Take the attenuation factor a = 0.8.
(DEC-14)(NOV 2015)
11)Derive the expressions for reflection coefficient and refraction coefficient and explain the behavior of travelling waves at short circuited line ?
12) Explain the behaviour of travelling waves at line terminations?

13) Explain Why a steep fronted surge wave form are more vulnerable to insulation**?(May 2015)(**8 mark)
14)Briefly explain with the aid of suitable diagrams, the statistical method of insulation co-ordination?(16 mark)(**May 2015)**
15)Draw the mathematical model for lightning discharge and explain.(or)Briefly describe a method of recording the occurrence of lightning in an over head transmission line?Nov-16
16)Explain the various methods of Protection against over voltages in OHT lines?(NOV-DEC-2011, MAY-2013,DEC-2013, 16)

UNIT-2
TWO MARKS

1. **Name A Few Gases Used As Insulation Medium?(May-2005)**

N2, CO2, CC2F2 (Freon), SF6 (Sulphur Hexa Fluoride)

2. **Name the theories explaining B.D in gaseous insulation?**

- Town sends Theory
- Streamer Theory.

3. **What are the physical conditions governing ionization mechanism in gases dielectrics?**

- Pressure
- Temperature
- Electrode configuration
- Nature of electrode surface
- Availability of initial conducting particles

4) What is primary ionization?

Electron produced at the cathode by some external means, during its travel towards the anode due to the field applied, make collisions with neutral atoms/molecules and liberate electrons & positive ions. The liberated ions make future collisions and the process continue. The electrons and the ions constitute current. This process is called primary ionization.

5) What is secondary ionization?

i).The librated positive ions,during the primary ionization process migrate towards cathode bombard and emit secondary electrons from the cathode.

ii).The excited atoms/molecules,got excited during the collision of initial electrons, emit photons which bombard the cathode & emit secondary electrons

iii.Metastable (excited particles)bombard the cathode metal surface & producesecondaryelectrons. The secondary electrons released as above make ionization collisions & produce additionalelectrons. The electrons again produce ionization collisions & the process repeats. This is called& secondary ionization. The discharge is self sustained because once the secondary electrons are formed. They take care of the situation. Where there are initial electrons at cathode or not ionization proceeds. That is called self sustained discharge.

6. Define primary ionization co-efficient. (Town-sends Ist ionization co-efficient)? MAY-17

The average number of ionizing collisions made by an electron per centimeter travel of the electron in the direction of the field is called Town-sends I^{st} ionization co-efficient .It depends on the gas pressure and E/P

7. What is Town-sends secondary ionization co-efficient?

It is the net number of secondary ions produced per incident positive ion (γ^1) or photon (γ^2) or metastable particle (γ^3)

$\gamma = (\gamma^1 + \gamma^2 + \gamma^3)$

$\gamma = f(E/P)$

8) **What is Town-sends condition for Breakdown?(May 2015)**

Town-sends current growth equation is $I = I_o e^{\alpha d}/1- \gamma (e^{\alpha d} - 1)$

Town-sends criterion for BD $\gamma (e^{\alpha d}-1) = 1$

Since $e^{\alpha d} >>> 1$

The criterion becomes

$\gamma e^{\alpha d} = 1$

Where γ = Town-sends secondary ionization coefficient

α= Town-sends primary ionization coefficient, d = gap

9. What is Spark voltage sparking distance?

We have Town-sends criterion for Breakdown is $\gamma e^{d} = 1$

The voltage applied which creates the above breakdown condition is called spark voltage V_s and the corresponding gap d is called sparking distance.

10) Demerits of Town-sends theory?

- Beyond a p.d > 1000 torr cm, this theory does net explain correctly.
- Town sends theory says that current growth depends on ionization. But actually it depends on gas pressure and geometry of gap.
- Town sends mechanism predicts time lag of 10-5 sec. But actually the time lag is 10-8sec.
- The discharge form is not as the one predicted by Town-sends theory. It is filamentary& irregular and not “diffused form” as predicted by town-sends.

11) Streamer theory is based on what?

- Streamer theory considers the influence of space charge on the applied field.

- Secondary avalanches are produced from the gap.
- Transformation from avalanche to streamer occurs when the length

of avalanche exceeds certain value.

- Streamer theory overcomes the demerits of Town-sends theory.

12. Explain why Electro negative gas has high BD value? (June-2012)

i. The molecules of (SF6 gas) electro negative gases have the property of electron attachment,(i.e., the outermost orbit of the molecules has holes)

ii. There molecules attach the electrons in the gap to become negative ions

iii. Negative ions have lesser mobility than electron

iv. This attachment plays an effective role of removing electrons which otherwise have lead to current growth and break down

v. Number of attaching electrons made by one electron drifting 1 cm in the direction of the field is called attachment coefficient.

13. Distinguish between BD in uniform field and BD in Non uniform field?(Dec-2007,April/May-18)

- In the uniform field, increase in applied voltage produces a Breakdown in the gap in the form of a spark with out any preliminary discharge.
- In the non uniform field, an increase in applied field, first cause a discharge in the gas around the points where the field is the highest. (Eg. Sharp Points, Curves of electrode). This from of discharge is called corona discharge, which extends finally as the field is increased and bridges the gap between the electrodes ultimately & cause BD.

14. What are the characteristics of corona discharge?

1. It has bluish luminescence.

2. It produces hissing noise.

3. Air surrounding the corona becomes converted to ozone.

4. Creates loss of Power.

5. Create radio interference.

6. It causes deterioration of the insulation surface.

15. What is corona inception field?

The voltage gradient required to produce visual ac corona in air at a conductor surface is called corona inception field.

16. Nature of corona on certain configuration of Electrodes?

1. Transmission line D.C

a. When the voltage is +veBluish white sheath over the entire surface of this conductor.

b. When the voltage is –veReddish glowing spots distributed along the length

2. Point to plane configuration

a. When the point is positiveCorona current increases steadily with voltage, after a point current becomes impulsed with repetitive frequency of 1KHz, the burst composing of small bursts, burst corona, ultimately leading to BD.

b. When the point is –veCorona appears as current pulse called Trichel pulses. The reception frequency is proportional to applied voltage and inversely proportion to pressure.

3. Sphere-Plane Configuration:

a. For small space – Uniform field
b. For fairly large spacing – The field is non uniform
c. For larger spacing - The field is non uniform
i.Corona inception field is proportional to the diameter of the sphere.
ii. B.D precedes corona.
iii.Corona is controlled by spacing.

4. Rod to Rod

1. BD Voltage higher when –ice

2. BD voltage depends on humidity of air.

3. The field is highly non uniform.

5. Sphere to sphere gap

1. Field is uniform up to the paint gap <d2

2. BDV does not depend on humidity and voltage wave form

3. Formative time lag is small.

4. Used for HV measurement.

17. What is Paschens Law? (Dec-2004,May-2005,Dec-2007,08,11,MAY-17,18)

Paschens law explains the relationship between the Break Down voltage and the product of pressure (p) and gap (d), in the case of Breakdown in gas. It states that, V = f (p.d) The Breakdown voltage is a function of p.d.Derivation

We Know Condition for BD as per Town sends theory is

γ (e $^{\alpha d}$-1) = 1

We know

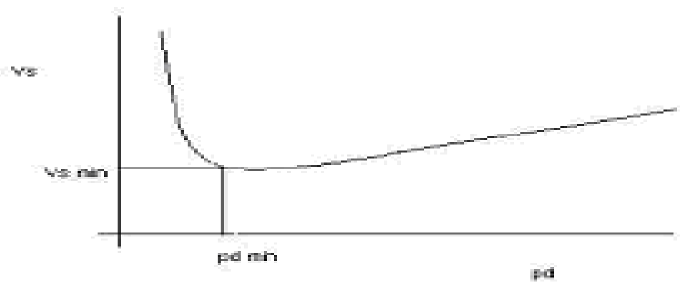
α= f_1 (E/p)

of $\gamma = f_2$ (E/p)

E = v/d Substituting we have f_2 (E/p) [$e^{f_1^{(E/p}}$] – 1 = 1

f_2 (V/pd) [$e^{f_1^{(V/pd)}}$]– 1 = 1 ------- eq.1 shows the relationship between V and pd

.ie V = f (p.d)



18. What is Vaccum?

Atmospheric Pressure = 760 torr

High Vacuum = 1 x 10^{-3} to 1 x 10^{-6} torr

Very high Vacuum = 1 x 10^{-6} to 1 x 10^{-8} torr

Ultra Vacuum = 10 x 10^{-8} torr & below

For electrical Insulation purposes

Vacuum => High

Vacuum=> 1 x 10^{-3} torr to 1 x 10^{-6} torr.

19. Basic of Breakdown in Vacuum?

I.There is no gas molecule in vacuum

ii. No collision – the initial electron crosses the gap without any collision.

iii.Hence BD not possible, (theoretically)

iv.But actually when applied voltage is very high somehow beyond a very high applied voltage due to some or other reasons gases are librated inside the chamber causing BD.

20. What are the various factors affecting B.D. in

medium?

- Gap length
- Geometry & material of electrode.
- Surface uniformity of the electrode
- Treatment of the surface (Surface treatment)
- Presence of extraneous particles & residual gas pressure in the gap.

21. Name the various mechanisms explaining Vacuum Break Down?

a) Particle Exchange Mechanism.

b) Field emission Mechanism.

c) Anode heating Mechanism.

d) Cathode heating Mechanism.

e) Clump theory.

22. What is Time lag for Break Down?(Dec-14)

The time difference between the instant of applied voltage and the occurrence of breakdown.

23. What are the requirements of gases for insulation purposes?

1) High dielectric strength

2) High thermal stability

24. What property of SF6 gas is not favorable in electrical approach?

It is not environmentally friendly and it causes global warming. Hence SF6 is used along with Air or other suitable gases.

25. Distinguish between the BD in pure liquid & commercial liquid? (DEC-2013)

Pure liquid

i. Theoretically only possible (hypothetical).

ii. BD is due to Electronic breakdown involving commission of electrons at fields greater than 100 KV/cm. Town-sends type of primary ionization & secretary ionization can be applicable.

Commercial liquid

Containssuspended particles, bubbles of air or liquid etc. BD Mechanisms are influenced by these impurities. BD depends on several factors

- Nature & condition of electrodes.

- Physical properties of liquid.
- The impurities present in the liquid.
- No single theory can explain the BD.

26. What are the parameters that alter the BD strength of liquid dielectrics?

- Physical properties like pressure, temperature.
- Dissolved impurities
- Suspended particles.
- Nature & conditions of electrodes

27. Name a few liquid dielectrics?

- Transformer oil
- Synthetic hydro carbons – (Polyolefin's)
- Chlorinated hydro carbons: P.C.B. (Toxic)
- Silicone oils. Alternative to PCB
- Esters
  - Natural Esters: Castor oil
  - Organic Ester & Phosphate esters (synthetic Esters)
- Hydrocarbons tetrachloride ethylene & per fluro poly ether.

28. Qualities of good dielectrics (liquid)?

1. High heat transfer capacity
2. Good dielectric strength
3. Good chemical satiety

29. BDV of pure liquid depends on what factors?

BDV of pure liquid depends on

Field applied.

- Gap separation.
- Cathode work function.
- Temperature.
- Density.
- Viscosity.
- Temperature of liquid.
- Molecular structure.

30. What are the various theories of BD of commercial liquids?(Dec-2008)

- Suspended particle mechanism.
- Cavitations and bubble mechanism.

- Thermal mechanism of breakdown.
- Stressed oil volume theory.

31. What is the principle of stressed oil volume Theory in Breakdown liquids?

The BDV of liquid dielectric depends on the region which is subjected to the highest stress and the volume of liquid contained in the region.

32. What are the characteristics of a good solid dielectric?

1. low dielectric loss
2. high mechanical strength
3. free from gaseous inclusions
4. free from moisture
5. resistance to thermal & chemical degradation
6. High BD Strength.

33. How can solid dielectrics be classified?

1. Organic dielectric e.g. Paper, Wood, rubber

2. In organic dielectrics.eg. mica, glass, porcelain, p v c, epoxy resins, Perspex.

34. What are the various Breakdown(BD) Mechanisms for solid dielectrics?

1. Assuming no external influences

1. Intrinsic BD.

   - Electronic BD.
   - Avalanche BD.

2. Electro Mechanical Fracture Mechanism.

3. Thermal BD.

2. Considering the External Influence

1. Chemical BD.
2. BD due to Tracking & Treeing.
3. BD due to internal discharge.

35. The usual Mechanism of BD in solid dielectric?

The usual Mechanism is Thermal BD.

36. What is the cause for long term deterioration & BD in solid dielectrics?

The long term deterioration & BD in solid dielectrics is due to Internal discharges.

37. What is meant by Intrinsic strength of a solid dielectric?(Dec-14)

All extraneous influences have to be isolated and the BD value which depends on the structure of the materials and the temperature is called intrinsic BD strength of solid dielectric

.Eg. Poly vinyl Alcohol

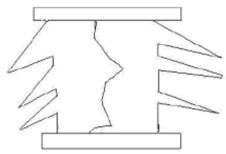
at – 1960c : 15 MV/cm (Intrinsic)

& at Normal. Temp: 5 MV/ cm to 10 MV/cm

38. What is 'TRACKING' and 'TREEING' is solid dielectric B.D?(NOV-2012)

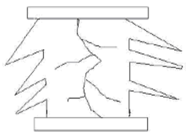
<u>TRACKING:</u>

Formation of a continuous conduction path across the surface of the insulation mainly due to surface erosion under voltage application is called 'Tracking'. Water -Conduction path-heat - Drying - Conduction film - Carbonization -B.D



<u>TREEING</u>

The spreading of spark channels during tracking in the form of the branches of tree is called Treeing.



39)What is meant by corona discharge? (May-june 2013)

The phenomenon of faint violet glow, hissing noise and ozone gas produced in the transmission lines during rainy seasons is called as corona.

In high voltage transmission lines, appearance of corona differs when positive and negative polarities of applied voltage. whenpositive polarities are applied. corona appears as bluish white sheath over the entire surface of the line. when negative polarities are applied, corona appears as reddish glowing spots distributed along the lines.

40)What are electronegative gases? (May-june 2013)(NOV 2015,17)

The electron attachment with neutral atom or molecules remove free electron in certain gases which leads to current growth and breakdown at low voltage. They are called electronegative gases and have high breakdown stress.

41) What are the properties required for a gaseous dielectric for HV applications?(DEC-2013)

- The most popular insulating gas. It is dense and rich in <u>fluorine</u>,
- This is a good discharge quencher.
- Good cooling properties.
- Excellent arc quenching.

- Corrosive decomposition products.
- Its price increased and supply got limited, as many manufacturing plants switched to production of more profitable perfluorocarbons.
- The most potent known greenhouse gas with extremely long atmospheric lifetime. Although most of the decomposition products tend to quickly re-form SF6, arcing or corona can produce disulfur decafluoride (S_2F_{10}), a highly toxic gas, with toxicity similar to phosgene.
- Sulfur hexafluoride in an electric arc may also react with other materials and produce toxic compounds, e.g. beryllium fluoride from beryllium oxide ceramics. Frequently used in mixtures with e.g. nitrogen or air.

42) What is mean by penning effect.(May-2014)

Paschen's law is not applicable in many gaseous mixtures. The outstanding example is the neon–argon mixture. A small admixture of argon in neon reduces the breakdown strength below that of pure argon or neon as for this lowering in the breakdown voltage is that the lowest excited state of neon is metastable and its excitation potential (16 eV) is about 0.9 eV greater than the ionization potential of argon. **The metastable atoms have a long life in neon gas, and on hitting argon atoms there is a very high probability of ionizing them. The phenomenon is known as the Penning effect.**

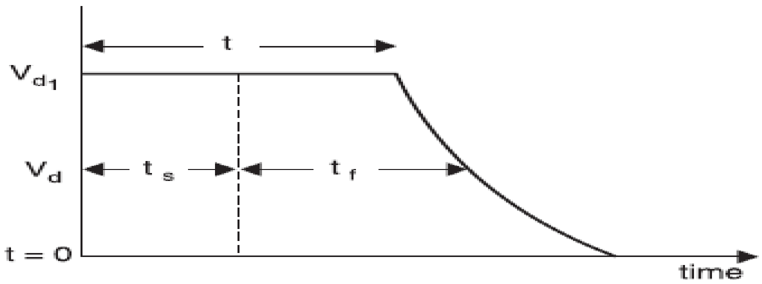
43**) What are the factors which affect breakdown of gaseous dielectrics?(May-2014)**

- Moisture.
- Dielectric strength.
- Stability
- Inflammability
- Conductivity

44)Name the various secondary ionization processes involved in gaseous dielectric breakdown? (Nov 2015)

i)Electron emission due to positive ion impact
ii) Electron emission due to photons
iii) Electron emission due to Metastable and Neutral Atoms

45)Define statistical time lag and formative time lag**?(May 2015)**
The time t which lapses between the application of the voltage sufficient to cause breakdown and appearance of of initiating electron is called statistical time lag t_s. After the appearance of electron a time t_t is required for the ionization processes to develop fully to cause the breakdown of the gap and this time is called the formative time lag ($t = t_s + t_t$)



Time lag components under a step voltage

46. Define Gas law.Dec-16

Gas law is defined as Pressure of the gas changes with temperature.

Pv=NRT
Where,
N-density of gas molecule
v-volume of the gas
T-temperature
R-constant

47. What is ionization by collision.Dec-16

The secondary ionization process by which secondary electrons are produced are the one which sustain a discharge after it is established is called ionization by collision

48. What are pure liquid dielectrics ? Nov/Dec-17

The liquid dielectrics mostly used are petroleum oils. Other oils used are synthetic hydrocarbons and halogenated hydrocarbons and for very high temperature applications silicone oils and fluorinated hydrocarbons are also used.

PART-B

1. **Explain Townsend's criterion for a spark.(June-2009, May-2011,18)(or)From the fundamental principle derive Townsend's criteria for the breakdown of gaseous dielectric medium (May 2015,Dec-2016)**

Townsend's second ionization coefficient

The current growth equation in the presence of secondary process is derived by

$\gamma = \gamma_1 + \gamma_2 + \gamma_3$ where γ is the second ionization coefficient and it is function of pressure,E/p

let we take n_+ −secondary electrons

n- total number of electron released from cathode and reached anode

n_0-no of electrons released by ultra violet radiation

$$n = n_0 + n_+$$

An electrons released from gas = $n - (n_0 + n_+)$

thereforeeach positive ionreleases γ effective electrons from the cathode

that is $n_+ = \gamma(n - (n_0 + n_+))$

$$n_{+} = \gamma n - \gamma n_0 - \gamma n_{+}$$

$(1+\gamma)n_{+} = \gamma(n - n_0)$

$$n_{+} = \frac{\gamma(n - n_0)}{(1+\gamma)}$$

w.k.t

$$n = (n_0 + n_{+})e^{\alpha d}$$

substituting n_{+} in the above expression
we get

$$n = (n_0 + \frac{\gamma(n - n_0)}{(1+\gamma)})e^{\alpha d}$$

simplify we get

$$n = \frac{n_0 e^{\alpha d}}{1 - \gamma(e^{\alpha d} - 1)}$$

It is written in terms of current

$$I = \frac{I_0 e^{\alpha d}}{1 - \gamma(e^{\alpha d} - 1)}$$

The current becomes infinite if

$$1 - \gamma(e^{\alpha d} - 1) = 0$$

$$\gamma(e^{\alpha d} - 1) = 1$$

$$\gamma e^{\alpha d} = 1$$

normally $e^{\alpha d} >> 1$

the current in the anode equals the current in the external circuit. Theoretically the current becomes infinitely large under the above mentioned condition but practically it is limited by the resistance of the external circuit and partially by the voltage drop in the arc. The condition $\gamma e^{\alpha d} = 1$ defines the condition for beginning of spark and is known as the Townsend criterion for spark formation or Townsend breakdown criterion. Using the above equations, the following three conditions are possible.

(1**)** $\gamma e^{\alpha d}$ **=1** The number of ion pairs produced in the gap by the passage of arc electron avalanche is sufficiently large and the resulting positive ions on bombarding the cathode are able to release one secondary electron and so cause a repetition of the avalanche process. The discharge is then said to be self-sustained as the discharge will sustain itself even if the source producingI_0 is removed. Therefore, the condition $\gamma e^{\alpha d}$ =1 defines the threshold sparking condition.

(2) $\gamma e^{\alpha d} >$ **1**Here ionization produced by successive avalanche is cumulative. The spark discharge grows more rapidly the more $\gamma e^{\alpha d}$ exceeds unity.

(3) $\gamma e^{\alpha d}$**<1** Here the current I is not self-sustained i.e., on removal of the source the current I_0 ceases to flow.

2. **State the criteria for sparking potential and hence obtain the relation between sparking potential and (pd) values (Paschens Law).discuss on the nature of variation of sparking potential with (pd) values.(Dec-2007,MAY-2013,Dec-14)(May 2015)**

The Townsend's Criterion: $\gamma(e^{\alpha d} - 1)$ = 1---equ(1)

Which enables the evaluation of breakdown voltage of the gap by the use of appropriate values of α /p and V corresponding to the values E/p when the current is too low to damage the cathode and also the space charge distortions are minimum. The calculated and experimentally determined values are obtained when the gaps are short or long and the pressure is relatively low.

An expression for the breakdown voltage for uniform field gaps as a function of gap length and gas pressure can be derived from the threshold equation by expressing the ionization coefficient α/p as a function of field strength E and gas pressure p i.e.,:

$$\frac{\alpha}{p} = f(\frac{E}{p})$$

substituting this in equ 1

$(e^{\alpha d} - 1) = \frac{1}{\gamma}$

$$e^{\alpha d} = 1 + \frac{1}{\gamma}$$

$$e^{f(\frac{E}{p})pd} = 1 + \frac{1}{\gamma}$$

Take ln on both side

$$f\left(\frac{E}{p}\right)pd = \ln(1 + \frac{1}{\gamma})$$

for uniform field $E = \frac{V_b}{d}$

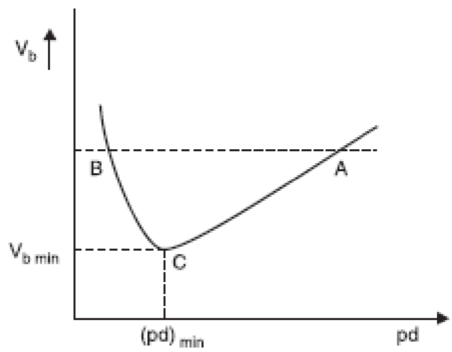
$\therefore\ f\left(\frac{\frac{V_b}{d}}{p}\right)pd$=K

$$f\left(\frac{V_b}{pd}\right) = \frac{K}{pd}$$

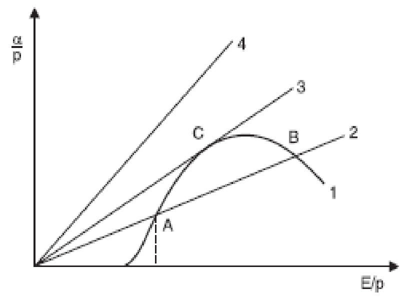
$$therefore\ V_b = F(pd)$$

This gives that the breakdown voltage of a uniform field gap is a unique function of the product of gas pressure and the gap length for a particular gas and electrode material. This relation is known as **Paschen's law**.

This relation does not mean that the breakdown voltage is directly proportional to product of **pd** even though it is found that for some region of the product **pd** the relation is linear i.e., the breakdown voltage varies linearly with the product **pd** values . The variation over a large range is shown in fig below.



compare Paschen's law and the Townsend's criterion for spark potential. We draw the experimentally obtained relation between the ionization coefficient α/p and the field strength f(E/p)



Now the Townsend's criterion αd = K can be re-written as

$$\frac{\alpha}{p} \cdot \frac{V}{E} = \frac{K}{p} \quad \text{or} \quad \frac{\alpha}{p} = \frac{K}{V} \cdot \frac{E}{P}$$

This is equation to a straight line with slope equal to K/V depending upon the value of K.

The higher the voltage the smaller the slope and therefore, this line will intersect the ionization curve at two points e.g., A and B in Fig above.

Therefore, there must exist two breakdown voltages at a constant pressure (p = constant), one corresponding to the small value of gap length i.e., higher E (E = V/d) i.e., point B and the other to the longer gap length i.e., smaller E or smaller E/p i.e., the point A.

At low values of voltage V the slope of the straight line is large and, therefore, there is no intersection between the line and the curve 1. This means no breakdown occurs with small voltages below Paschen's minimum irrespective of the value of **pd.**

The point C on the curve indicates the lowest breakdown voltage or the minimum sparking potential. The spark over voltages corresponding to points A, B, C are shown in the Paschen's curve in Fig. above.

By considering the efficiency of ionization of electrons traversing the gap with different electron energies.

Assuming that the Townsend's second ionization coefficient V is small for values pd > (pd)min., electrons crossing the gap make more frequent collision with the gas molecules than at (pd)min.

but the energy gained between the successive collision is smaller than at (pd). Hence, the probability of ionization is lower unless the voltage is increased.

In case of (pd) < $(pd)_{min}$., the electrons cross the gap without making any collision and thus the sparking potential is higher. The point $(pd)_{min}$., therefore, corresponds to the highest ionization efficiency and hence minimum sparking potential.

An analytical expression for the minimum sparking potential can be obtained using the general expression for α/p.

$$\frac{\alpha}{p} = Ae^{\frac{Bp}{E}} \;\; or \; \alpha = pAe^{\frac{Bpd}{V_b}}$$

$$e^{\frac{Bpd}{V_b}} = \frac{pA}{\alpha} \quad or \; \frac{1}{\alpha} = \frac{e^{\frac{Bpd}{V_b}}}{pA}$$

$$\frac{1}{\alpha d}d = \frac{e^{\frac{Bpd}{V_b}}}{pA}$$

w.k.t

$$\alpha d = \ln\left(1 + \frac{1}{v}\right)$$

Therefore

$$d = \frac{e^{\frac{Bpd}{V_b}}}{pA} \ln\left(1 + \frac{1}{v}\right)$$

Assume $\ln\left(1 + \frac{1}{v}\right) = K$

so that

$$d = \frac{e^{\frac{Bpd}{V_b}}}{pA} \mathrm{k}$$

$$e^{\frac{Bpd}{V_b}} = \frac{dpA}{k}$$

Taking ln on both sides

$$\frac{Bpd}{V_b} = ln \frac{APd}{K}$$

$$V_b = \frac{Bpd}{ln \frac{APd}{K}}$$

Differentiating the above equation with respect to pd and equate to zero

we get

$$ln \frac{APd}{K} = 1$$

$$ln \frac{APd}{K} = e$$

$$pd_{min} = \frac{ek}{A}$$

W.K.T

$$V_{b\ min} = \frac{Bpd}{ln \frac{APd}{K}}$$

$$V_{b\ min} = \frac{B\ ek/A}{1}$$

The typical values for A, B and V for air are A = 12, B = 365 and V= 0.02.

3.Discuss Meek's theory of breakdown in gases under non-uniform field. (May-2008)

or

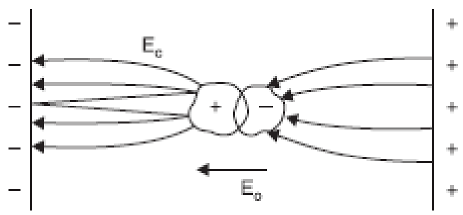
Discuss STREAMER OR KANAL MECHANISM OF SPARK in gases under non-uniform field.(MAY-2014)

the charges in between the electrodes separated by a distance **d**increase by a factor $e^{\alpha d}$ when field between electrodes is uniform.

This is valid only if we assume that the field E_0 = V/d is not affected by the space charges of electrons and positive ions. Rather has observed that if the charge concentration is higher than 10^6 but lower than 10^8 the growth of an avalanche is weakened i.e., dn/dx<$e^{\alpha d}$.

Whenever the concentration exceeds 10^8, the avalanche current is followed by steep rise in current and breakdown of the gap takes place.

The weakening of the avalanche at lower concentration and rapid growth of avalanche at higher concentration have been attributed to the modification of the electric field E_0 due to the space charge field



The above Fig shows the electric field around an avalanche as it progresses along the gap and the resultant field i.e., the superposition of the space charge field and the original field E_0.

Since the electrons have higher mobility, the space charge at the head of the avalanche is considered to be negative and is assumed to be concentrated within a spherical volume.

Due to the filed at the head of the avalanche is strengthened. The field between the two assumed charge centers i.e., the electrons and positive ions is the electrons and positive ions is decreased as the field due to the charge centers opposes the main field E_0

Again the field between the positive space charge centre and the cathode is strengthened as the space charge field aids the main field E_0 in this region.

It has been observed that if the charge carrier number exceeds 10^6, the field distortion becomes noticeable.

If the distortion of field is of 1%, it would lead to a doubling of the avalanche but as the field distortion is only near the head of the avalanche, it does not have a significance on the discharge phenomenon.

if the charge carrier exceeds 10^8, the space charge field becomes almost of the same magnitude as the main field E^0 and hence it may lead to initiation of a streamer. The space charge field, therefore, plays a very important role in the mechanism of electric discharge in a non-uniform gap.

Townsend suggested that the electric spark discharge is due to the ionization of gas molecule by the electron impact and release of electrons from cathode due to positive ion bombardment at the cathode.

According to this theory, the formative time lag of the spark should be at best equal to the electron transit time t_r.

At pressures around atmospheric and above p.d. > 10^3 Torr-cm, the space charge developed in an avalanche is capable of transforming the avalanche into channels of ionization known as streamers that lead to rapid development of breakdown. the avalanche head reaches a critical value of

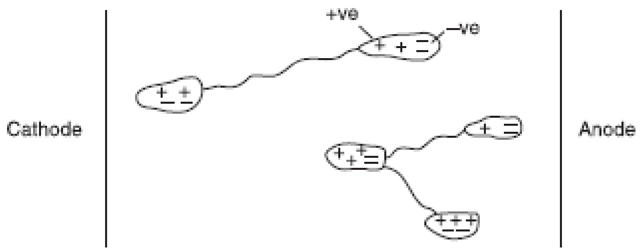
$n_0e^{\alpha x}\approx 10^8$ or $\alpha x_c \approx 18$ to 20

whereXc is the length of the avalanche path in field direction when it reaches the critical size, If the gap length d <Xc, the initiation of streamer is unlikely.

The short-time lags associated with the discharge development led Raether and streamer of Kanal mechanism for spark formation, in which the secondary mechanism results from photo-ionization of gas molecules and is independent of the electrodes Raether and Meek have proposed that independently Meek and Loeb to the advancement of the theory of when the avalanche in the gap reaches a certain critical size the combined space charge field and externally applied field E_0 lead to intense ionization and excitation of the gas particles in front of the avalanche head.

There is recombination of electrons and positive ion resulting in generation of photons and these photons in turn generate secondary electrons by the photo-ionization process.

These electrons under the influence of the electric field develop into secondary avalanches as shown in Fig below since photons travel with velocity of light, the process leads to a rapid development of conduction channel across the gap.



Raether after thorough experimental investigation developed an empirical relation for the streamer spark criterion of the form

$$\alpha x_c = 17.7 + \ln x_c + \ln\frac{E_r}{E_0}$$

where$E_r$is the radial field due to space charge and E_0 is the externally applied field. Now for transformation of avalanche into a streamer $E_r \approx$ E

Therefore, $\alpha x_c = 17.7 + \ln x_c$

For a uniform field gap, breakdown voltage through streamer mechanism is obtained on the assumption that the transition from avalanche to streamer occurs when the avalanche has just crossed the gap. The equation above, therefore, becomes

$\alpha d = 17.7 + \ln d$

When the critical length $x_c \geq \alpha d$ minimum breakdown by streamer mechanism is brought about.

The condition $X_c = d$ gives the smallest value of α(alpha) to produce streamer breakdown.

Meek suggested that the transition from avalanche to streamer takes place when the radial field about the positive space charge in an electron avalanche attains a value of the order of the externally applied field. He showed that the value of the radial field can be obtained by using the expression.

$$E_r = 5.3 \times 10^{-7} \frac{\alpha e^{\alpha x}}{\left(\frac{x}{p}\right)^{\frac{1}{2}}} \text{volts/Cm}$$

wherex is the distance in cm which the avalanche has progressed, p the gas pressure in Torr and α(alpha) the Townsend coefficient of ionization by electrons corresponding to the applied field E.

The minimum breakdown voltage is assumed to correspond to the condition when the valanche has crossed the gap of length d and the space charge field E_r approaches the externally applied field i.e., at x = d, E_r= E.

Substituting these values in the above equation, we have

$$E = 5.3 \times 10^{-7} \frac{\alpha e^{\alpha x}}{\left(\frac{d}{p}\right)^{\frac{1}{2}}}$$

taking ln on both sides

$$\ln E = -14.5 + \ln \alpha - \frac{1}{2} ln \frac{d}{p} + \alpha d$$

Add - ln p on both sides

$$\ln E - \ln p = -14.5 + \ln \alpha - \ln p - \frac{1}{2} ln \frac{d}{p} + \alpha d$$

$$\ln \frac{E}{p} = -14.5 + \ln \frac{\alpha}{p} - \frac{1}{2} ln \frac{d}{p} + \alpha d$$

The experimentally determined values of $\frac{\alpha}{p}$ and the corresponding E/p are used to solve the above equation using trial and error method. Values of $\frac{\alpha}{p}$ corresponding to E/p at a given pressure are chosen until the equation is satisfied.

4. What are the preferred properties of gaseous dielectric for high voltage applications? (May-2005)

The gases used in wide application of power system to provide insulation to various equipments and substations. The gases are also used in circuit breakers for arc interruption besides providing insulation between breaker contacts.

The various gases used are (i) air (ii) oxygen (iii) hydrogen (iv) nitrogen (v) CO_2 and (vi) electronegative gases like sulphur hexafluoride, arcton etc.

The various properties of gases are:

(i) High dielectric strength.

(ii) Thermal and chemical stability.

(iii) Non-inflammability.

(iv) High thermal conductivity. This assists cooling of current carrying conductors immersed in the gas and also assists the arc-extinction process.

(v) It should have a low dissociation temperature, a short thermal time constant (ratio of energy contained in an arc column at any instant to the rate of energy dissipation at the same instant) and should not produce conducting products such as carbon during arcing.

(vi) Commercial availability at moderate cost. Of the simple gases air is the cheapest and most widely used for circuit breaking.

Hydrogen has better arc extinguishing property but it has lower dielectric strength as compared with air. Also if hydrogen is contaminated with air, it forms an explosive mixture.

Nitrogen has similar properties as air, CO_2 has almost the same dielectric strength as air but is a better arc extinguishing medium at moderate currents. Oxygen is a good extinguishing medium but is chemically active.

SF_6 has outstanding arc-quenching properties and good dielectric strength. Of all these gases, SF_6 and air are used in commercial gas blast circuit breakers.

The suitable mixture of SF_6 with N_2 is a good replacement for SF_6. Mixture is not only cost effective, it is less sensitive to find non-uniformities present within the equipment.

GIS, C.B., capacitors, CT, PT and cables. A ratio 70% of SF6 and 30% of N_2 is found to be optimum for circuit breaking.

With this ratio, the C.B. has higher recovery rate than pure SF_6 at the same partial pressure. The future of using SF_6 with N_2 or He for providing insulation and arc interruption is quite bright.

5. Discuss the current growth in a gas subjected to uniform and non-uniform electric field and corona discharge. (Dec-2008) (or)

Explain clearly breakdown in non-uniform fields and corona discharge. (Dec-2004, June-2012, Dec-2013)

If the electric field is uniform and if the field is increased gradually, just when measurable ionization begins, the ionization leads to complete breakdown of the gap.

In non-uniform fields, before the spark or breakdown of the medium takes place, there are many manifestations in the form of visual and audible discharges. These discharges are known as *Corona discharges*.

The Corona is defined as a self-sustained electric discharge in which the field intensified ionization is localised only over a portion of the distance (non-uniform fields) between the electrodes.

The phenomenon is of particular importance in high voltage engineering where most of the fields encountered are non-uniform fields unless of course some design features are involved to make the filed almost uniform.

Corona is responsible for power loss and interference of power lines with

The communication lines as corona frequency lies between 20 Hz and 20 kHz.

This also leads to deterioration of insulation by the combined action of the discharge ion bombarding the surface and the action of chemical compounds that are formed by the corona discharge.

When a voltage higher than the critical voltage is applied between two parallel polished wires, the glow is quite even.

After operation for a short time, reddish beads or tufts form along the wire, while around the surface of the wire there is a bluish white glow. If the conductors are examined through a stroboscope.

i) The reddish tufts or beads are formed when the conductor is negative.

ii) Smoother bluish white glow when the conductor is positive.

The a.c. corona viewed through a stroboscope has the same appearance as direct current corona.

As corona phenomenon is initiated a hissing noise is heard and ozone gas is formed which can be detected by its characteristic colour.

When the voltage applied corresponds to the critical disruptive voltage, corona phenomenon starts but it is not visible because the charged ions in the air must receive some finite energy to cause further ionization by collisions.

For a radial field, it must reach a gradient (visual corona gradient) g_ua the surface of the conductor to cause a gradient g_0, finite distance away from the surface of the conductor.

The distance between g_0 and $g_v$is called the energy distance. According to Peek, this distance is equal to (r + 0.301 r) for two parallel conductors and (r + 0.308 r) for coaxial conductors.

this it is clear that g_v is not constant as g_0 is, and is a function of the size of the conductor. The electric field intensity for two parallel wires is given as

$$E = 30\left(1 + \frac{0.301}{\sqrt{r\delta}}\right)\delta \text{kv/cm}$$

Investigation with point-plane gaps in air have shown that when point is positive, the corona current increases steadily with voltage.

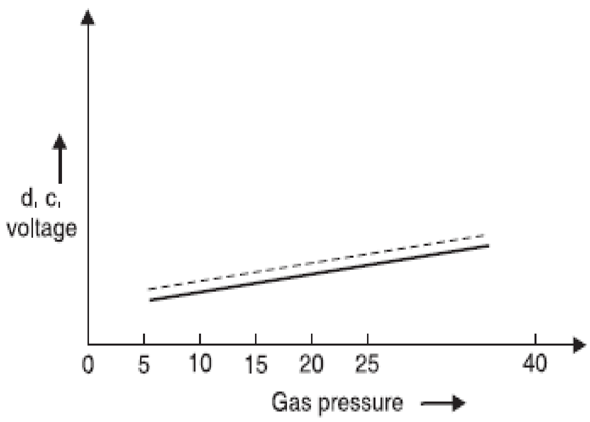
At sufficiently high voltage, current amplification increases rapidly with voltage up to a current of about 10^{-7}A, after which the current becomes pulsed with repetition frequency of about 1 kHz composed of small bursts. This form of corona is known as *burst corona*.

The average current then increases steadily with applied voltage, leading to breakdown. With point-plane gap in air when negative polarity voltage is applied to the point and the voltage exceeds the onset value, the current flows in vary regular pulses known as Trichel pulses.

The onsetvoltage is independent of the gap length and is numerically equal to the onset of streamers under positive voltage for the same arrangement. The pulse frequency increases with voltage and is a function of the radius of the cathode, the gap length and the pressure.

A decrease in pressure decreases the frequency of the pulses. It should be noted that the breakdown voltage with negative polarity is higher than with positive polarity except at low pressure.

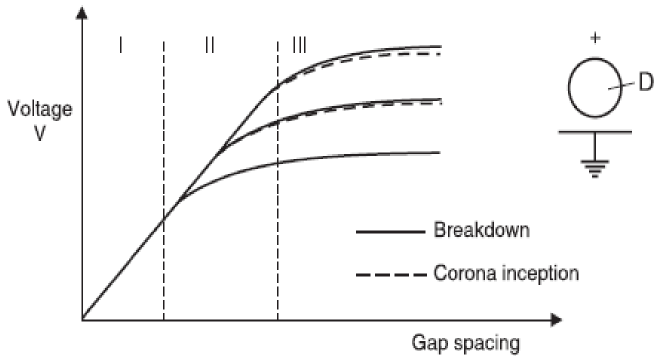
Therefore, under alternating power frequency voltage the breakdown of non-uniform field gap invariably takes place during the positive half cycle of the voltage wave.



When the spacing is small the breakdown characteristics for the two polarities nearly coincide and no corona stabilized region is observed.

As the spacing is increased, the positive characteristics display the distinct high corona breakdown up to a pressure of about 7 bars, followed by a sudden drop in breakdown strengths.

Under the negative polarity, the corona stabilized region extends to much higher pressures.



The above graph shows the corona inception and breakdown voltages of the sphere-plane arrangement.

(i) For small spacing's (Zone–I), the field is uniform and the breakdown voltage depends mainly on the gap spacing.

(ii) In zone–II, where the spacing is relatively larger, the electric field is non-uniform and the breakdown voltage depends on both the sphere diameter and the spacing.

(iii) For still larger spacings (Zone-III) the field is non-uniform and the breakdown is preceded by corona and is controlled only by the spacing. The corona inception voltage mainly depends on the sphere diameter.

6. Explain the properties and characteristics of liquid dielectrics. (May-2005)

<u>The liquid dielectrics are:</u>

The liquid dielectrics mostly used are petroleum oils. Other oils used are synthetic hydrocarbons and halogenated hydrocarbons and for very high temperature applications silicone oils and fluorinated hydrocarbons are also used.

<u>Properties of liquid dielectric are:</u>

i)The dielectric strength

(ii)The dielectric constant

(iii)The electrical conductivity. Other important properties are viscosity, thermal stability, specific gravity, flash point etc.

<u>The factors which affect the dielectric strength of oil are:</u>

- Presence of fine water droplets and the fibrous impurities. The presence of even 0.01% water in oil brings down the dielectric strength to 20% of the dry oil value.
- The presence of fibrous impurities brings down the dielectric strength much sharply. Therefore, whenever these oils are used for providing electrical insulation, these should be free from moisture, products of oxidation
- The main consideration in the selection of a liquid dielectric is its chemical stability.
- The other considerations are the cost, the saving in space, susceptibility to environmental influences etc.

7. Explain briefly various theories of breakdown in liquid dielectrics. (Dec-2008, May-2011,MAY-2013,17,Dec-2013,Dec-14,16,17)

The four theories of breakdown in liquid dielectrics are:

- ✓ Electronic Breakdown
- ✓ Electro convection Breakdown
- ✓ Cavity Breakdown
- ✓ Suspended Solid Particle Mechanism

Electronic Breakdown

Once an electron is injected into the liquid, it gains energy from the electric field applied between the electrodes.

It is presumed that some electrons will gain more energy due to field than they would lose during collision.

These electrons are accelerated under the electric field and would gain sufficient energy to knock out an electron and thus initiate the process of avalanche.

The threshold condition for the beginning of avalanche is achieved when the energy gained by the electron equals the energy lost during ionization (electron emission) and is given by

$e\lambda E = Chv$

where λ is the mean free path, hv is the energy of ionization and C is a constant.

Dielectric strengths of pure liquids:

Liquid Strength (MV/cm)
Benzene 1.1
Goodoil 1.0–4.0
Hexane 1.1–1.3
Nitrogen 1.6–1.88
Oxygen 2.4
Silicon 1.0–1.2

The electronic theory whereas predicts the relative values of dielectric strength satisfactorily, the formative time lags observed are much longer as compared to the ones predicted by the electronic theory.

Suspended Solid Particle Mechanism:

Commercial liquids will always contain solid impurities either as fibers or as dispersed solid particles. The permittivity of these solids (E_1) will always be different from that of the liquid (E_2). Let us assume these particles to be sphere of radius r. These particles get polarized in an electric field E and experience a force which is given as

$$F = r^3 \frac{\epsilon_1 - \epsilon_2}{\epsilon_1 + 2\epsilon_2} E \frac{dE}{dx}$$

and this force is directed towards a place of higher stress if $\varepsilon 1 > \varepsilon 2$ and towards a place of lower stress if $\varepsilon 1 < \varepsilon 2$ when$\varepsilon 1$ is the permittivity of gas bubbles. The force given above increases as the permittivity of the suspended particles ($\varepsilon 1$) increases. If $\varepsilon 1 \rightarrow \infty$

$$F = r^3 E \frac{dE}{dx}$$

Thus, the force will tend the particle to move towards the strongest region of the field. In a uniform electric field which usually can be developed by a small sphere gap, the field is the strongest in the uniform field region.

Here $\frac{dE}{dx} \to 0$ so that the force on the particle is zero and the particleremains in equilibrium. Therefore, the particles will be dragged into the uniform field region. Since the permittivity of the particles is higher than that of the liquid, the presence of particle in the uniform field region will cause flux concentration at its surface.

Other particles if present will be attracted towards the higher flux concentration.

If the particles present are large, they become aligned due to these forces and form a bridge across the gap.

The field in the liquid between the gap will increase and if it reaches critical value, breakdown will take place.

If the number of particles is not sufficient to bridge the gap, the particles will give rise to local field enhancement and if the field exceeds the dielectric strength of liquid, local breakdown will occur near the particles and thus will result in the formation of gas bubbles which have much less dielectric strength and hence finally lead to the breakdown of the liquid.

stressed oil volume mechanism

The movement of the particle under the influence of electric field is opposed by the viscous force posed by the liquid and since the particles are moving into the region of high stress, diffusion must also be taken into account.

We know that the viscous force is given by (Stoke's relation) $F_V = 6\pi\eta r v$ where η is the viscosity of liquid, rthe radius of the particle and vthe velocity of the particle.

Equating the electrical force with the viscous force we have

$$6\pi\eta r v = r^3 E \frac{dE}{dx}$$

$$v = \frac{r^2}{6\pi\eta} E \frac{dE}{dx}$$

However, if the diffusion process is included, the drift velocity due to diffusion will be given by

$$v_d = -\frac{D}{N}\frac{dN}{dx} = -\frac{KT}{6\pi\eta r}\frac{dN}{Ndx}$$

whereD = KT/6πηra relation known as Stokes-Einstein relation. Here K is Boltzmann's constant and Tthe absolute temperature. At any instant of time, the particle should have one velocity and, therefore,equation$v = v_d$

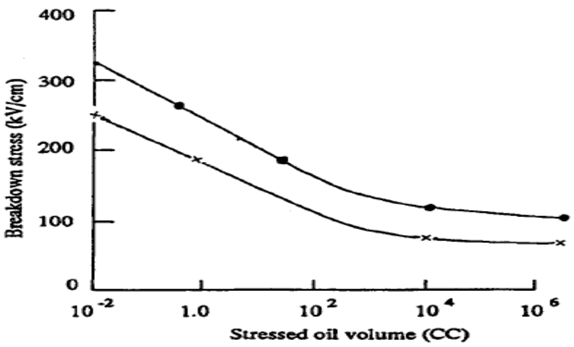
$$-\frac{KT}{6\pi\eta r}\frac{dN}{Ndx} = \frac{r^2}{6\pi\eta} E \frac{dE}{dx}$$

cancel dx both sides

$$\frac{KT}{r}\frac{dN}{N} = r^2\, E\, dE$$

$$\frac{KT}{r}\ln N = r^2 \frac{E^2}{2}$$

It is clear that the breakdown strength *E* depends upon the concentration of particles *N*, radius *r* of particle, viscosity η of liquid and temperature *T* of the liquid. The below fig shows variation of breakdown voltage stress with the stressed oil volume



It has been found that liquid with solid impurities has lower dielectric strength as compared toits pure form. Also, it has been observed that larger the size of the particles impurity the lower theoverall dielectric strength of the liquid containing the impurity.

Cavity Breakdown

It has been observed experimentally that the dielectric strength of liquid depends upon the hydrostatic pressure above the gap length.
The higher the hydrostatic pressure, the higher the electric strength, which suggests that a change in phase of the liquid is involved in the breakdown process.

In fact, smaller the head of liquid, the more are the chances of partially ionized gases coming out of the gap and higher the chances of breakdown.

This means a kind of vapour bubble formed is responsible for the breakdown. The following processes might lead to formation of bubbles in the liquids:
(*i*) Gas pockets on the surface of electrodes.
(*ii*) Due to irregular surface of electrodes, point charge concentration may lead to corona discharge, thus vapourizing the liquid.
(*iii*) Changes in temperature and pressure.
(*iv*) Dissociation of products by electron collisions giving rise to gaseous products.

It has been suggested that the electric field in a gas bubble which is immersed in a liquid of permittivity ε_2 is given by

$$E_b = \frac{3E_0}{\epsilon_2 + 2}$$

Where E_0 is the field in the liquid in absence of the bubble.
The bubble under the influence of the electric field E_0 elongates keeping its volume constant.

When the field $E_b$equals the gaseous ionization field, discharge takes place which will lead to decomposition of liquid and breakdown may follow.
A more accurate expression for the bubble breakdown strength is given as

$$E_b = \frac{1}{\varepsilon_2 - \varepsilon_1}\left\{\frac{2\pi\sigma\,(2\varepsilon_2 + \varepsilon_1)}{r}\left[\frac{\pi}{4}\sqrt{\frac{V_b}{2rE_0}} - 1\right]\right\}^{\frac{1}{2}}$$

where σ is the surface tension of the liquid, ε_2 and ε_1 are the permittivities of the liquid and bubble, respectively, *r* the initial radius of the bubble and $V_b$the voltage drop in the bubble.

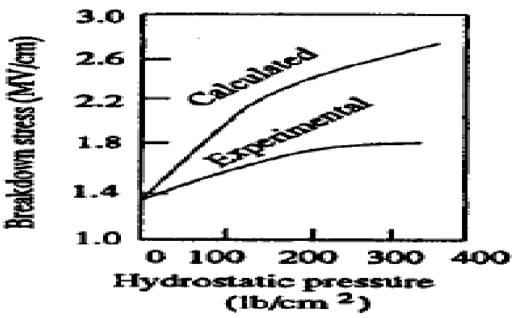
From the expressionit can be seen that the breakdown strength depends on the initial size of the bubble which of course depends upon the hydrostatic pressure above the bubble and temperature of the liquid.
Since the above formation does not take into account the production of the initial bubble, the experimental values of breakdown were found to be much less than the calculated values.

Later on it was suggested that only incompressible bubbles like water bubbles can elongate at constant volume according to the simple gas law $pV = NRT$.

Such a bubble under the influence of electric field changes its shape to that of a prolate spheroid and reaches a condition of instability when β, the ratio of the longer to the shorter diameter of the spheroid is about 1.85 and the critical field producing the instability will be given by

$$E_c=600\frac{\sqrt{\pi\sigma}}{\varepsilon_2 r}\left[\frac{\varepsilon_2}{\varepsilon_2-\varepsilon_1}-G\right]\mathrm{H}$$

For transformer oil ε_2 = 2.0 and water globule with *r* = 1 μm, σ= 43 dynes/cm, the above equation gives E_c= 226 KV/cm.



Theoretical and experimental breakdown stresses in *n*-hexane

Electro convection Breakdown

It has been recognized that the electro convection plays an important role in breakdown of insulating fluids subjected to high voltages.

When a highly pure insulating liquid is subjected to high voltage, electrical conduction results from charge carriers injected into the liquid from the electrode surface.

The resulting space charge gives rise to columbic forces which under certain conditions causes hydrodynamic instability, yielding convecting current. It has been shown that the onset of instability is associated with a critical voltage.

As the applied voltage approaches the critical voltage, the motion at first exhibits a structure of hexagonal cells and as the voltage is increased further the motion becomes turbulent.

Thus, interaction between the space charge and the electric field gives rise to forces creating an eddy motion of liquid.

It has been shown that when the voltage applied is near to breakdown value, the speed of the eddy motion is given by v_e = ε ρ 2 / where ρ is the density of liquid. In liquids, the ionic drift velocity is given by
V_d=KV

where$K$ is the mobility of ions.

Let

$$M\frac{V_e}{V_d} = \sqrt{\frac{\varepsilon_2}{\rho}}/\mathrm{KE}$$

The ratio Mis usually greater than unity and sometimes much greater than unity Thus in the theory of electro convection, Mplays a dominant role.

The charge transport will be largely by liquid motion rather than by ionic drift. The criterion for instability is that the local flow velocity should be greater than drift velocity.

8. Discusses in details any one mechanism of break down in solid dielectric, mention their dielectric properties. (Dec-2007, June-2009,18).

(Or)

Classify the various mechanisms occurring on solid dielectrics explain them briefly. (Dec-2004, June-2012 Dec-2013)

(Or)

State why the very high intrinsic strength of a solid dielectrics is not fully realized in practice? Explain the different mechanisms by which breakdown occurs in solid dielectrics in practice?(Nov 2015)

The various mechanisms are:
(i) Intrinsic Breakdown,
(ii) Electromechanical Breakdown,
(iii) Breakdown Due to Treeing and Tracking,
(iv) Thermal Breakdown,
(v) Electrochemical Breakdown.

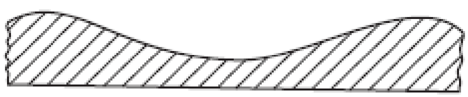
Intrinsic Breakdown

1.Electronic breakdown

If the dielectric material is pure and homogeneous, the temperature and environmental conditions suitably controlled and if the voltage is applied for a very short time of the order of 10^{-8} second, the dielectric strength of the specimen increases rapidly to an upper limit known as intrinsic dielectric strength.

The intrinsic strength, therefore, depends mainly upon the structural design of the material i.e.,the material itself and is affected by the ambient temperature as the structure itself might change slightly by temperature condition.

In order to obtain the intrinsic dielectric strength of a material, the samples are so prepared that there is high stress in the centre of the specimen and much low stress at the corners as shown in Fig



Specimen designed for intrinsic breakdown

The intrinsic breakdown is obtained in times of the order of 10^{-8} sec. and, therefore, has been considered to be electronic in nature.

The stresses required are of the order of one million volt/cm.

The intrinsic strength is generally assumed to have been reached when electrons in the valance band gain sufficient energy from the electric field to cross the forbidden energy band to the conduction band.

In pure and homogenous materials, the valence and the conduction bands are separated by a large energy gap at room temperature, no electron can jump from valance band to the conduction band.

2.Avalanche or streamer breakdown

The conductivity of pure dielectrics at room temperature is, therefore, zero. However, in practice, no insulating material is pure and, therefore, has some impurities and/or imperfections in their structural designs.

The impurity atoms may act as traps for free electrons in energy levels that lie just below the conduction band is small.

An amorphous crystal will, therefore, always have some free electrons in the conduction band.

At room temperature some of the trapped electrons will be excited thermally into the conduction band as the energy gap between the trapping band and the conduction band is small.

As an electric field is applied, the electrons gain energy and due to collisions between them the energy is shared by all electrons.

In an amorphous dielectric the energy gained by electrons from the electric field is much more than they can transfer it to the lattice.

Therefore, the temperature of electrons will exceed the lattice temperature and this will result into increase in the number of trapped electrons reaching the conduction band and finally leading to complete breakdown.

When an electrode embedded in a solid specimen is subjected to a uniform electric field, breakdown may occur.

An electron entering the conduction band of the dielectric at the cathode will move towards the anode under the effect of the electric field.

During its movement, it gains energy and on collision it loses a part of the energy. If the mean free path is long, the energy gained due to motion is more than lost during collision.

The process continues and finally may lead to formation of an electron avalanche similar to gases and will lead finally to breakdown if the avalanche exceeds a certain critical size.

Electromechanical Breakdown

When a dielectric material is subjected to an electric field,charges of opposite nature are induced on the two opposite surfaces of the material and hence a force of attraction is developed and the specimen is subjected to electrostatic compressive forces and when these forces exceed the mechanical withstands strength of the material, the material collapses.

If the initial thickness of the material is d_0 and is compressed to a thickness dunder the applied voltage V then the compressive stress developed due to electric field is

$$F = \frac{1}{2}\varepsilon_0\varepsilon_r\frac{v^2}{d^2}$$

where$\varepsilon_r$is relative permittivity of the specimen.If is the young modulus,the mechanical compressive strength is

$$\gamma \ln\frac{d_0}{d}$$

equating the two under equilibrium condition ,we have

$$\frac{1}{2}\varepsilon_0\varepsilon_r\frac{v^2}{d^2} = \gamma\ln\frac{d_0}{d}$$

$$v^2 = d^2\frac{2\gamma}{\varepsilon_0\varepsilon_r}\ln\frac{d_0}{d}$$

$$v^2 = d^2\,k\ln\frac{d_0}{d}$$

Differentiating with respect to d,we have

$$2v\frac{dv^2}{dd} = k\left[2d\ln\frac{d_0}{d} - d^2\frac{d}{d_0}.\frac{d_0}{d^2}\right] = 0$$

$$2d\ln\frac{d_0}{d} = d$$

$$\ln\frac{d_0}{d} = \frac{1}{2}$$

$$\frac{d_0}{d} = 0.6$$

For any real value of voltage V,the reduction in thickness of the specimen cannot be more than 40%.

If the ratio V/d at this value of V is less than the intrinsic strength of the specimen, a further increase in Vshall make the thickness unstable and the specimen collapses.

The highest apparent strength is then obtained by substituting d = 0.6 $d_0$in the above expressions.

$$\frac{v}{d} = \sqrt{\frac{2\gamma}{\varepsilon_0\varepsilon_r}\ln 1.67}$$

$$\frac{v}{d_0} = E_0 = 0.6\sqrt{\frac{\gamma}{\varepsilon_0\varepsilon_r}}$$

The above equation is approximate only as γ depends upon the mechanical stress. The possibility of instability occuring for lower, average field is ignored.

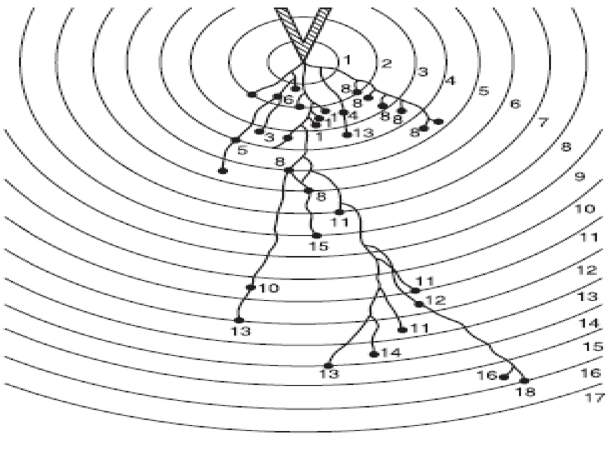
Breakdown due to Treeing and Tracking

- We know that the strength of a chain is given by the strength of the weakest link in the chain. Similarly whenever a solid material has some impurities in terms of some gas pockets or liquid pockets in it the dielectric strength of the solid will be more or less equal to the strength of the weakest impurities.
- Suppose some gas pockets are trapped in a solid material during manufacture, the gas has a relative permittivity of unity and the solid material ε_r,the electric field in the gas will be $\varepsilon_r$times the field in the solid material. As a result,the gas breaks down at a relatively lower voltage.
- The charge concentration here in the void will make the field more non-uniform. The charge concentration in such voids is found to be quite large to give fields of the order of 10 MV/cm which is higher than even the intrinsic breakdown.

  - These charge concentrations at the voids within the dielectric lead to breakdown step by step and finally lead to complete rupture of the dielectric.
  - Since the breakdown is not caused by a single discharge channel and assumes a tree like structure as shown in Fig,below it is known as breakdown due to treeing.
  - The treeing phenomenon can be readily demonstrated in a laboratory by applying an impulse voltage between point plane electrodes with the point embedded in a transparent solid dielectric such as Perspex.
- The treeing phenomenon can be observed in all dielectric wherever non-uniform fields prevail.
- prevention
  using clean, dry, undamaged surface. It is mostly observed in capacitors and cables

Tracking

- Suppose we have two electrodes separated by an insulating material and the assembly is placed in an outdoor environment.
- Some contaminants in the form of moisture or dust particles will get deposited on the surface of the insulation and leakage current starts between the electrodes through the contaminants say moisture.
- The current heats the moisture and causes breaks in the moisture films. These small films then act as electrodes and sparks are drawn between the films.
- The sparks cause carbonization and volatilization of the insulation and lead to formation of permanent carbon tracks on the surface of insulations.
- Therefore, tracking is the formation of a permanent conducting path usually carbon across the surface of insulation.
- For tracking to occur, the insulating material must contain organic substances. For this reason, for outdoor equipment, tracking severely limits the use of insulation having organic substances.
- The rate of tracking can be slowed down by adding filters to the polymers which inhibit carbonization.



- Prevention
  material chosen should be resistant to tracking, moisture repellent greases are used, adding filters to the polymers

Electrochemical Breakdown

Whenever cavities are formed in solid dielectrics, the dielectric strength in these solid specimen decreases. When the gas in the cavity breaks down, the surfaces of the specimen provide instantaneous anode and cathode.

Some of the electrons dashing against the anode with sufficient energy shall break the chemical bonds of the insulation surface.

Similarly, positive ions bombarding against the cathode may increase the surface temperature and produce local thermal instability.

Similarly, chemical degradation may also occur from the active discharge products e.g.,O_3, NO_2 etc. formed in air.

The net effect of all these processes is a slow erosion of the material and a consequent reduction in the thickness of the specimen.

Normally, it is desired that with ageing, the dielectric strength of the specimen should not decrease.

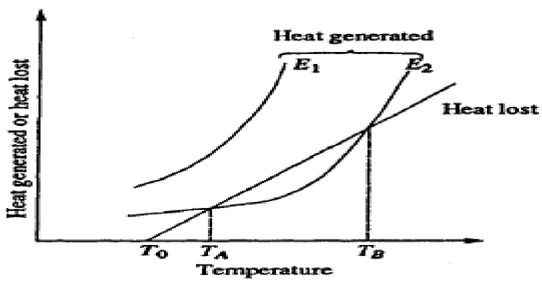
However, because of defects in manufacturing processes and/or design, the dielectric strength decreases with time of voltage application or even without voltage application and in many cases, the decrease in dielectric strength (E_b) with time follows the following empirical relation.

$t\, E_b^n$= constant

where the exponent ndepends upon the dielectric material.

Thermal Breakdown

The breakdown voltage of solid dielectric increase with its thickness.Heat is generated due to flow of current,this current heats up material and further temp rises.The heat generated is transferred to the surrounding medium by conduction through the solid dielectric and by radiation from its outer surfaces. Equilibrium is reached when the heat used to raise the temperature of the dielectric, plus the heat radiated out, equals the heat generated.Breakdown occurs when heat generated exceeds heat dissipated. The thermal instability condition is shown in below Fig.



Breakdown Due to Internal Discharges

Solid insulating materials contain voids orcavities within the medium or at the boundaries between the dielectric and theelectrodes. These voids are generally filled with a medium of lower dielectricstrength, and the dielectric constant of the medium in the voids is lower than that ofthe insulation. Hence, the electric field strength in the voids is higher than that acrossthe dielectric. Therefore, even under normal working voltages the field in the voidsmay exceed their breakdown value, and breakdown may occur.

Let us consider a dielectric between two conductors as shown in Fig.If we divide the insulation into three parts, an electrical network of C_1, C_2,C_3formed as shown in Fig. In this C1 represents the capacitance of the void or cavity, $C_2$is the capacitance of the dielectric which is in series with the void, and C_3 is the capacitance of the rest of the dielectric. When the applied voltage is *V*, the voltage across the void, v_1 is given by the same equation.

$$V_1=\frac{Vd_1}{d_1+d_2\frac{\varepsilon_0}{\varepsilon_1}}$$

where d_1 and d_2 are the thickness of the void and the dielectric, respectively, having permittivities $\varepsilon_0, \varepsilon_1$.

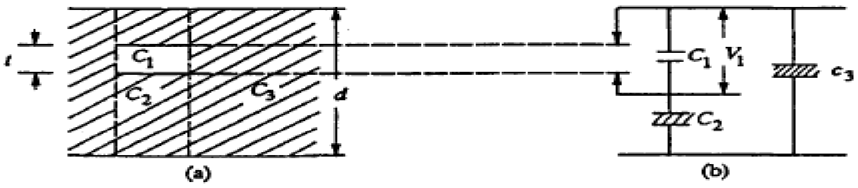
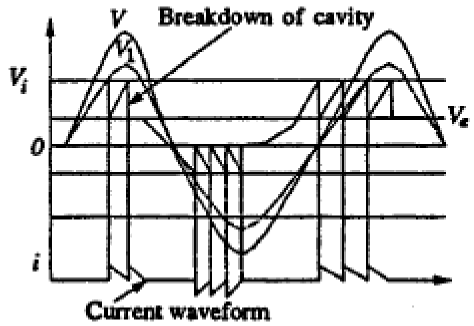


Fig. Electrical discharge in a cavity and its equivalent circuit

When a voltage *V* is applied, V_1 reaches the breakdown strength of the medium in the cavity (V_i) and breakdown occurs. V_i is called the' 'discharge inception voltage". When the applied voltage is a.c., breakdown occurs on both the half cycles and the number of discharges will depend on the applied voltage.



Sequence of cavity breakdown under alternating voltages

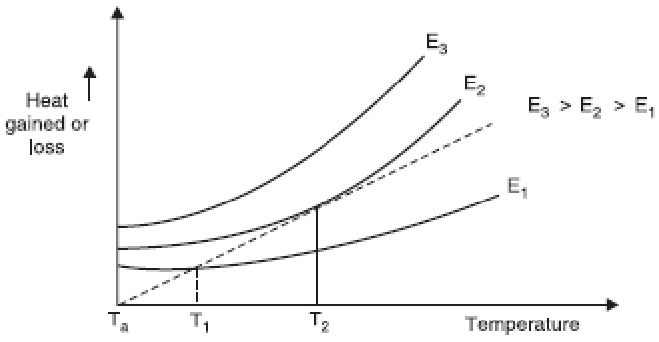
9. Explain the phenomenon of thermal breakdown in solid dielectrics. Derive an expression for critical thermal breakdown voltage (V_C) and critical electrical field (E_C) for the same. State clearly assumption made. (May-2008,May-2014)

The insulating material is subjected to an electric field, the material gets heated up due to conduction current and dielectric losses due to polarization.

The conductivity of the material increases with increase in temperature and a condition of instability is reached when the heat generated exceeds the heat dissipated by the material and the material breaks down.

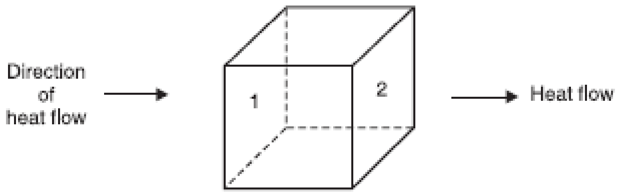
Fig below.Shows various heating curves corresponding to different electric stresses as a function of specimen temperature.

Assuming that the temperature difference between the ambient and the specimen temperature is small, Newton’s law of cooling is represented by a straight line.



Thermal stability or instability of different fields

The test specimen is at thermal equilibrium corresponding to field E_1 at temperature T_1 as beyond that heat generated is less than heat lost. Unstable equilibrium exists for field E_2 at T_2, and for field E_3 the state of equilibrium is never reached and hence the specimen breaks down thermally.



In order to obtain basic equation for studying thermal breakdown, let us consider a small cube within the dielectric specimen with side Δx and temperature difference across its faces in the direction of heat flow (assume here flow is along x-direction) is ΔT. Therefore, the temperature gradient is

$$\frac{\Delta T}{\Delta x} = \frac{dT}{dx}$$

Let $\Delta x^2 = A$. The heat flow across face 1

$KA \frac{dT}{dx}$joules

Heat flow across face 2

$$KA \frac{dT}{dx} = KA \frac{d}{dx}(\frac{dT}{dx})\Delta x$$

Here the second term indicates the heat input to the differential specimen. Therefore the heat adsorbed by the differential cube volume

$$\frac{KA\ \frac{d}{dx}\left(\frac{dT}{dx}\right)\Delta x}{\Delta V} = K\ \frac{d}{dx}\left(\frac{dT}{dx}\right)$$

The heat input to the block will be partly dissipated into the surrounding and partly it will raise the temperature of the block. Let CV be the thermal capacity of the dielectric, σ the electrical conductivity, E the electric field intensity.

The heat generated by the electric field = σE_2 watts, and suppose the rise in temperature of the block is ΔT, in time dt, the power required to raise the temperature of the block by ΔT is

$C_v \frac{dT}{dx}$watts

Therefore $C_v \frac{dT}{dx} + K\ \frac{d}{dx}\left(\frac{dT}{dx}\right) = \sigma E^2$

Which thermal instability will reach and the dielectric will lose its insulating properties. However, unfortunately the equation can be solved in its present from CV, K and σ is all functions of temperature and in fact σ may also depend on the intensity of electrical field.

Therefore, to obtain solution of the equation, we make certain practical assumptions and we consider two extreme situations for its solution.

Case 1: Assume that the heat adsorbed by the block is very fast and heat generated due to the electric field is utilized in raising the temperature of the block and no heat is dissipated at is known as impulse thermal breakdown. The main equation reduces to

$$C_v \frac{dT}{dx} = \sigma E^2$$

The objective now is to obtain critical field strength E_c which will generate sufficient heat very fast so that above requirement is met, Let

$$E = \left(\frac{E_c}{t_c}\right)t$$

i.e the field is a ramp function

$$\sigma E^2 = C_v \frac{dT}{dt} = C_v \frac{dT}{dE} . \frac{dE}{dt}$$

$$\sigma = \sigma_0 e^{-\frac{u}{KT}}$$

Where K is the Boltzmann's constant and $\sigma_0$is the conductivity at ambient temperatureT_0

Substituting these values in the simplified equation, we have

$$\sigma_0 e^{-\frac{u}{KT}} E^2 = C_v \frac{dT}{dE} . \frac{dE}{dt}$$

$$\frac{dE}{dt} = \left(\frac{E_c}{t_c}\right)$$

therefore

$$\sigma_0 e^{-\frac{u}{KT}} E^2 = C_v \frac{dT}{dE} . \frac{E_c}{t_c}$$

$$\sigma_0 E^2 \frac{t_c}{E_c} dE = C_v \frac{dT}{e^{-\frac{u}{KT}}}$$

$$\frac{\sigma_0}{C_v} E^2 \frac{t_c}{E_c} dE = \frac{dT}{e^{-\frac{u}{KT}}}$$

$$\frac{\sigma_0}{C_v} \frac{t_c}{E_c} E^2 dE = dT\, e^{+\frac{u}{KT}}$$

integrate on both sides

$\frac{\sigma_0}{C_v} \frac{t_c}{E_c} \int_0^{E_c} E^2 dE = \int_{T_0}^{T_c} e^{+\frac{u}{KT}} \;\; dT$The integral on left hand side

$$\frac{\sigma_0}{C_v} \frac{t_c}{E_c} \int_0^{E_c} E^2 dE = \frac{\sigma_0}{C_v} \frac{t_c}{3E_c} {E_c}^3$$

The integral on Right hand side

$$\int_{T_0}^{T_c} e^{+\frac{u}{KT}} \;\; dT = \frac{k}{u} e^{+\frac{u}{KT}} {T_0}^2$$

Where $T_c \ggg\!> T_0$

Therefore

$$E_c = \frac{3C_v}{\sigma_0 t_c} \frac{k{T_0}^2}{u} e^{+\frac{u}{KT}}$$

10. Explain the various mechanisms (processes) of electric breakdown in vacuum. (Dec-2008,May-2011, Dec-2013,17,May-2014,17)

The following mechanisms are:
(i) Field emission; (ii) Thermionic emission; (iii) Field and Thermionic emission; (iv) Secondary emission by positive ion bombardment; (v) Secondary emission by photons; and (vi) Pinch effect.

<u>Non-metallic Electron Emission Mechanism</u>

The pre-breakdown conduction current in vacuum normally originates from a nonmetallic electrode surface.

These are present in the form of insulating/semiconducting oxide layer on the surfaces or as impurities in the electrode material.

These micro inclusions present in the electrode surface can produce strong electron emission and significantly reduce the break down strength of the gap.

Even when a vacuum system is completely sealed off, the electrode surfaces may still get contaminated.

It has been observed that when glass is heated to ‘its’ working temperature for sealing the electrodes into a closed container, fluxes are vaporized from the glass which get deposited in the cool inner surfaces in the form of spherical particles up to a μm diameter .

Therefore, the surface of a sealed electrode may have on its surface contaminates e.g., sodium, potassium, boron aluminium and silicon.

When an electric field is applied across such electrodes the oxides adsorbates and dust particles, then undergo chemical changes e.g., oxides and adsorbates undergo chemical reactions which are initiated by photons, electrons and ions and thus these contaminants limit the maximum field intensity for the following reasons:

(i) The adsorbates and dust enhance the field emission of electrons.

(ii) The oxides adsorbates and dust particles enhance the secondary electron emission.

(iii) The oxides adsorbates and dust particles exhibit stimulated desorption of molecules and ions under the impact of electrons, protons or ions.

Due to these mechanism, there is increase in electron emission process and therefore, more electric field energy is converted into kinetic energy of electron and ions which leads to an increase in surface energy of the metal.

Thus, the electric strength of the gap may reduce to a level as low as 10 kV/ cm as compared to 104 kV/cm which is required for the field emission process.

Clump Mechanism

The vacuum breakdown mechanism based on this theory makes following assumption:

(i) A loosely bound particle known as clump exists on one of the electrode surfaces.

(ii) When a high voltage is applied between the two electrodes, this clump gets charged and subsequently gets detached from the mother electrode and is attracted by the other electrode.

(iii) The breakdown occurs due to a discharge in the vapour or gas released by the impact to the particle at the opposite electrode.

It has been observed that for a certain vacuum gap if frequent recurrent electric breakdowns are carried out, the withstand voltage of the gap increases and after certain number of breakdown, it reaches an optimum maximum value.

This is known as conditioning of electrodes and is of paramount importance from practical reasons. In this electrode conditioning, the micro-emission sites are supposed to have been destroyed.

Various methods for conditioning the electrodes have been suggested. Some of these are

(i) To treat the electrodes by means of hydrogen glow discharge. This method gives more consistent results.

(ii) Allowing the pre-breakdown currents in the gap to flow for some time or to heat the electrodes in vacuum to high temperature.

(iii) Treating the electrodes with repeated spark breakdown. This method is however quite time consuming.

The area of electrodes for breakdown of gases, liquids, solids or vacuum plays an important role. It has been observed that if the area of electrodes is increased for the same gap distance in uniform field, the breakdown voltages are reduced.

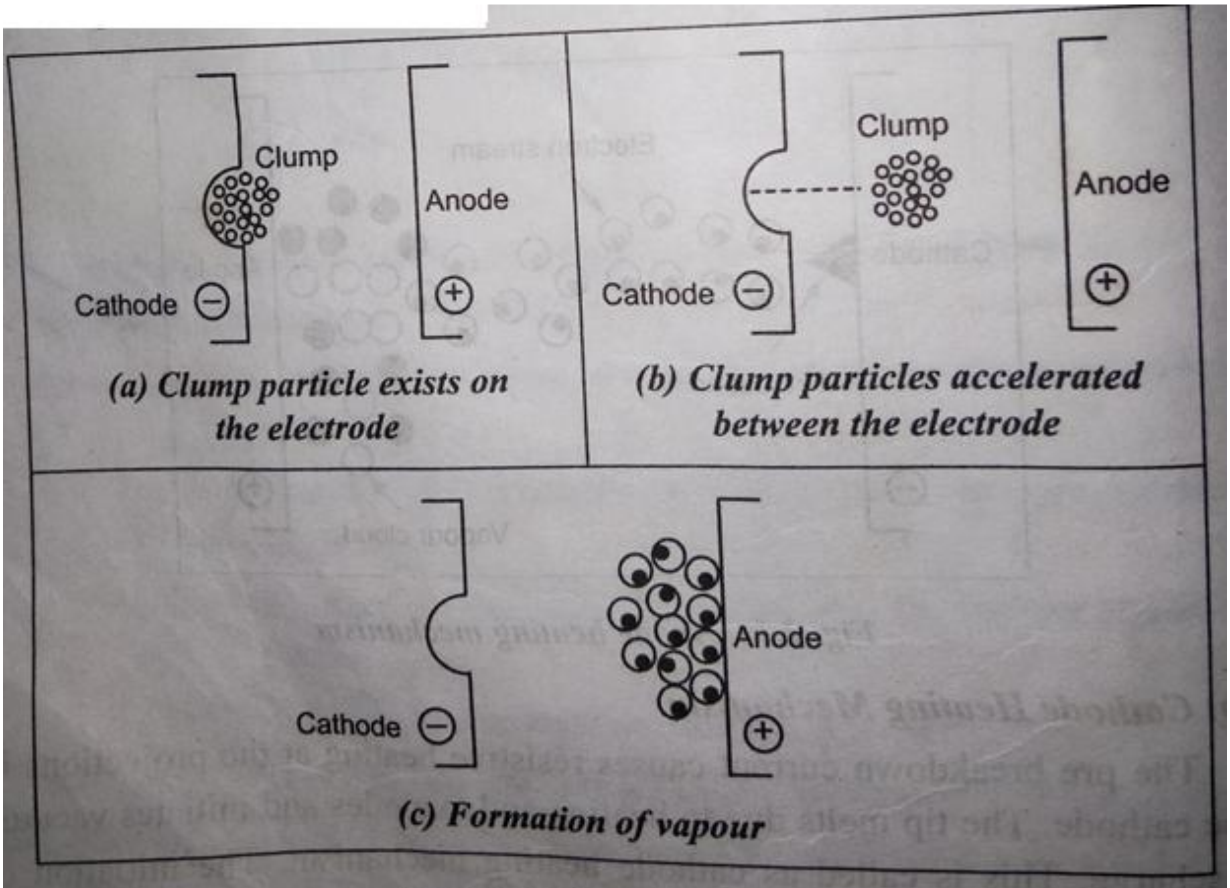


Fig. 2.16. Clump mechanism

11. List the properties of composite dielectric and short term breakdown. (Dec-2008, May-2011,MAY-17)

(OR)

i)Discuss the important properties of composite dielectrics

ii)Discuss the various mechanisms of breakdown in composite dielectrics(Dec 2015)

Different dielectric materials can be in parallel with each other (air or SF_6 gas in parallel with solid insulation) or in series with one another.Such insulating systems are called as composite dielectrics.

Properties of composite Dielectric:(Dec 2015)

Effect of multiple layer:

- Different layers of dielectric have a higher dielectric strength than a single dielectric.
- Significant in having a wide variations of dielectric strength measured at different points on its surface.

Effect of Layer Thickness:

- Breakdown voltage increases with increase in layer thickness. Breakdown occurs at the interfaces and note at other layer in case of layered constructions.

- In case of insulating paper with layered construction, the thickness varies from point to point and the dielectric strength varies. Variation of thickness gives a rough surface which helps for better impregnation. Low thickness of paper causes breakdown.

Investigations on composite Dielectrics:

- Thickness of the solid dielectric.
- Dielectric constant of liquid and solid dielectric

Effect of interfaces:

- Pre-breakdown
- Breakdown strength.

Breakdown mechanism in composite Dielectrics(Dec-14)(Dec 2015)

They are two types of breakdown mechanism in composite dielectric they are.

- Short-term Breakdown.
- Long-term Breakdown.

Short-Term Breakdown:

When the applied electric field is high, failure may occur in seconds or even faster without damaging the insulating surface prior to breakdown is called as short-term breakdown.

When the applied voltage is very close to the breakdown voltage, breakdown of composite dielectric occurs due to discharges.

The discharges of given magnitude can enter the insulation from the surface and propagate rapidly into its volume under critical stress to cause breakdown.

Breakdown strength increases due to

- The presence of more electrons (bombarding particles) than positive ions.
- Local field intensifications due to
    - The presence of impurities.
    - Variations in the thickness of solid insulations.

Long-Term Breakdown:

Long term breakdown occurs due to aging of insulations from thermal process and partial discharges. Long term breakdown arise due to the following.

- Ageing and breakdown due to partial discharges.
- Ageing and breakdown due to accumulation of charges on insulator surfaces.

Ageing and break down due to partial Discharges:

In composite dielectric, gas filled cavities will be present within the dielectric or adjacent to the interface between the conductor and the dielectrics.

When voltage is applied to the dielectric, discharges takes place within gas filled cavities. These discharges are called as partial discharges.

Failure of composite dielectric occurs depends on:

- Geometry of the cavity.
- Nature of the dielectric.

The degree of ageing depends on discharge inception voltage. The discharge inception voltage depends on:

Permittivity of the dielectrics ε_r

Thickness of the cavity,g.

$$\therefore V_i = \left(\frac{E_g}{\varepsilon_r}\right)(t+\epsilon_r g) ----------------------\rightarrow (1)$$

Where E_g=breakdown strength of the cavity.

t=Thickness of dielectric.

Assume(g+t) is a constant, say C

Adding and subtracting g in equation (1),We get

$$V_i = \frac{E_g}{\varepsilon_r}(t+g+\varepsilon_r g - g)$$

$$= \frac{E_g}{\varepsilon_r}[(\varepsilon_r - 1)g + C] ----------------------(2)$$

Differentiating equation (2) with respect to g,we get

$$\frac{dV_i}{d_g} = \frac{(\varepsilon_{r-1})}{\varepsilon_r}E_g + \frac{\varepsilon_{r-1}}{\varepsilon_r}g\frac{dE}{dg} + \frac{c}{\varepsilon_r}\frac{dE}{dg} = \frac{(\varepsilon_{r-1})}{\varepsilon_r}\left\{E_g + g\frac{dE}{dg} + \frac{C}{\varepsilon_r - 1}\frac{dE}{dg}\right\}\frac{dV_i}{d_g}$$

$$= \frac{(\varepsilon_{r-1})}{\varepsilon_r}\left\{E_g + \frac{dE}{dg}\left(g + \frac{C}{\varepsilon_r - 1}\right)\right\} -------------(3)$$

Where $E_g = Positive, \frac{dE}{dg} = Negativeorzero$

Assumptions:

- $E_g = \varepsilon_r . E$
- $\frac{E_g(max)}{E_g} = 1$

Where E=Applied electric field

Paschen's curve can be used to explain breakdown of the gas gap when these assumptions are valid. When the voltage is applied, the breakdown of gas in the cavity occurs, and discharge progresses.

This discharge cause rise in temperature and pressure of gas. This causes decrease in the extinction voltage levels and erosion of cavity occurs.

Conclusions:

V_i decreases as cavity depth increases and follows Paschen's curve.
E<2 $V_{i,}$ erosion of cavity occurs but breakdown will not takes place and the life of insulating is long.
E> 2 $V_{i,}$ erosion and break down takes place due to ageing.

Aging and breakdown due to accumulation of charges on insulator surfaces:

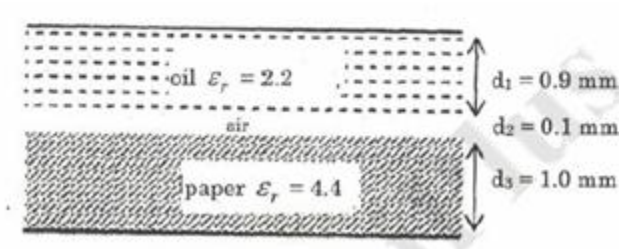
When electric field is applied to the composite dielectric, discharge occurs due to the charges (Electron or positive ions) gets deposited on the solid insulator surface.

These charges stays for a long durations (ays or weeks).this accumulation of charges increases the conductivity and increases the discharged magnitudes which causes damage to the dielectric surface. The discharge increases as the life of the insulation increases.

For clean surface,V_i value depends on on:

- Nature of dielectric
- Size of dielectric
- Shape of Dielectric

12.A certain dielectric can be considered to be represented by the equivalent circuit shown in figure.1.What is the maximum voltage that can be applied across the dielectric, If partial discharges in air to be avoided? State any assumption made(April/May 2015)



Permittivites of dielectric:K_1, K_2, K_3

$$E_i = \frac{\sigma}{\varepsilon_0 K_1}$$

Where i=1,2,3 and maximum applied voltage across each dielectric is represented by E_1,E_2,E_3, ε_0 - is the permittivity of free space,σ-charge density i.e charge per unit area

Assume $\sigma = 10^{-7} coloumb/m^2$

$$E_1 = \frac{\sigma}{\varepsilon_0 K_1} = \frac{10^{-7}}{2.2 \times 8.854 \times 10^{-12}} = 5133.7 \text{ v/m}$$

$E_2 = \frac{\sigma}{\varepsilon_0 K_2} = \frac{10^{-7}}{1 \times 8.854 \times 10^{-12}} = 11294.3$ v/m

$E_3 = \frac{\sigma}{\varepsilon_0 K_3} = \frac{10^{-7}}{4.4 \times 8.854 \times 10^{-12}} = 2566.8$ v/m

Total voltage across dielectric $\Delta V = E_1 d_1 + E_2 d_2 + E_3 d_3$

Where d_1, d_2, d_3 are thickness of the dielectrics

$\Delta V = 5133.7 \times 0.9 \times 10^{-3} + 11294.3 \times 0.1 \times 10^{-3} + 2566.8 \times 1 \times 10^{-3}$

$\Delta V = 4.620 + 1.129 + 2.5668$

$\Delta V = 8.3158$ V

UNIVERSITY QUESTIONS

PART-A

1. Name A Few Gases Used As Insulation Medium? **(May-2005)**
2. Explain why Electro negative gas has high BD value? **(June-2012)**
3. Distinguish between BD in uniform field and BD in Non uniform field? **(Dec-2007)**
4. Explain why Electro negative gas has high BD value? **(June-2012)**
5. Distinguish between BD in uniform field and BD in Non uniform field? **(Dec-2007)**
6. What is Paschens Law? **(Dec-2004,May-2005,Dec-2007,08,11)**
7. Distinguish between the BD in pure liquid & commercial liquid? **(DEC-2013)**
8. What are the various theories of BD of commercial liquids? **(Dec-2008)**
9. What is 'TRACKING' and 'TREEING' is solid dielectric B.D? **(NOV-2012)**
10. What is meant by corona discharge? **(May-june 2013)**
11. What are electronegative gases? **(May-june 2013)**
12. What are the properties required for a gaseous dielectric for HV applications? **(DEC-2013)**
13. What is Time lag for Break Down? **(Dec-14)**
14. What is meant by Intrinsic strength of a solid dielectric? **(Dec-14)**
15. What is mean by penning effect. **(May-2014)**
16. What are the factors which affect breakdown of gaseous dielectrics? **(May-2014)**
17) Name the various secondary ionization processes involved in gaseous dielectric breakdown? **(Nov 2015)**
18) What are electronegative gases? (May-june 2013)(**NOV 2015**)
19) What is Town-sends condition for Breakdown?(May 2015)
20) Define statistical time lag and formative time lag **?(May 2015)**
21) Define Gas law.Dec-16
*22)*What is ionization by collision.Dec-16

PART-B

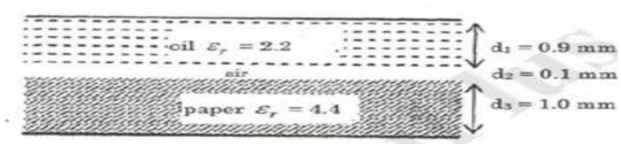
1. Explain Townsend's criterion for a spark **.(June-2009, May-2011)(May 2015)(Dec-2016)**

2. State the criteria for sparking potential and hence obtain the relation between sparking potential and (pd) values (Paschens Law).discuss on the nature of variation of sparking potential with (pd) values**.(Dec-2007, MAY-2013, Dec-14)(May 2015)**
3.Discuss Meek's theory of breakdown in gases under non-uniform field. **(May-2008)**
4.What are the preferred properties of gaseous dielectric for high voltage applications? **(May-2005)**
5.Explain clearly breakdown in non-uniform fields and corona discharge. **(Dec-2004, June-2012, Dec-2013)**
6.Explain the properties and characteristics of liquid dielectrics.**(May-2005)**
7.Explain briefly various theories of breakdown in liquid dielectrics. **(Dec-2008,May-2011,MAY-2013,Dec-2013, Dec-14,16)**
8.Classify the various mechanisms occurring on solid dielectrics explain them briefly. **(Dec-2004, June-2012 Dec-2013)(Dec 2015)**
Discuss STREAMER OR KANAL MECHANISM OF SPARK in gases under non-uniform field**.(MAY-2014)**
9)Explain the phenomenon of thermal breakdown in solid dielectrics. Derive an expression for critical thermal breakdown voltage (V_C) and critical electrical field (E_C) for the same. State clearly assumption made.**(May-2008,May-2014)**

10)Explain the various mechanisms (processes) of electric breakdown in vacuum. **(Dec-2008,May-2011, Dec-2013,May-2014)**

11)List the properties of composite dielectric and short term breakdown**. (Dec-2008, May-2011)(Dec 2015)**

12.A certain dielectric can be considered to be represented by the equivalent circuit shown in figure.1.What is the maximum voltage that can be applied across the dielectric, If partial discharges in air to be avoided? State any assumption made(April/May 2015)



UNIT-3
TWO MARKS

1. What is the necessity for generating high voltages?(May-2014)

- ✓ Applications like electric microscope,
- ✓ X rays, particle accelerators,
- ✓ Electrostatic precipitators etc.
- ✓ Testing power apparatuses.
- ✓ Insulation testing.

2. What are the various methods available for generating High DC voltage?

- ➢ Half & full wave rectifiers.
- ➢ Voltage multiplayer circuits, Cockcroft Walton Circuit Delta-tran/Engi-tran
- ➢ Van de Graff generators.
- ➢ Electro static generators.

3. What is the expression for average ripple in a Cock- craft Walten voltage multipler?

$\delta v = I[2n(2n+1)]/fC\ 2$

Where δv = total ripple

I = the current

n = number stages

f = frequency of input voltage.

4. What is the expression for regulation (drop in voltage) ∆v in a cock croft Walten method?

$\Delta v = 2/fc\ [(2n_3/3) + (n_2/2) - (n/6)]$

Where Δv = voltage drop

f = frequency

c = capacitance

n = number of stages

5. Give the expression for optimum number of stages in a cock croft Walter voltage multiplier ?

$N_{optimum} = \sqrt{V_{max}}.\ F_c/I_f$

WhereV max = Maximum of voltage

f = frequency

c = capacitance

I = current

6. State the principle of Van de Graff generator? (M/J-2009)

Mechanical energy is directly converted into electrostatic, electrical energy (without any electromagnetic conversion, as in the case of an electromagnetic machine like synchronous generator).

7. How Impulse voltages are produced in the lab?(M/J-2012)

Capacitors previously charged to DC voltage is discharged into a wave shaping network(LR, R1 R2, R3 or other combination) by closing a switch. This gives the desired output (double exponential wave).

8. What is the principle of Marx circuit?

A bank of capacitors are charged in parallel and then discharged in series into a wave shaping network to produce a lighting impulse voltage, double exponential fast rising & slow decaying voltage.

9. How switching Impulse voltage can be produced in the lab?

- Impulse generator circuits can be used by suitably modifying the R1 & R2.
- Power Tr or Testing Tr, excited by dc voltages giving oscillatory wave (Tesla coill)

10. What are the components of a multistage impulse generator?

Dc charging unit, charging resistors, generator capacitors and spark gaps , wave shaping resistors and capacitors , triggering system , voltage dividers and gas insulated impulse generators.

11. Define the duration of the wave.

It is defined as the total time of the wave during which the current is at least 10% of its peak value.

12. How is impulse currents of large value produced?(A/M-2005)

A bank of capacitors connected in parallel are charged to a specified value and are discharged through a series R-L circuit.

13. How will you generate rectangular current pulses with high magnitudes?(N/D-2004)

They are generated by discharging a pulse network.

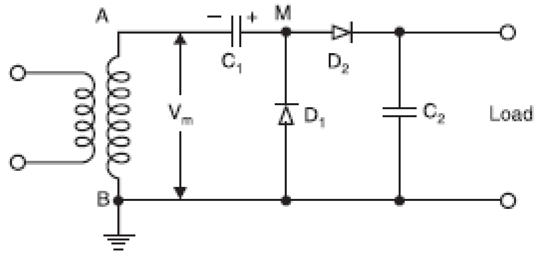
14. What is trigatron gap? Mention the advantage of trigatron gap?(Dec-14,MAY-17)

A **trigatron** is a type of triggerable spark gap switch designed for high current and high voltage, (usually 10-100 kV and 20-100 kA, though devices in the mega-ampere range exist as well).It requires much smaller voltage for operation compared to the three-electrode gap.

15. What are the components of a trigatron gap?

It consists of a high voltage spherical electrode of suitable size, an earthed main electrode of spherical shape and a trigger electrode through the main electrode.

16. Draw the voltage doubler circuit.



17. What are the disadvantage of using cascade transformer with isolating transformer?(N/D-2007,A/M-2011)

- Expensive and requires more space due to the use of more units.
- Difficult to repair.

18.What are the advantages of using cascade transformer with isolating transformer?

(N/D-2009)

- Natural cooling is sufficient.
- Transformers are compact size.
- Constructional is identical.
- Three phase connection in star or delta possible.

19) Define rise time or front time Fall time?(Dec-2013)

- It is the time required or the response to raise from 10% to 90 % or 0 to 100% of the final value at the very first instance.
- Rise time of standard impulse wave 0f 1.2/50μs,1000 KV-1.2 μs
- Fall or tail time to 50% peak value

20)What is peak value?

The maximum positive deviations of the output wth respect to its desired value are known as peak value.

21) What is tesla coil?(N/D-2008, 2016April-18)

- Power Tr or Testing Tr, excited by dc voltages giving oscillatory wave will produce by using (Tesla coill).

22) What are the impulse wave specifications?(A/M-2008,M/J-2009,MAY-2013)

The impulse waveform can be specified by,

- Rise or front time.
- Fall or tail time to 50% peak value.

- Peak value.
- Delay time.

23) Give any two methods of switching surge generations in laboratory? (MAY-JUNE 2013)

- Impulse generator circuit modified to give longer durations wave shapes.
- Power transformer or testing transformer excited by DC voltages.

24)What are the disadvantage of half wave rectifier circuit?(DEC-2013)

The single phase half-wave rectifier circuits have the following disadvantages:
(*i*) The size of the circuits is very large if high and pure d.c. output voltages are desired.
(*ii*) The h.t. transformer may get saturated if the amplitude of direct current is comparable with the nominal alternating current of the transformer.
It is to be noted that all the circuits considered here are able to supply relatively low currents and therefore are not suitable for high current applications such as HVDC transmission.

25) what are the advantage of series resonance circuit?(may-2014)

(i) The power requirements in KW of the feed circuit are (kVA)/Q where kVA is the reactive power requirements of the load and Q is the quality factor of variable reactor usually greater than 40. Hence, the requirement is very small.

(ii) The series resonance circuit suppresses harmonics and interference to a large extent. The near sinusoidal wave helps accurate partial discharge of measurements and is also desirable for measuring loss angle and capacitance of insulating materials using Schering Bridge.

(iii) In case of a flashover or breakdown of a test specimen during testing on high voltage side, the resonant circuit is detuned and the test voltage collapses immediately.

(iv) No separate compensating reactors (just as we have in case of test transformers) are required. This results in a lower overall weight.

(v) When testing SF6 switchgear, multiple breakdowns do not result in high transients. Hence, no special protection against transients is required.

(vi) Series or parallel connections of several units is not at all a problem. Any number of units can be connected in series without bothering for the impedance problem which is very severely associated with a cascaded test transformer. In case the test specimen requires large current for testing, units may be connected in parallel without any problem.

26) What are the advantages of cascaded transformer units for HVAC generation (D-14)

I.The advantage of this scheme is that the natural cooling is sufficient
ii.Transformers are light and compact.
iii. Transportation and assembly is easy.
iv. Also the construction is identical for isolating transformers and the high voltage cascade units.
v. Three phase connection in delta or star is possible for three units.
vi. Testing transformers of ratings up to 10 MVA are cascade connections to give high voltages up to 2.25 MV are available for both indoor and outdoor applications.

27) What are the difference between a high voltage testing transformer and a power transformer? APRIL/MAY-2015

HIGH VOLTAGE TESTING TRANSFORMER	POWER TRANSFORMER
high voltage testing transformers are used for lower voltage distribution networks as a means to end user connectivity. (11kV, 6.6 kV, 3.3 kV, 440V, 230V) and are generally rated less than 200 MVA.	Power transformers are used in transmission network of higher voltages for step-up and step down application (400 kV, 200 kV, 110 kV, 66 kV, 33kV) and are generally rated above 200MVA.
A high voltage testing transformer may have one primary and one divided or "Tapped" secondary, or two or more secondaries.	A power transformer usually has one primary and one secondary, and one input and output.
A high voltage testing transformer operates at light loads during major parts of the day.	Power transformers generally operate at nearly full – load.
The performance of a high voltage testing transformer is judged from all – day – efficiency.	The performance of the power transformers is generally judged from commercial efficiency
flux density is low	flux density is high

28) What do you mean by tracking index? APRIL/MAY-2015

The numerical value of voltage that initiates or causes the formation of a track is called the "tracking index" and this is used to qualify the surface properties of dielectric materials.

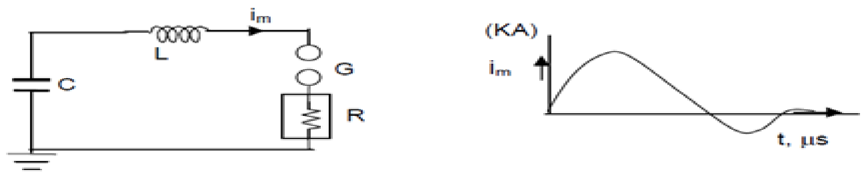
29) Mention the specification of impulse current as per Indian standard.(NOV-2015)

Diverter class	Diverter rating	Impulse current rating (8/20 μs) (amperes)	High current rating (8/20 μs) (amperes)	Long duration rating – duration is given in μs (amperes)
A	Low voltage (230V to 600V)	1500 to 2500	10,000	50-500μs
B	Distribution voltages(400V to 33kV)	5000	65,000	75-1000μs
C	Station type lighting arresters (11kV and above)	10,000	100,000	150-2000μs

30.Give any two methods of switching surge generations in laboratory? (May-june 2013)

- Impulse generator circuit modified to give longer durations wave shapes.
- Power transformer or testing transformer excited by DC voltages.

31) How is the circuit inductance controlled and minimizes in impulsemesurements?(NOV-15)



(a) Basic circuit of an impulse current generator

(b) Impulse current waveform

- The impulse current is generated by bank of capacitors connected in parallel are charged from dc source to certain voltage and discharged into RL circuit, The resistance R decides the wave front and wave tail of the impulse wave form. The inductance L decides the magnitude of the impulse current, air cored high current inductor usually a spiral tube of a few turns is used ie low inductance is needed in order to get high current magnitudes.

32.what is DELTATRON or ENGETRON circuit.Dec-16

A combination of cock-croft Walton type voltage multiplier with cascaded transformer DC rectifier used for very voltage but limited output current having high stability, small ripple factor and fast regulation. This circuit is called DELTATRON or ENGETRON circuit.

33.A 12 stage impulse generator has 0.12microfared capacitors. The wave front and wave tail resistances connected are 400ohms and 600ohms respectively. If the load capacitor is 800 pf. Find the front and tail time of the impulse wave produced.MAY-2017

TO FIND:

t_1 and t_2

SOLUTION:

C_1=0.12/12=0.01 microfarad

C_2=0.008 microfarad

R_1=400ohm

R_2=600 ohm

Time to front t_1= $3(R_1)(C_1C_2/C_1+C_2)$

=3(400)(0.01x0.008x10^-6)/(0.01+0.008x10^-6)

=9.599x10^-6 sec

Time to tail t_2= $0.7(R_1+R_2)(C_1+C_2)$

=0.7(400+600)(0.01+0.008x10^-6)

= 7 sec

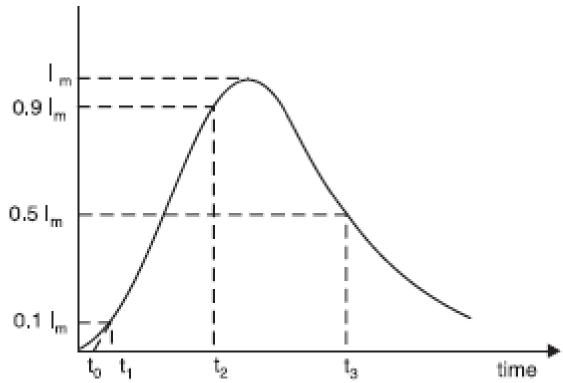
34.What are the advantages of Vande-Graff generator ?Nov/Dec-17

(*i*) Very high voltages can be easily generated

(*ii*) Ripple free output

(*iii*) Precision and flexibility of control

35.Draw the standard. impulse waveform. Nov/Dec-17



36.What is cascade transformer.April/May-18

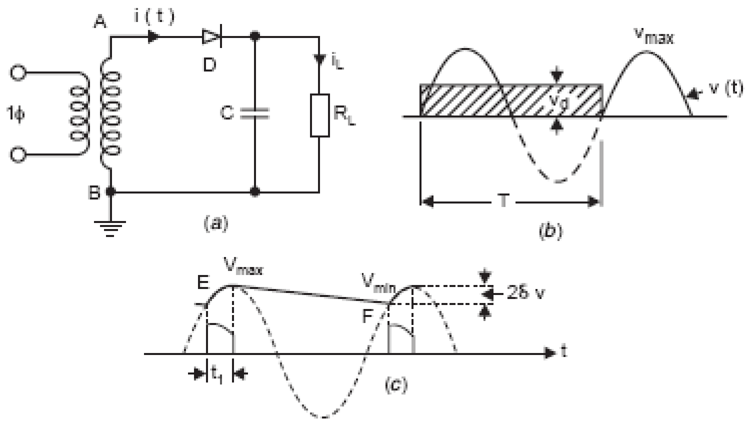
A high-voltage source consisting of a limited number of step-up **transformers** with their secondaries in series, the primary of each after the first being supplied from a pair of taps on the secondary of the preceding.

PART-B

1. **Explain any one method of voltage multiplier circuits.(M/J-2012,N/D-2004,M/J-2011)**

- The simplest circuit for generation of high direct voltage is the half wave rectifier shown in Fig. Here RL is the load resistance and C the capacitance to smoothen the d.c. output voltage.
- If the capacitor is not connected, pulsating d.c. voltage is obtained at the output terminals whereas with the capacitance C, the pulsation at the output terminal are reduced.
- Assuming the ideal transformer and small internal resistance of the diode during conduction the capacitor C is charged to the maximum voltage V_{max}during conduction of the diode D.
- Assuming that there is no load connected, the d.c. voltage across capacitance remains constant at V_{max}whereas the supply voltage oscillates between $+V_{max}$and during negative half cycle the potential of point A becomes – $V_{max}$and hence the diode must be rated for $2V_{max}$.

- This would also be the case if the transformer is grounded at A instead of B as shown in Fig. below. Such a circuit is known as voltage doublerdue to Villard for which the output voltage would be taken across D. This d.c. voltage, however, oscillates between zero and $2V_{max}$and is needed for the Cascade circuit.



- If the circuit is loaded, the output voltage does not remain constant at V_{max}. After point E.
- The supply voltage becomes less than the capacitor voltage, diode stops conducting. The capacitor can not discharge back into the a.c. system because of one way action of the diode. Instead, the current now flows out of C to furnish the current $I_L$through the load.
- While giving up this energy, the capacitor voltage also decreases at a rate depending on the time constant CR of the circuit and it reaches the point F corresponding to V_{min}.
- Beyond F, the supply voltage is greater than the capacitor voltage and hence the diode D starts conducting charging the capacitor C again to $V_{max}$and also during this period it supplies current to the load also.
- This second pulse of $i_p(i_c + i_l)$ is of shorter duration than the initial charging pulse as it serve mainly to restore into C the energy that C meanwhile had supplied to load. Thus, while each pulse of diode current lasts much less than a half cycle, the load receives current more continuously from C.
- Assuming the charge supplied by the transformer to the load during the conduction period t, which is very small to be negligible, the charge supplied by the transformer to the capacitor during conduction equals the charge supplied by the capacitor to the load. Note that $i_c >> i_L$. During one period T = 1/f of the a.c voltage, a charge Q is transferred to the load RL and is given as

$$Q = \int_T iL(t)dt = \int_T \frac{V_{RL}(t)}{RL} dt = \pi = \frac{I}{f}$$

Where I is the mean value of the d.c output $iL(t)$ and $V_{RL}(t)$ the d.c. voltage which includes a ripple as shown in Fig.2.1. This charge is supplied by the capacitor over the period T when the voltage changes from V_{max} to V_{min} over approximately period T neglecting the conduction period of the diode. Suppose at any time the voltage of the capacitor is V and it decreases by an amount of dv over, the time dt then charge delivered by the capacitor during this time is

$$d_Q = Cd_v$$

Therefore, if voltage changes from V_{max} to V_{min} the charge delivered by the capacitor.

$$\int dQ = \int_{V_{max}}^{V_{min}} Cd_v = -C(V_{max} - V_{min})$$

Or the magnitude of charge delivered by the capacitor

$$Q = C(V_{max} - V_{min})$$

Using equation (2.2)

$$Q = 2\delta VC$$

Therefore, $2\delta VC = \pi$

Or

$$\delta V = \frac{\pi}{2C} = \frac{1}{2fC}$$

- The above Equation δV shows that the ripple in a rectifier output depends upon the load current and the circuit parameter like *f* and *C*. The product *fC*is, therefore, an important design factor for the rectifiers.
- The higher the frequency of supply and larger the value of filtering capacitor the smaller will be the ripple in the d.c. output.

The single phase half-wave rectifier circuits have the following disadvantages:

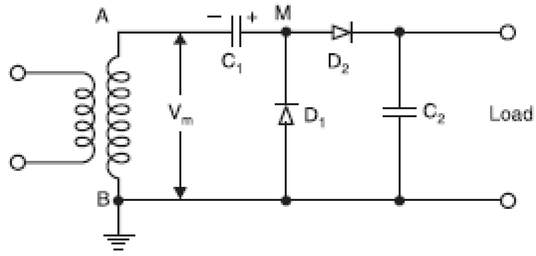
(i) The size of the circuits is very large if high and pure d.c. output voltages are desired.

(ii) The H.T transformer may get saturated if the amplitude of direct current is comparable with the nominal alternating current of the transformer.

- It is to be noted that all the circuits considered here are able to supply relatively low currents and therefore are not suitable for high current applications such as HVDC transmission.
- When high d.c. voltages are to be generated, voltage doubler or cascaded voltage multiplier circuits are used. One of the most popular doublercircuit due to Grimacer is shown in Fig below.
- Suppose B is more positive with respect to A and the diode D1 conducts thus charging the capacitor C1 to $V_{max}$with polarity During the next half cycle terminal A of the capacitor C1 rises to $V_{max}$and hence terminal M attains a potential of 2 V_{max}. Thus, the

capacitor C_2 is charged to 2 V_{max}through D_2. Normally the voltage across the load will be less than 2 V_{max}depending

upon the time constant of the circuit $C2RL$.



voltagedoubler circuit

2. Explain with neat diagram the n-stage Cockcroft-Walton circuit. Derive an expression for total ripple content in output voltage and hence deduce the condiction for optimum number of stages (A/M-2008,N/D-2007,DEC-2013,May-2014,Dec-14,16).

The multistage single phase cascade circuit of the Cockroft- Walton circuit.

No Load Operation:

- The portion ABM'MA is exactly indentical to Greinarcher voltage doubler circuit and the voltage across C becomes 2Vmax when M attains a voltage 2Vmax.
- During the next half cycle when B becomespositive with respect to A, potential of M falls and,therefore, potential of N also falls becoming lessthan potential at M′ hence C_2 is charged through D_2.
- Next half cycle A becomes more positive andpotential of M and N rise thus charging C'_2 through D'_2. Finally all the capacitors C'_1, C'_2, C'_3, C1, C_2,and C_3 are charged. The voltage across the columnof capacitors consisting of C_1, C_2, C_3, keeps onoscillating as the supply voltage alternates.
- Thiscolumn, therefore, is known as oscillating column. However, the voltage across the capacitances C_1, C_2, C_3, remains constant and is known as smoothening column.
- The voltages at M′, N′, and O′ are 2 V_{max}4 $V_{max}$and 6 V_{max}. Therefore, voltageacross all the capacitors is 2 V_{max}except for $C_1$where it is V_{max}only. The total output voltage is 2n V_{max} where n is the number of stages.
- Thus, theuse of multistage arranged in the manner shown enables very high voltage to be obtained. The equalstress of the elements (both capacitors and diodes) used is very helpful and promotes a modular designof such generators.

Generator Loaded: When the generator is loaded, the output voltage will never reach the value 2n Vmax. Also, the output wave will consist of ripples on the voltage. Thus, we have to deal with two quantities, the voltage drop ΔV and the ripple δV.

Suppose a charge q is transferred to the load per cycle. This charge is q = I/f = IT. The charge comes from the smoothening column, the series connection of C'_1, C'_2, C'_3,. If no charge were transferred during T from this stack via D_1, D_2, D_3, to the oscillating column, the peak to peak ripple would merely be

But in practice charges are transferred.

$$2\delta V = \pi \sum_{n=0}^{n} \frac{1}{c_i{}'}$$

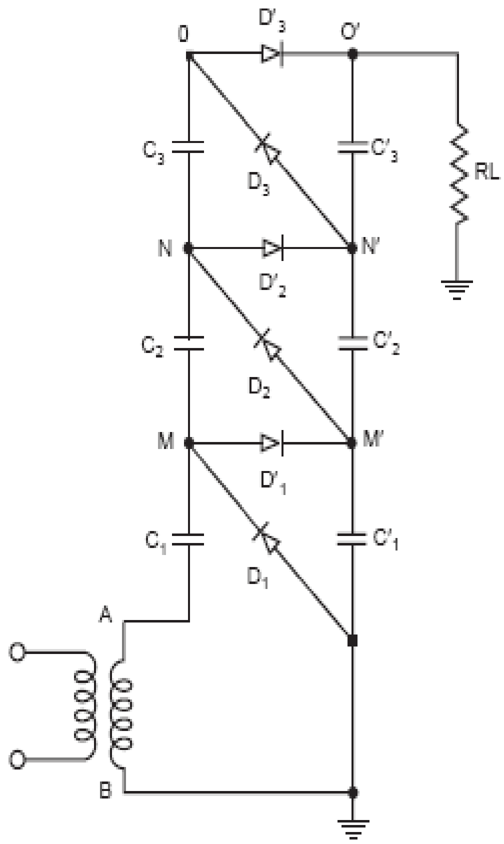
For n-stage circuits, the total ripple will be

$$2\delta V = \frac{1}{f}\left[\frac{1}{c_i{}'} + \frac{2}{c'_{in-1}} + \frac{3}{c'_{n-2}} + \cdots + \frac{n}{c'_1}\right]$$

$$\delta V = \frac{1}{2f}\left[\frac{1}{c_i{}'} + \frac{2}{c'_{in-1}} + \frac{3}{c'_{n-2}} + \cdots + \frac{n}{c'_1}\right]$$

From equation above it is clear that in a multistage circuit the lowest capacitors are responsible for most ripple and it is, therefore, desirable to increase the capacitance in the lower stages. However, this is objectionable from the view point of High Voltage Circuit where if the load is large and the load voltage goes down, the smaller capacitors (within the column) would be overstressed. Therefore, capacitors of equal value are used in practical circuits *i.e.,* $C'_n = C'_n - 1 = C'1 = C$ and the ripple is given as

$$\delta\text{v} = \frac{In(n+1)}{2fc * 2}$$



- It is to be noted that in general it is more economical to use high frequency and smaller value of capacitance to reduce the ripples or the voltage drop rather than low frequency and high capacitance.
- Cascaded generators of Cockroft-Walton type are used and manufactured world wide these days. A typical circuit is shown in Fig above. In general a direct current upto 20 mA is required for high voltages between 1 mv and 2 mv. In case where a higher value of current is required, symmetrical
- Cascaded rectifiers have been developed. These consist of mainly two rectifiers in cascade with a common smoothing column. The symmetrical cascaded rectifier has a smaller voltage drop and also a smaller voltage ripple than the simple cascade.
- The alternating current input to the individual circuits must be provided at the appropriate high potential; this can be done by means of isolating transformer. Fig shows a typical cascaded rectifier circuit.

Ripple in cascaded voltage multiplier circuit derivation :

Let f = Supply frequency.

Q = Charge transferred in each cycle**.**

I_1 = Load current from the rectifier.

t_1 = Conduction period of rectifier.

t_2 = Non – Conduction period of rectifier.

δv = Ripple voltage (peak to peak).

$I_1 = \frac{dq}{dt} = \frac{q}{t_2}$

Since $t_1 << t_2$ and $t_1 + t_2 = \frac{1}{f}$; $t_2 = \frac{1}{f}$

Also q = C_2 δv

$\delta v = \frac{q}{C_2} = \frac{I_1 t_2}{C_2} = \frac{I_1}{fC_2}$

Mean voltage drop from $2V_{max} = \frac{I_1}{f} [\frac{1}{C_1} + \frac{2}{C_2}]$

Let C_2 , $C_{2,}$................, C_{2n} be the capacitance = C.

Let q be the change transferred from C_{2n} to the load.

Ripple at the capacitance C_{2n} will be $\frac{I_1}{fC}$.

Ripple at the capacitance $C_{2n-2} = \frac{2I_1}{fC}$

. .

Ripple at the capacitance $C_2 = \frac{nI_1}{fC}$

For n stages, Total Ripple (δv) = $\frac{I_1}{fC}$ [1+2+3…………+n]

$= \frac{I_1}{fC} [\frac{n(n+1)}{2}]$

Average ripple = $\frac{Total\ ripple}{2}$

$= \frac{\delta v}{2} = \frac{I_1}{4fC}$ (n) (n+1)

Ripple contribution is more due to the lowest capacitances $C_1, C_2, C_3, C_4,$ etc. Ripple can be reduced if the capacitances of these capacitors is increases proportionately i.e., C_1, C_2 are made nC,

C_3, C_4 are made (n-1)C and so on.

Therefore, Total ripple = $\frac{nI_1}{fC}$

Where, n = Number of stages.

Percent ripple = % ripple = $\frac{\delta v\ X\ 100}{nV_{max}}$

Determination of Optimum Number of Stages

Change in voltage ΛV is caused due to the ripple (δv).

Let $C_1, C_2, \dots\dots\dots, C_n$ = C

Capacitance C_{2n} *is charged to* V_{max} - Total ripple

$$= 2V_{max}\ \frac{nI_1}{fC}$$

Similarly Capacitance C_{2n-1} is charged to $2V_{max}$ -$\frac{2nI_1}{fC} - \frac{(n-1)I_1}{fC}$

Capacitance V_2 is charged to $2V_{max}$ - $\frac{2nI_1}{fC}$ - $\frac{2(n-1)I_1}{fC}$ -$\frac{2XI_1}{fC} + \frac{I_1}{fC}$

Therefore, Voltage drop across C_{2n} (ΛV_{2n}) = $\frac{nI_1}{fC}$

Voltage drop across C_{2n-1} (ΛV_{2n-2}) = $\frac{I_1}{fC}$ [2n + (n - 1)]

Voltage drop across C_2 (ΛV_2) = $\frac{I_1}{fC}$ [2n + 2(n – 1)+………+ 2 – 1]

Total Voltage drop = ΛV_{2n} + ΛV_{2n-2}………….. ΛV_2

$$= \frac{I_1}{fC}\,[\textstyle\sum_1^n 2n^2 - \sum_1^n n]$$

$$= \frac{I_1}{fC}\,[2.\frac{n(n+1)(2n+1)}{6} - \frac{n(n+1)}{2}\ ]$$

$$= \frac{I_1}{fC}[\frac{n(n+1)}{2}\,[\frac{4n+2}{3} - 1]]$$

$$= \frac{I_1}{fC}\,[\frac{n(n+1)(4n-1)}{6}]$$

$$= \frac{I_1}{fC}\,[\frac{2n^3}{3} + \frac{n^2}{2} - \frac{n}{6}]$$

For the number of stages n ≥ 4, We may neglect the n^2 and n terms, because small compared to that of n^3 term.

$$\Lambda V = \frac{I_1}{fC}\,[\frac{2n^3}{3}] \qquad \text{………………………….(3.1)}$$

$$\%\text{Regulation} = \frac{\Lambda V}{2nV_{max}}\ \text{X } 100$$

To determine optimum value of n, differentiate equation (3.1) with respect to n, we get

$$2V_{max} = \frac{I_1}{fC}\,[2.\frac{3n^2}{3}\ ]$$

$$n^2 = \frac{V_{max}}{I_1}\ \text{fC}$$

$$n_{optimu\ m} = \sqrt{\frac{fC\ V_{max}}{I_1}}$$

Design details:

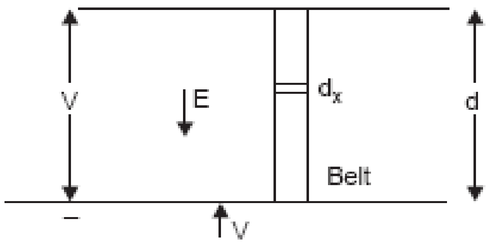
Production of voltage = 10KV to 2MV

Current = 10KV to 100mA

Frequency = 10 kHz

3.Discuss with neat diagram the Van-de Graff generator.(M/J-2012,A/M-2005,N/D-2008,2015,2016,17,M/J-2009,M/J-2012 (A/M-2011,MAY-2013&2014,17,18)

- In electromagnetic generators, current carrying conductors are moved against the electromagnetic forces acting upon them.
- In contrast to the generator, electrostatic generators convert mechanical energy into electric energy directly.
- The electric charges are moved against the force of electric fields, thereby higher potential energy is gained at the cost of mechanical energy. The basic principle of operation is explained with the help of Fig below.



- An insulated belt is moving with uniform velocity v in an electric field of strength E (x). Suppose the width of the belt is b and the charge density σ consider a length dx of the belt, the charge dq= σbdx.

The forced experienced by this charge (or the force experienced by the belt)

$$dF = Ed_q = E\sigma bd_x$$

$$F = \sigma b \int E\, d_x$$

Normally the electric field is uniform

$$F = \sigma bv$$

The power required to move the belt

$$= Force \times velocity$$

$$= F_v = \sigma bV_v$$

Now current

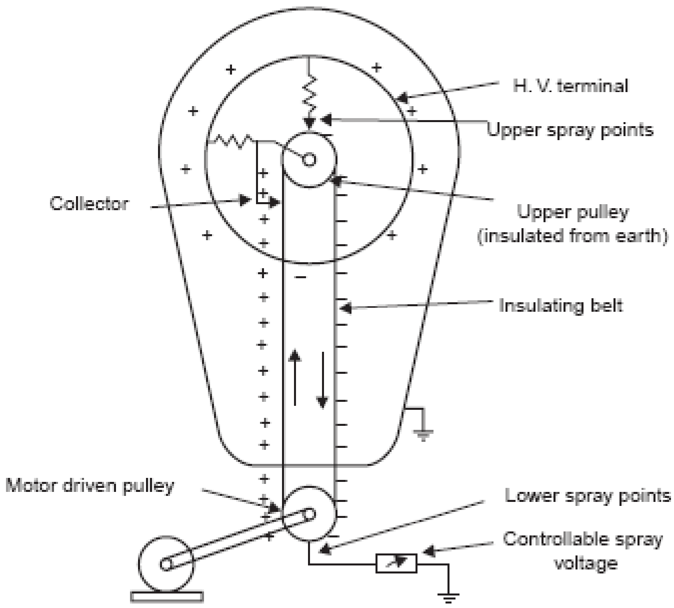
$$I = \frac{d_q}{d_t} = \sigma b V_v \frac{d_x}{d_t} = \sigma b$$

The power required to move the belt

$$P = F_v = \sigma b V_v = VI$$

Assuming no losses, the power output is also equal to VI

- Fig below shows belt driven electrostatic generator is called VandeGraff generator.
- An insulating belt is run over pulleys. The belt, the width of which may vary from a few cms to meters is driven at a speed of about 15 to 30 m/sec, by means of a motor connected to the lower pulley.
- The belt near the lower pully is charged electro statically by an excitation arrangement. The lower charge spray unit consists of a number of needles connected to the controllable d.c. source (10 kV–100 kV) so that the discharge between the points and the belt is maintained.
- The charge is conveyed to the upper end where it is collected from the belt by discharging points connected to the inside of an insulated metal electrode through which the belt passes.
- The entire equipment is enclosed in an earthed metal tank filled with insulating gases of good dielectric strength viz. SF6 etc.
- So that the potential of the electrode could be raised to relatively higher voltage without corona discharges or for a certain voltage a smaller size of the equipment will result.
- Also, the shape of the H.T electrode should be such that the surface gradient of electric field is made uniform to reduce again corona discharges, even though it is desirable to avoid corona entirely.
- An isolated sphere is the most favorable electrode shape and will maintain a uniform field E with a voltage of $E_r$where r is the radius of the sphere.



- As the h.t. electrode collects charges its potential rises. The potential at any instant is given as $V = q/C$ where q is the charge collected at that instant.
- It appears as though if the charge were collected for a long time any amount of voltage could be generated. However, as the potential of electrode rises, the field set up by the electrode increases and that may ionise the surrounding medium and, therefore, this would be the limiting value of the voltage. In practice, equilibrium is established at a terminal voltage which is such that the charging current

$$I = C\frac{dv}{dt}$$

equals the discharge current which will include the load current and the leakage and corona loss currents.

- The moving belt system also distorts the electric field and, therefore, it is placed within properly shaped field grading rings. The grading is provided by resistors and additional corona discharge elements.
- The collector needle system is placed near the point where the belt enters the h.t. terminal.
- A second point system excited by a self-inducing arrangement enables the down going belt to be charged to the polarity opposite to that of the terminal and thus the rate of charging of the latter, for a given speed, is doubled.
- The self inducing arrangement requires insulating the upper pulley and maintaining it at a potential higher than that of the h.t. terminal by connecting the pulley to the collector needle system.

- The arrangement also consists of a row of points (shown as upper spray points in diagram) connected to the inside of the h.t. terminal and directed towards the pulley above its points of entry into the terminal.
- As the pulley is at a higher potential (positive), the negative charges due to corona discharge at the upper spray points are collected by the belt.
- This neutralizes any remaining positive charge on the belt and leaves an excess of negative charges on the down going belt to be neutralized by the lower spray points.
- Since these negative charges leave the h.t. terminal, the potential of the h.t. terminal is raised by the corresponding amount.

The advantages of the generator are:

(*i*) Very high voltages can be easily generated

(*ii*) Ripple free output

(*iii*) Precision and flexibility of control

The disadvantages are:

(*i*) Low current output

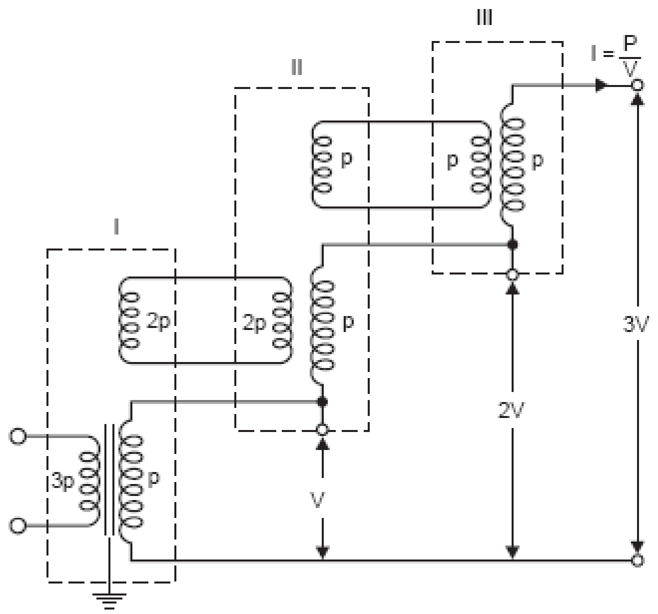
(*ii*) Limitations on belt velocity due to its tendency for vibration. The vibrations may make it difficult to have an accurate grading of electric fields.

4. Describe the cascade transformer connection to generate high alternating voltage. (A/M-2005, A/M-2008,MAY-2013,DEC-2013)

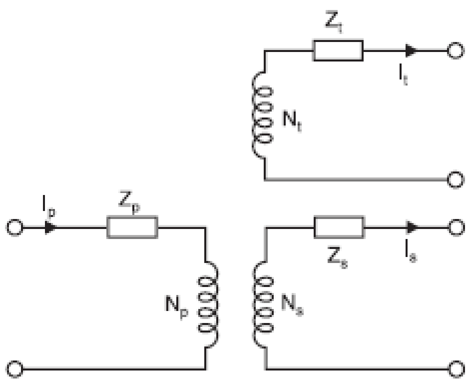
- For voltages higher than 400 KV, it is desired to cascade two or more transformers depending upon the voltage requirements.With this, the weight of the whole unit is subdivided into single units and, therefore, transport and erection becomes easier.
- Also, with this, the transformer cost for a given voltage may be reduced, since cascaded units need not individually possess the expensive and heavy insulation required in single stage transformers for high voltages exceeding 345 kV.
- It is found that the cost of insulation for such voltages for a single unit becomes proportional to square of operating voltage.Fig shows a basic scheme for cascading three transformers. The primary of the first stage transformer is connected to a low voltage supply.
- A voltage is available across the secondary of this transformer. The tertiary winding (excitation winding) of first stage has the same number of turns as the primary winding, and feeds the primary of the second stage transformer.
- The potential of the tertiary is fixed to the potential V of the secondary winding as shown in Fig below.The secondary winding of the second stage transformer is

connected in series with the secondary winding of the first stage transformer, so that a voltage of 2V is available between the ground and the terminal of secondary of the second stage transformer.

- Similarly, the stage-III transformer is connected in series with the second stage transformer. With this the output voltage between ground and the third stage transformer, secondary is 3V.
- it is to be noted that the individual stages except the upper most must have three-winding transformers. The upper most, however, will be a two winding transformer.
- Fig below shows metal tank construction of transformers and the secondary winding is not divided. Here the low voltage terminal of the secondary winding is connected to the tank. The tank of stage-I transformer is earthed.
- The tanks of stage-II and stage-III transformers have potentials of V and 2V, respectively above earth and, therefore, these must be insulated from the earth with suitable solid insulation.
- Through h.t. bushings, the leads from the tertiary winding and the h.v. winding are brought out to be connected to the next stage transformer.



- However, if the high voltage windings are of mid-point potential type, the tanks are held at 0.5 V, 1.5 V and 2.5 V, respectively.
- This connection results in a cheaper construction and the high voltage insulation now needs to be designed for *V*/2 from its tank potential.
- The main disadvantage of cascading the transformers is that the lower stages of the primaries of the transformers are loaded more as compared with the upper stages.
- The loading of various windings is indicated by

- *P* in Fig. For the three-stage transformer, the total output *VA* will be 3*VI* = 3*P* and, therefore, each of the secondary winding of the transformer would carry a current of *I* = *P/V*.
- The primary winding of stage-III transformer is loaded with *P* and so also the tertiary winding of second stage transformer. Therefore, the primary of the second stage transformer would be loaded with 2*P*. Extending the same logic, it is found that the first stage primary would be loaded with *P*.
- Therefore, while designing the primaries and tertiaries of these transformers, this factor must be taken into consideration.The total short circuit impedance of a cascaded transformer from data for individual stages can be obtained. The equivalent circuit of an individual Stage.
- Here *Zp, Zs,* and *Zt,* are the impedances associated with each winding. The impedances are shown in series with an ideal 3-winding transformer with corresponding number of turns *Np, Ns* and *Nt.*
- The impedances are obtained either from calculated or experimentally-derived results of the three shortcircuit tests between any two windings taken at a time.
- 

Let *Zps*= leakage impedance measured on primary side with secondary short circuited and tertiary open.

Zpt= leakage impedance measured on primary side with tertiary short circuited and secondary open.

Zst= leakage impedance on secondary side with tertiary short circuited and primary open.

If these measured impedances are referred to primary side then

*Zps = Zp+ Zs, Zpt= Zp+ Zt*and *Zst= Zs+ Zt*

Solving these equations, we have

$Z_p=(Z_{ps}+Z_{pt}-Z_{st})/2$,$Z_s=(Z_{ps}+Z_{st}-Z_{pt})/2$

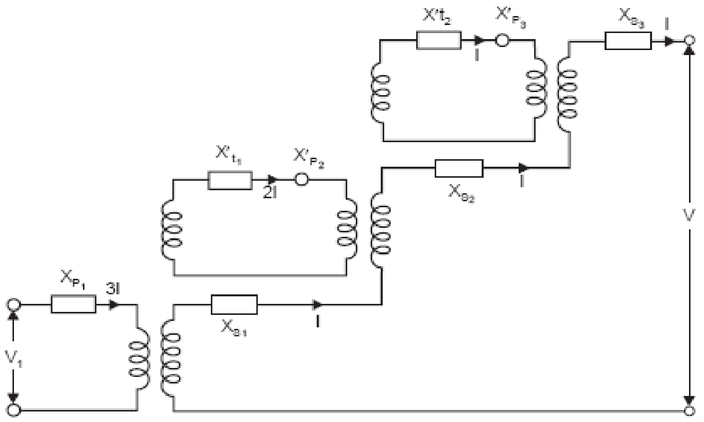
And $Z_t=(Z_{pt}+Z_{st}-Z_{ps})$

Assuming negligible magnetizing current, the sum of the ampere turns of all the windings must be zero.

N_pI_p-N_sI_s-N_tI_t=0

Assuming lossless transformer, we have

$Z_p=jX_p$, $Z_s=jX_s$ *and* $Z_t=jX_t$



5.Explain the principle of operation of resonant transformer.(N/D-2008)

- The equivalent circuit of a single-stage-test transformer along with its capacitive load is shown in Fig. Here L_1 represents the inductance of the voltage regulator and the transformer primary, Lthe exciting inductance of the transformer, *L*2 the inductance of the transformer secondary and *C* the capacitance of the load.

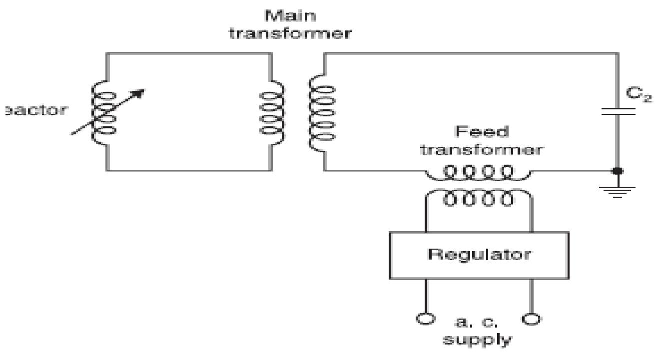
- Normally inductance *L* is very large as compared to *L*1 and *L*2 and hence its shunting effect can be neglected. Usually the load capacitance is variable and it is possible that for certain loading, resonance may occur in the circuit suddenly and the current will then only be limited by the resistance of the circuit and the voltage across the test specimen may go up as high as 20 to 40 times the desired value.

- Similarly, presence of harmonics due to saturation of iron core of transformer may also result in resonance.

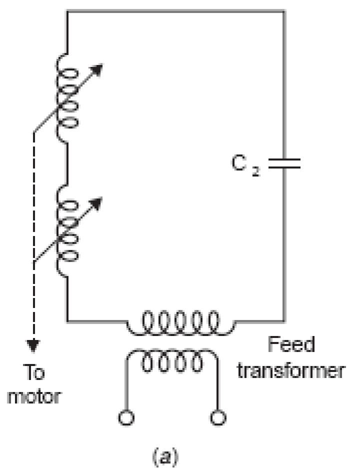
- Third harmonic frequencies have been found to be quite disastrous. With series resonance, the resonance is controlled at fundamental frequency and hence no unwanted resonance occurs.

- The development of series resonance circuit for testing purpose has been very widely welcome by the cable industry as they faced resonance problem with test transformer while testing short lengths of cables. In the initial stages, it was difficult to manufacture continuously variable high voltage and high value reactors to be used in the series circuit and therefore, indirect methods to achieve this objective were employed.

- Below diagram shows a continuously variable reactor connected in the low voltage winding of the step up transformer whose secondary is rated for the full test voltage. *C*2 represents the load capacitance.



- If *N* is the transformation ratio and *L* is the inductance on the low voltage side of the transformer, then it is reflected with *N*2 *L* value on the secondary side (load side) of the transformer.
- For certain setting of the reactor, the inductive reactance may equal the capacitive reactance of the circuit, hence resonance will take place. Thus, the reactive power requirement of the supply becomes zero and it has to supply only the losses of the circuit.
- However, the transformer has to carry the full load current on the high voltage side. This is a disadvantage of the method.
- The inductor are designed for high quality factors $Q = \omega L / R$. The feed transformer, therefore, injects the losses of the circuit only. It has now been possible to manufacture high voltage continuously variable reactors 300 kV per unit using a new technique with split iron core. With this, the testing step up transformer can be omitted as shown in below.
- The inductance of these inductors can be varied over a wide range depending upon the capacitance of the load to produce resonance.



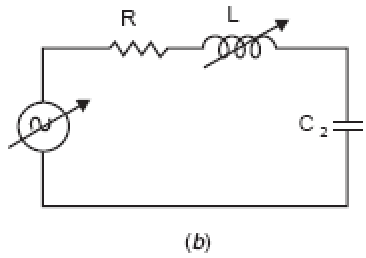


Fig above (*b*) represents an equivalent circuit for series resonance circuit. Here *R* is usually of low value. After the resonance condition is achieved, the output voltage can be increased by increasing the input voltage.

The feed transformers are rated for nominal current ratings of the reactor. Under resonance, the output voltage will be

$V_o = V/R\omega C_2$

Where V is the supply voltage.

Since at resonance

$\omega L = 1/\omega C_2$

Therefore $V_{o} = V\omega L/R = VQ$

where *Q* is the quality factor of the inductor which usually varies between 40 and 80. This means that with *Q* = 40, the output voltage is 40 times the supply voltage.

It also means that the reactive power requirements of the load capacitance in kVA is 40 times the power to be provided by the feed transformer in KW. This results in a relatively small power rating for the feed transformer.

The following are the advantages of series resonance circuit.

(i) The power requirements in KW of the feed circuit are (kVA)/Q where kVA is the reactive power requirements of the load and Q is the quality factor of variable reactor usually greater than 40. Hence, the requirement is very small.

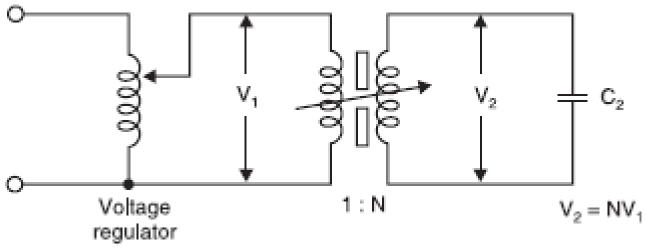
(ii) The series resonance circuit suppresses harmonics and interference to a large extent. The near sinusoidal wave helps accurate partial discharge of measurements and is also desirable for measuring loss angle and capacitance of insulating materials using Schering Bridge.

(iii) In case of a flashover or breakdown of a test specimen during testing on high voltage side, the resonant circuit is detuned and the test voltage collapses immediately. The short circuit current is limited by the reactance of the variable reactor. It has proved to be of great value as the weak part of the isolation of the specimen does not get destroyed. In fact, since the arc flash over has very small energy, it is easier to observe where exactly the flashover is occurring by delaying the tripping of supply and allowing the recurrence of flashover.

(iv) No separate compensating reactors (just as we have in case of test transformers) are required. This results in a lower overall weight.

(v) When testing SF6 switchgear, multiple breakdowns do not result in high transients. Hence, no special protection against transients is required.

(vi) Series or parallel connections of several units is not at all a problem. Any number of units can be connected in series without bothering for the impedance problem which is very severely associated with a cascaded test transformer. In case the test specimen requires large current for testing, units may be connected in parallel without any problem.



Here the variable reactor is incorporated into the high voltage transformer by introducing a variable air gap in the core of the transformer. With this connection, variation in load capacitance and losses cause variation in input current only. The output voltage remains practically constant. Within the units of single stage design, the parallel resonant method offers optimum testing performance.

6. Explain with neat diagram MARX circuit and its operations. (A/M-2011,A/M-2008,M/J-2009,A/M-2011,17)

(OR)

Starting from The Basic MARX Circuit Develop The Circuit Of A Morden Multi-Stage Impulse Generater And Explain Its Operation. Discuss On The Significance Of Various Parameter (N/D2007,N/D-2007,DEC-2013,N/D-2015,April-18)

In order to obtain higher and higher impulse voltage, a single stage circuit is inconvenient for the following reasons:

(i) The physical size of the circuit elements becomes very large.

(ii) High d.c. charging voltage is required.

(iii) Suppression of corona discharges from the structure and leads during the charging period is difficult.

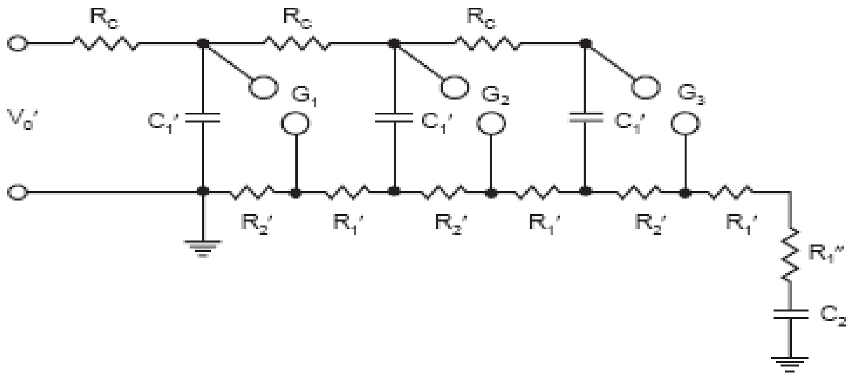
(iv) Switching of vary high voltages with spark gaps is difficult.

- Multiplier circuit which is commonly used to obtain impulse voltages with as high a peak value as possible for a given d.c. charging voltage.
- Depending upon the charging voltage available and the output voltage required a number of identical impulse capacitors are charged in parallel and then discharged in series, thus obtaining a multiplied total charging voltage corresponding to the number of stages.
- Fig below shows a 3-stage impulse generator circuit due to Marx employing ‘b’ circuit connections. The impulse capacitors C1 are charged to the charging voltage V0 through the high charging resistors Rcin parallel.
- When all the gaps G break down, the C1′ capacitances are connected in series so that C2 is charged through the series connection of all the wave front resistances R1′ and finally all C1′ and C2 will discharge through the resistors R2′ and R1′.

- Usually Rc>>R2 >>R1. If in Fig below the wave tail resistors R2′ in each stage are connected in parallel to the series combination of R1′, G and C1′, an impulse generator of type circuit 'a' is obtained.

- In order that the Marx circuit operates consistently it is essential to adjust the distances between various sphere gaps such that the first gap G1 is only slightly less than that of G2 and so on.

- If is also necessary that the axes of the gaps G be in the same vertical plane so that the ultraviolet radiations due to spark in the first gap G, will irradiate the other gaps. This ensures a supply of electrons released from the gap electrons to initiate breakdown during the short period when the gaps are subjected to over voltages.



The wave front control resistance can have three possible locations

(i) entirely within the generator

(ii) entirely outside the generator

(iii) partly within and partly outside the generator.

The first arrangement is unsatisfactory as the inductance and capacitance of the external leads and the load form an oscillatory circuit which requires to be damped by an external resistance.

The second arrangement is also unsatisfactory as a single external front resistance will have to withstand, even though for a very short time, the full rated voltage and therefore, will turn out to be inconveniently long and would occupy much space.

A compromise between the two is the third arrangement as shown in Fig. below and thus both the "space economy" and damping of oscillations are taken care of.

It can be seen that Fig below can be reduced to the single stage impulse generator. After the generator has fired, the total discharge capacitance $C1$ may be given as,

$$\frac{1}{c'_n}\sum^{n}\frac{1}{c'_1}$$

The equivalent front resistance

$$R_1 = \sum^{n} R'_1 + R"_2$$

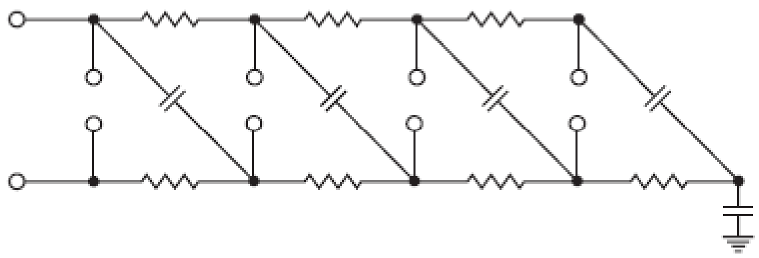
And the equivalent tail control resistance

$$R_2 = \sum^{n} R'_2$$

Where n is the number of stages

where the load is earthed during the charging period, without the necessity for an isolating gap. The impulse output voltage has the same polarity as the charging voltage is case of Marx circuit,

it is reversed in case of Goodlet circuit. Also, on discharge, both sides of the first spark gap are raised to the charging voltage in the Marx circuit but in case of Goodlet circuit they attain earth potential.

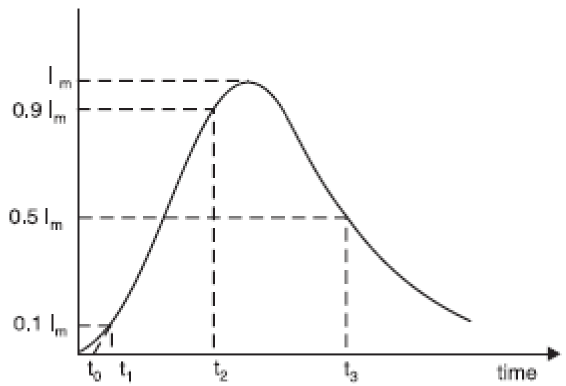


7. Draw and explain the circuits of producing impulse wave.(N/D-2004, N/D-2007,MAY-2013)

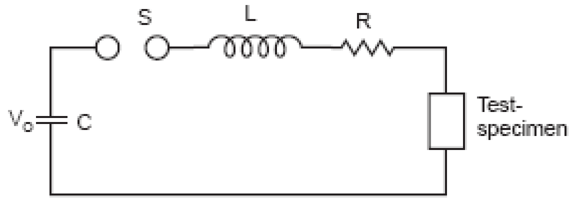
(OR)

Explain in detail the methods of switching surge generation from impulse generator and from power transformer.(M/J-2012,A/M-2011,M/J-2014)

The impulse current wave is specified on the similar lines as an impulse voltage wave. A typical impulse current wave is shown graph High current impulse generators usually consist of a large number of capacitors connected in parallel to the common discharge path.



The equivalent circuit of the generator is shown in Fig below and approximates to that of a capacitance C charged to a voltage V_0 which can be considered to discharge through an inductance L and a resistance R. In practice both L and R are the effective inductance and resistance of the leads, capacitors and the test objects.



After the gap S is triggered, the laplace transform current is given as

$$I(s) = \frac{V_0}{s}\frac{1}{R + SL + {}^{1}\!/_{cs}}$$

$$= \frac{V}{L}\frac{1}{S^2 + {}^{R}\!/_{LS}\,{}^{1}\!/_{LC}}$$

$$= \frac{V}{L}\frac{1}{(S+\alpha)^2 + \omega^2}$$

Where

$\alpha = \frac{R}{2L}$and$\omega = \left(\frac{1}{LC} - \frac{R^2}{4L^2}\right)^{\frac{1}{2}}$

$$or$$

$$\omega = \frac{1}{\sqrt{LC}}\left(1 - \frac{R^2 c}{4L}\right)^{\frac{1}{2}} = \frac{1}{\sqrt{LC}}(1 - V^{2)^{\frac{1}{2}}}$$

Where

$$V = \frac{R}{2}\sqrt{\frac{C}{L}}$$

Take the inverse laplace we have the current

$$i(t) = \frac{V}{\omega L} e^{-\alpha t} \sin \omega t$$

For current i(t) to be maximum $\frac{di(t)}{dt}$=0

$\frac{di(t)}{dt} = \frac{V}{\omega L} [\omega e^{-\alpha t} \cos \omega t - \alpha e^{-\alpha t} \sin \omega t]$=0

$= \frac{V}{\omega L} e^{-\alpha t} [\omega \cos \omega t - \alpha \sin \omega t]$=0

Or

$$\frac{\omega}{\sqrt{\sigma^2 + \omega^2}} \cos \omega t - \frac{\alpha}{\sqrt{\sigma^2 + \omega^2}} \sin \omega t = 0$$

or

$$\sin \Theta \cos \omega t - \cos \Theta \sin \omega t = 0$$

or

$$\sin(\Theta - \omega t) = 0$$

or

$$\omega t = 0$$

or

$$t_{max} = \frac{\Theta}{\omega t}$$

Where t_{max} is the time when the first maximum value of current occurs and

$$\Theta = sin^{-1} \frac{\omega}{\sqrt{\sigma^2 + \omega^2}}$$

$$= sin^{-1} \frac{\omega}{\left[\frac{R_2}{4L^2} + \frac{1}{LC} - \frac{R^2}{4L^2}\right]^{\frac{1}{2}}}$$

$$= sin^{-1} \sqrt{LC} \omega$$

$$t_{max} = \frac{sin^{-1} \sqrt{LC} \omega}{\omega}$$

$$= \frac{sin^{-1} \sqrt{LC} \frac{1}{\sqrt{LC}} (1 - V^2)^{\frac{1}{2}}}{\frac{1}{\sqrt{LC}} (1 - V^2)^{\frac{1}{2}}}$$

$$t_{max} = \sqrt{LC} (1 - V^2)^{\frac{-1}{2}} sin^{-1} (1 - V^2)^{\frac{1}{2}} = \sqrt{LC} \frac{sin^{-1} (1 - V^2)^{\frac{1}{2}}}{(1 - V^2)^{\frac{1}{2}}}$$

Susbstuting the value of t=t_{max} in (3.25) the first maximum value of currents is given by

$$I_{max} = \frac{V_0\sqrt{LC}}{(1-V^2)^{\frac{1}{2}}L} \; Exp\left[-\frac{R\sqrt{LC}sin^{-1}(1-V^2)^{\frac{1}{2}}}{2L(1-V^2)^{\frac{1}{2}}}\right]$$

$$\sin\{\frac{(1-V^2)^{\frac{1}{2}}}{\sqrt{LC}}\sqrt{LC}(1-V^2)^{\frac{1}{2}}sin^{-1}(1-V^2)^{\frac{1}{2}}\}$$

$$= \frac{V_0}{(1-V^2)^{\frac{1}{2}}}\sqrt{\frac{C}{L}} \;\; Exp\left[\frac{-Vsin^{-1}(1-V^2)^{\frac{1}{2}}}{(1-V^2)^{\frac{1}{2}}}\right]\sin\{sin^{-1}(1-V^2)^{\frac{1}{2}}\}$$

$$=V_0\sqrt{\frac{C}{L}\; Exp\left[\frac{-Vsin^{-1}(1-V^2)^{\frac{1}{2}}}{(1-V^2)^{\frac{1}{2}}}\right]}$$

Equation (3.26) can be rewritten an

$$I_{max} = V_0\sqrt{\frac{C}{L}f_{(v)} = \sqrt{\frac{2W}{L}}f_{(v)}}$$

where

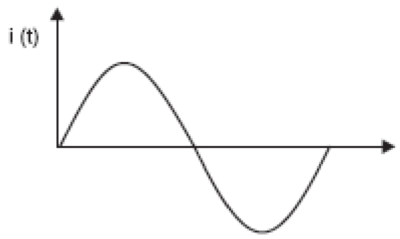
$$W = \frac{1}{2}CV^2$$

The initial energy stored by the generator

If R=0,V=0 then from equation (3.26) it is clear that

$$I = V_0\sqrt{\frac{C}{L}} \; and\; from\, equation$$

$$i(t) = V_0\sqrt{\frac{C}{L}}\sin\frac{t}{\sqrt{LC}}$$



Current response of circuit in

- From equation it is clear that for maximum value of current the inductance of the circuit should be low for a given initial energy W.

- The usual value of f (ν) without adding damping elements varies between 0.85 and 0.95. Unidirectional impulse can be produced by damping with additional resistance. However, this results in reduced peak value of current e.g.

- the value of the current during critical damping (R= 2√LC) is about 0.368 times its value when no damping (R = 0) is present. It has been found that an approximately unidirectional wave form can be obtained by the use of a non-linear damping resistance in the circuit with a reduction of $I_m$to only about 0.7 times and the V_0 √C L

- The effective inductance of the unit can be reduced by subdividing the capacitance C into groups of smaller units.

8. Explain With Neat Diagram The Triggering And Synchronization Of The Impulse Generator. (OR) EXPLAIN THE FUNCTION AND OPERATION OF TRIGATRON GAP. NOV/DEC-2015

Impulse generators are normally operated in conjunction with cathode ray oscillographs for measurement and for studying the effect of impulse waves on the performance of the insulations of the equipments.

- Since the impulse waves are of shorter duration, it is necessary that the operation of the generator and the oscillograph should be synchronized accurately and if the wave front of the wave is to be recorded accurately, the time sweep circuit of the oscillograph should be initiated at a time slightly before the impulse wave reaches the deflecting plates.

If the impulse generator itself initiates the sweep circuit of the oscillograph, it is then necessary to connect a delay cable between the generator or the potential divider and the deflecting plates of the oscilloscope so that the impulse wave reaches the plates at a controlled time after the sweep has been tripped.

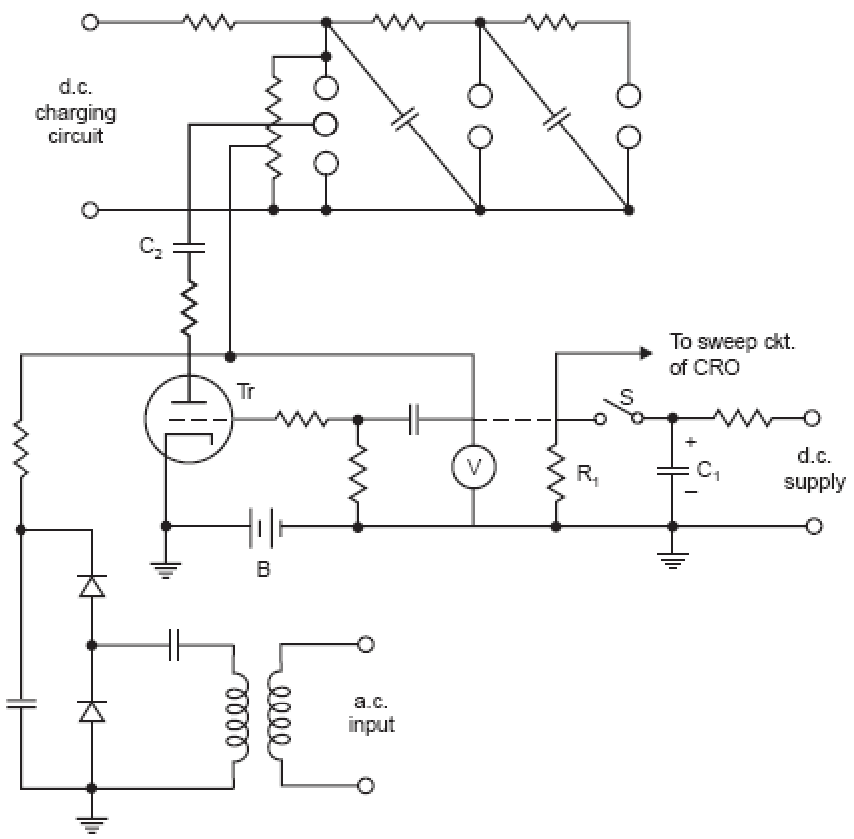
- However, the use of delay cable leads to inaccuracies in measurement. For this reason, some tripping circuits have been developed where the sweep circuit is operated first and then after a time of about 0.1 to 0.5 μ sec. the generator is triggered.

One of the methods involves the use of a three-sphere gap in the first stage of the generator as shown in Fig below .

- The spacing between the spheres is so adjusted that the two series gaps are able to withstand the charging voltage of the impulse generator. A high resistance is connected between the outer spheres and its centre point is connected to the control sphere so that the voltage between the outer spheres is equally divided between the two gaps.

- If the generator is now charged to a voltage slightly less than the breakdown voltage of the gaps, the breakdown can be achieved at any instant by applying an impulse of either polarity and of a peak voltage not less than one fifth of the charging voltage to the control sphere.

The operation is explained as follows. The switch *S* is closed which initiates the sweep circuit of the oscillograph. The same impulse is applied to the grid of the thyratron tube. The inherent time delay of the thyratron ensures that the sweep circuit begins to operate before the start of the high voltage impulse.



- A further delay can be introduced if required by means of a capacitance-resistance circuit R_1C_1. The tripping impulse is applied through the capacitor $C2$.

- During the charging period of the generator the anode of the thyratron tube is held at a positive potential of about 20 kV. The grid is held at negative potential with the help of battery *B* so that it does not conduct during the charging period.

- As the switch Sis closed, the trigger pulse is applied to the grid of the thyratron tube which conducts and a negative impulse of 20 kV is applied to the central sphere which triggers the impulse generator.

- Fig below shows a trigatron gap which is used as the first gap of the impulse generator and consists essentially of a three-electrode gap.

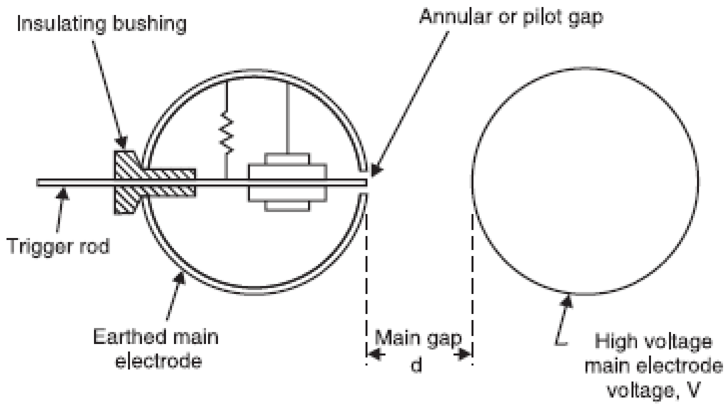
- The high voltage electrode is a sphere and the earthed electrode may be a sphere, a semi-sphere or any other configuration which gives homogeneous electric field. A small hole is drilled into the earthed electrode into which a metal rod projects.

- The annular gap between the rod and the surrounding hemisphere is about 1 mm. A glass tube is fitted over the rod electrode and is surrounded by a metal foil which is connected to the earthed hemisphere.

- The metal rod or trigger electrode forms the third electrode, being essentially at the same potential as the drilled electrode, as it is connected to it through a high resistance, so that the control or tripping pulse can be applied between these two electrodes.

- When a tripping pulse is applied to the rod, the field is distorted in the main gap and the latter breaks down at a voltage appreciably lower than that required to cause its breakdown in the absence of the tripping pulse.

- The function of the glass tube is to promote corona discharge round the rod as this causes photoionisation in the annular gap and the main gap and consequently facilitates their rapid breakdown.



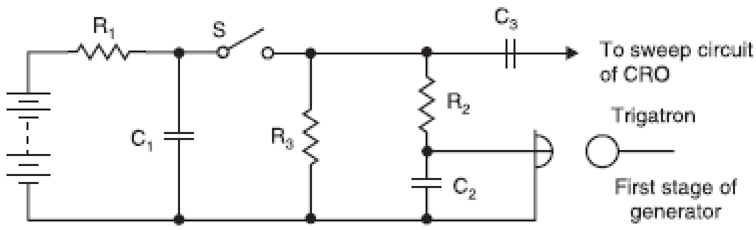
- For single stage or multi-stage impulse generators the trigatron gaps have been found quite satisfactory and these require a tripping voltage of about 5 kV of either polarity.

- The tripping circuits used today are commercially available and provide in general two or three tripping pulses of lower amplitudes. Fig below shows a typical tripping circuit. The capacitor C_1 is charged through a high

- Resistance R_1. As the remotely controlled switch S is closed, a pulse is applied to the sweep circuit of the oscillograph through the capacitor C_3.

- At the same time the capacitor C_2 is charged up and a triggering pulse is applied to the trigger electrode of the trigatron. The requisite delay in triggering the generator can be provided by suitably adjusting the values of R_2 and C_2.

- The residual charge on C_2 can be discharged through a high resistance $R3$. These days lasers are also used for tripping the spark gap.

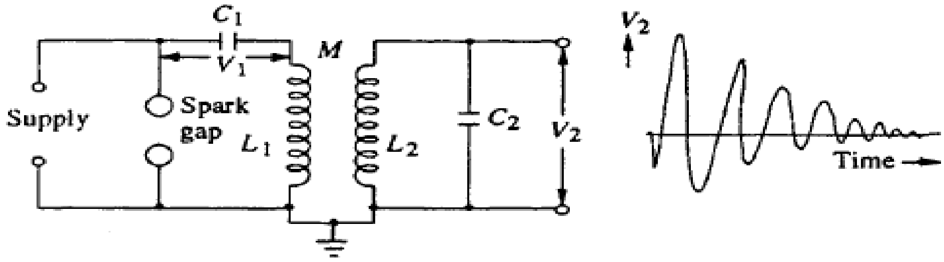


- The trigatron also has a phase shifting circuit associated with it so as to synchronise the initiation time with an external alternating voltage.

- Thus, it is possible to combine high alternating voltage tests with a superimposed impulse wave of adjustable phase angle. The trigatron is designed so as to prevent the overcharging of the impulse capacitors in case of an accidental failure of triggering. An indicating device shows whether the generator is going to fire correctly or not. An additional feedback circuit provides for a safe wave chopping and oscillograph release, independent of the emitted control pulse.

9. What is tesla coil? Derive an expression for damped high frequency oscillations obtained from a tesla coil. Give its advantage (Dec-14,17)

The commonly used high frequency resonant transformer is the Tesla coil, which is a doubly tuned resonant circuit shown schematically in Fig.. The primary voltage rating is 10 kV and the secondary may be rated to as high as 500 to 1000 kV. The primary is fed from a d.c. or a.c. supply through the condenser Ci. A spark gap G connected across the primary is triggered at the desired voltage *V* which induces a high self-excitation in the secondary



(a) Equivalent circuit (b) Output waveform

. The primary and the secondary windings ($L_1$and L_2) are wound on an insulated former with no core (air-cored) and are immersed in oil. The windings are tuned to a frequency of 10 to 100 kHz by means of the condensers $C_1$and C_2.
The output voltage *V* is a function of the parameters L_1, L_2 C_1, $C_2$and the mutual inductance *M.* Usually, the winding resistances will be small and contribute only for damping of the oscillations. The analysis of the output waveform can be done in a simple manner neglecting the winding resistances. Let the condenser C_1be charged to a voltage $V_1$when the spark gap is triggered. Let a current $i_1$flow through the primary winding *L1* and produce a current $i_2$through $L_2$and C_2
Then,

$$V_1 = \frac{1}{C_1}\int_0^t i_1\,dt + L_1\frac{di_1}{dt} + M\frac{di_2}{dt}$$

And

$$0 = \frac{1}{C_2}\int_0^{t_2} i_2\,dt + L_2\frac{di_2}{dt} + M\frac{di_1}{dt}$$

The Laplace transformed equations for the above are $\frac{V_1}{s} = \left[L_1 s + \frac{1}{C_1 s}\right] I_1$ +MSI_2

And

$$0 = [MS]I_1 + \left[L_2 s + \frac{1}{C_2 s}\right] I_2$$

Where I_1 and $I_2$are the Laplace transformed values of $i_{1\,,}$ i_2 the output voltage V_1across the condenser C_2

$$V_2 = \frac{1}{C_2}\int_0^t i_2\,dt$$

Or transformed equation is

$$V_2(s) = \frac{I_2}{C_2(s)}$$

Where $V_2(s)$ is the Laplace transform ofV_2

The solution for V_2 from the above equation will be

$$N_2 = \frac{MV_1}{\sigma L_1 L_2 C_1} \frac{1}{\Upsilon_2{}^2 - \Upsilon_1{}^2} [\cos \Upsilon_1 t - cos \Upsilon_2 t]$$

Where

$$\sigma^2 = 1 - \frac{M^2}{L_1 L_2} = 1 - K^2$$

K=coefficient of coupling between the winding L_1 and L_2

$$\Upsilon_{1,2} = \frac{\omega_1{}^2 + \omega_2{}^2}{2} + \sqrt{\left(\frac{\omega_1{}^2 + \omega_2{}^2}{2}\right)^2 - \omega_1{}^2 \omega_2{}^2 (1 - k^2)}$$

$$W_1 = \frac{1}{\sqrt{L_1 C_1}} \text{and} W_2 = \frac{1}{\sqrt{L_2 C_2}}$$

The output waveforms is shown in Fig 6.13.6 The peak amplitude of the secondary voltage V_2 can be expressed as

$$V_{2max} = V_2 e \sqrt{\frac{L_2}{L_1}}$$

Where

$$e = \frac{2\sqrt{(1-\sigma)}}{\sqrt{(1+a)^2 - 4\sigma a}}$$

$$a = \frac{L_2 C_2}{L_1 C_1} = \frac{\omega_1{}^2}{\omega_2{}^2}$$

A more simplified analysis for the Tesla coil may be presented by considering that the energy stored in the primary circuit in the capacitance C_1 is transferred to C_2 via the magnetic coupling. If W_1 is the energy stored in C_1 and W_2 is the energy transferred to C_2 and if the efficiency of the transformer is T], then

$$W_1 = \frac{1}{2} \eta C_1 v_1{}^2 = (\frac{1}{2} C_2 v_2{}^2)$$

From which $V_2 = V_1 \sqrt{\frac{\eta C_1}{C_2}}$

It can be shown that if the coefficient of coupling K is large the oscillation frequency is less, and for large values of the winding resistances and AT, the waveform may become a unidirectional impulse. This is shown in the next sections while dealing with the generation of switching surges.

PROBLEM:1

A Cockcroft-Walton type voltage multiplier has eight stages with capacitances, all equal to 0.05 PF. The supply transformer secondary voltage is 125 kV at a frequency of 150 Hz. If the load current to be supplied is 5 mA, find *(a)* the percentage ripple, *(b)* the regulation, and *(c)* the optimum number of stages for minimum regulation or voltage drop. APRIL/MAY-2015,17

SOLUTION:

(a) Calculation of Percentage Ripple

The ripple voltage $\delta V = \frac{1}{fc}\frac{(n)(n+1)}{2}$

I=5mA, f=150Hz, C=0.05µF, and n=8,

$\delta V = \frac{5\times10^{-3}}{150\times0.05\times10^{-6}} \times \frac{8\times9}{2}$

% ripple$= \frac{\delta V\times100}{2nV_{max}} = \frac{24\times100}{2\times125\times8}$

=1.2%

(b) ***Calculation of regulation***

Voltage drop, $\Delta V = \frac{1}{f_c}\left(\frac{2}{3}n^3 + \frac{n^2}{2} - \frac{n}{6}\right)$

$= \frac{5\times10^{-3}}{150\times0.05\times10^{-6}}\left[\left(\frac{2}{3}\times8^3\right) + \left(\frac{1}{2}\times8\right)\right]$

=248 kV

Regulation $\left(\frac{V}{2nV_{max}}\right) = \frac{248}{2\times8\times125} = \frac{124}{1000}$

=12.4%

(c) **Calculation of optimum number of stages ($n_{optimum}$)**

Since n>5,

$$n_{optimum} = \sqrt{V_{max}\, f\,\frac{C}{I}}$$

$$= \sqrt{\frac{125\times150\times0.05\times10^{-6}\times10^{+3}}{5\times10^{-3}}} = 13.69 = 14\ stages$$

PROBLEM:2
An impulse generator has eight stages with each condenser rated for 0.16microF and 125 kV. The load capacitor available is 1000 pF. Find the series resistance and the damping resistance needed to produce 1.2/50}is impulse wave. What is the maximum output voltage of the generator, if the charging voltage is 120kV? APRIL/MAY-2015
SOLUTION :

C_1 , the generator capacitance $=\frac{0.16}{8}$=0.02μF

C_2, the load capacitance =0.001μF

t_1, the time to front =1.2μs

$$= 3.0\ R_1 \frac{C_1 C_2}{C_1 + C_2} \times \frac{1}{3}$$

$$R_1 = 1.2 \times 10^{-6} \frac{0.021 \times 10^{-6}}{0.02 \times 0.001 \times 10^{-12}} \times \frac{1}{3}$$
$$= 420\Omega$$

t_2, time to tail = $0.7(R_1 + R_2)(C_1 + C_2)$

$$= 50 \times 10^{-6} s$$

Or, 0.7(420+$R_2)(0.021 \times 10^{-6)} = 50 \times 10^{-6} s$

$$R_2 = 2981\ \Omega$$

The d.c charging voltage for eight stages is

$$V = 8 \times 120 = 960kV$$

The maximum output voltage is

$$\frac{V}{R_1 C_2 (\alpha - \beta)} \left(e^{-\alpha t 1} - e^{-\beta t 1}\right)$$

Where

$$\alpha = \frac{1}{R_1 C_2}\ \beta = \frac{1}{R_2 C_1}\ and\ V\ is\ the\ d.c\ charging\ voltage,$$

Substituting for $R_1 C_1$ and $R_2 C_2$

$$\alpha = 0.7936 \times 10^{+6}$$

$$\beta = 0.02335 \times 10^{+6}$$

Maximum output voltage =932.6kV

10.HOW ARE THE WAVE FRONT AND WAVE TAIL TIME CONTROLLED IN IMPULSE GENERATOR CIRCUIT.(NOV-2015)

The most commonly used configurations for impulse generators are the circuits shown in Figs,6.15b and c. The advantages of these circuits are that the wave front and wave tail times are independently controlled by changing either R_1 and R_2 separately secondly the test objects which are mainly capacities in nature from part of C_2

For the configuration shown in fig 6.15 b the output voltage across C_2 is given by

$$V_0(t) = \frac{1}{C_2}\int_0^t i_2 dt$$

Performing Laplace transformation $\frac{1}{C_2 s} I_2(s) = V_0(s)$

Where $i_2$is the current throughC_2.

Taking the current through $C_1$and I_1 its transformed, value as $I_1(s)$,Taking the current through C_1 as i_1 and its transformed value as $I_1(s)$

$$I_2(s) = \left[\frac{R_2}{R_2 + \frac{1}{C_2 s}}\right] I_1(s)$$

$$I_1(s) = \frac{V}{S}\frac{1}{\frac{1}{C_1 s} + R_1 + \frac{R_2\frac{1}{C_2 s}}{R_2+\frac{1}{C_2 s}}}$$

Where

$\frac{R_2\frac{1}{C_2 s}}{R_2+\frac{1}{C_2 s}}$ Represents the impedance of the parallel combination of R_2 and C_2

Substution of $I_1(s)$ gives

$$V_0(s) = \frac{1}{C_1 s}\frac{R_2}{R_2 + \frac{1}{C_2 s}}\frac{V}{S}\frac{1}{\frac{1}{C_1 s} + R_1 + \frac{R_2\frac{1}{C_2 s}}{R_2+\frac{1}{C_2 s}}}$$

After simplification and Rearrangement,

$$V_0(s) = \frac{V}{R_1 C_2}\left[\frac{1}{S^2 + \left(\frac{1}{C_1 R_1} + \frac{1}{C_2 R_2} + \frac{1}{C_2 R_1}\right) S + \frac{1}{C_1 C_2 R_1 R_2}}\right]$$

Hence, the roots of the equation,

$$S^2 + \left(\frac{1}{C_1R_1} + \frac{1}{C_2R_2} + \frac{1}{C_2R_1}\right)S + \frac{1}{C_1C_2R_1R_2}$$

And found from the relations

$$\alpha + \beta = -\left(\frac{1}{C_1R_1} + \frac{1}{C_2R_2} + \frac{1}{C_2R_1}\right)$$

$$\alpha\beta = \frac{1}{C_1C_2R_1R_2}$$

Taking inverse transform of $V_0(s)$ gives

$$V_0(s) = \frac{1}{R_1C_2(\alpha - \beta)}[\exp(-\alpha t) - \exp(-\beta t)]$$

Usually $\frac{1}{C_1R_1}$ and $\frac{1}{C_2R_2}$ will be much smaller compared to $\frac{1}{R_1C_2}$

Hence, the roots may be approximated as

$\alpha = \frac{1}{R_1C_2}$ And $\beta = \frac{1}{R_2C_1}$

Following a similar analysis, it may be shown that the output waveform for the circuit configuration of fig.5.15c will be

$$V_0(t) = \frac{VC_1R_2\alpha\beta}{\beta - \alpha}[\exp(-\alpha t) - \exp(-\beta t)]$$

Where α and β are the roots of the Eq(6.19). The approximate values of α and β given by Eq.(6.21) are valid for this circuits also.

The equivalent circuits given in fig 6.15d is a combination of the configurations of fig. 6.15b and fig.6.15c. The resistance R_1 is made into two parts and kept on either side of R_2 to give greater flexibility for the circuits.

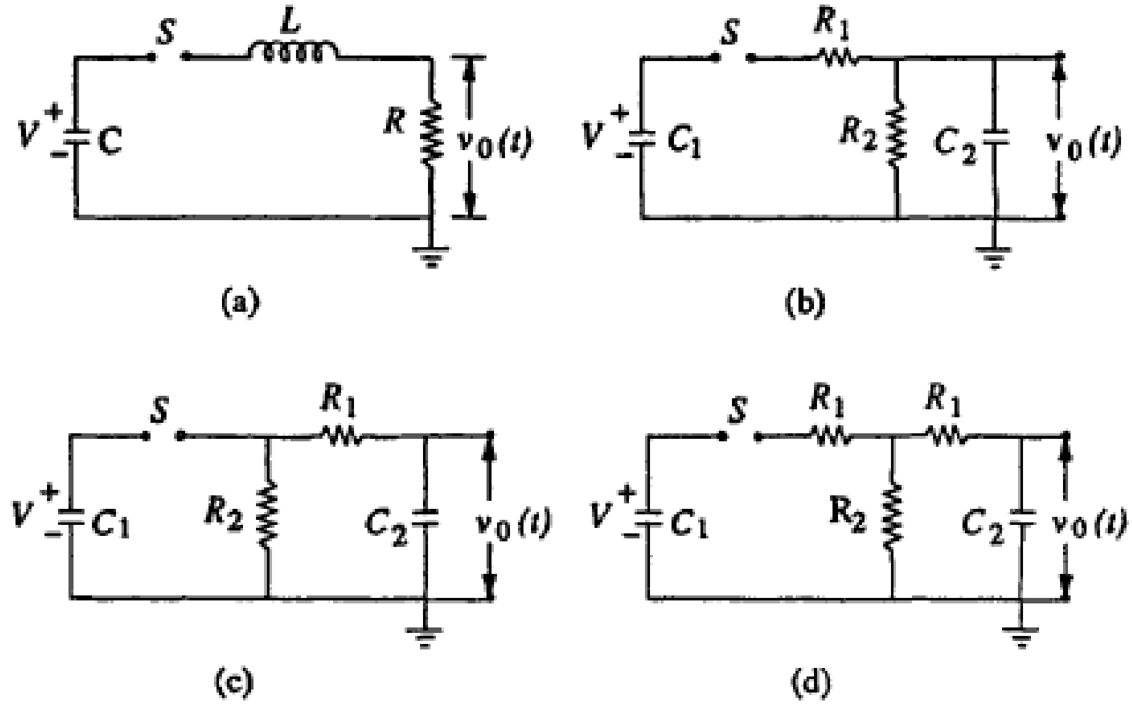


Fig. 6.15 Circuits for producing impulse waves

11.mention the necessity of generating high dc voltage.Dec-16

High voltages in labs are mainly required in the fields of electrical engineering and applied physics. These high voltages (*ac*, *dc*, *impulse*) are used for many applications.

Few applications:-

- electron microscopes and x ray units require *high DC* voltages of the order of 100 kv or more.
- electrostatic precipitator, particle accelerators in nuclear physics require D*C voltages* of the order of kilo-volts or even mega-volts.
- for testing power apparatus rated for extra high transmission voltages 400kV and above, high voltages of one million volts or even more are required.
- ***high impulse voltages*** are used to simulate the *over-voltages* that occur in power system due to **lightening** or **switching** action.

In the field of electrical engineering the main requirement of high voltages is for ***insulation testing*** of various components in power system. This is why there is a need to generate high voltages in laboratories.

UNVERSITY QUESTIONS:

PART-A

1. State the principle of Van de Graff generator ?**(MAY/JUN -2009)**
2. How Impulse voltages are produced in the lab?**(M/J -2012)**
3. How is impulse currents of large value produced?**(A/M-2005)**
4. How will you generate rectangular current pulses with high magnitudes**?(N/D-2004)**
5. What are the disadvantage of using cascade transformer with isolating transformer?**(N/D-2007,A/M-2011)**
6. What are the advantages of using cascade transformer with isolating transformer?
7. What are the impulse wave specifications?**(A/M-2008,M/J-2009)**
8. The impulse waveform can be specified by,
9. What is tesla coil?**(N/D-2008,16)**
10. Explain the operation of basic impulse generator.**(May-2013)**
11. Explain cascade transformer method of HVDC generation**.(May-2013)**
12. Explain the operation of Vande Graff generator from the electrostatic principle.**(May-2013)**
13. How Impulse voltages are produced in the lab?**(M/J-2012)**
14. Define rise time or front time Fall time**?(Dec-2013)**
15. What are the disadvantage of half wave rectifier circuit?**(DEC-2013)**
16. Give any two methods of switching surge generations in laboratory? **(MAY-JUNE 2013)**
17. What are the impulse wave specifications**?(A/M-2008,M/J-2009,MAY-2013)**
18. What is Time lag for Break Down?**(Dec-14)**
19. What is meant by Intrinsic strength of a solid dielectric?**(Dec-14)**
20. What is mean by penning effect.**(May-2014)**

21.What are the factors which affect breakdown of gaseous dielectrics**?(May-2014)**

22.What are the difference between a high voltage testing transformer and a power transformer? **APRIL/MAY-2015**

23.What do you mean by tracking index? **APRIL/MAY-2015**

24) Mention the specification of impulse current as per Indian standard**.(NOV-2015)**

25) How is the circuit inductance controlled and minimizes in impulse mesurements?(NOV-15)

26)what is DELTATRON or ENGETRON circuit.Dec-16

PART-B

1.Explain any one method of voltage multiplier circuits**.(MAY/JUN-2012,NOV/DEC-2004,M/J-2012)**

2. Explain with neat diagram the n-stage Cockcroft-Walton circuit. Derive an expression for total ripple content in output voltage**.(NOV/DEC -2007, MAY/JUN -2008, NOV/DEC -2007,Dec 14,16**

3.Discuss with neat diagram the Van-de Graff generator**.(MAY/JUN -2012, MAY/JUN -2005, NOV/DEC -2008,2015,16 MAY/JUN -2009, MAY/JUN -2012 (MAY/JUN -2013&2014)-**

4. Describe the cascade transformer connection to generate high alternating voltage. **(MAY/JUN -2005, MAY/JUN -2008,DEC-2013)**

5.Explain the principle of operation of resonant transformer**.(NOV/DEC -2006**. Explain with neat diagram MARX circuit and its operations. **(MAY/JUN -2011, MAY/JUN -2008, MAY/JUN -2013, MAY/JUN -2011**

7. Draw and explain the circuits of producing impulse wave**.(NOV/DEC -2004, NOV/DEC -2007)**

8.Draw and explain the circuits of producing impulse wave**.(N/D-2004, N/D-2007,MAY-2013)**

9)Explain in detail the methods of switching surge generation from impulse generator and from power transformer**.(M/J-2012,A/M-2011,M/J-2014)**

10)What is tesla coil? Derive an expression for damped high frequency oscillations obtained from a tesla coil. Give its advantage **(Dec-14)**

11) A Cockcroft-Walton type voltage multiplier has eight stages with capacitances, all equal to 0.05 PF. The supply transformer secondary voltage is 125 kV at a frequency of 150 Hz. If the load current to be supplied is 5 mA, find *(a)* the percentage ripple, *(b)* the regulation, and *(c)* the optimum number of stages for minimum regulation or voltage drop.**APRIL/MAY-2015**

12) An impulse generator has eight stages with each condenser rated for 0.16microF and 125 kV. The load capacitor available is 1000 pF. Find the series resistance and the damping resistance needed to produce 1.2/50}is impulse wave. What is the maximum output voltage of the generator, if the charging voltage is 120kV? **APRIL/MAY-2015**

13)Starting from The Basic MARX Circuit Develop The Circuit Of A Morden Multi-Stage Impulse Generater And Explain Its Operation. Discuss On The Significance Of Various Parameter (N/D2007,N/D-2007,DEC-2013,N/D-2015)

14)Explain the function and operation of trigatron gap. Nov/dec-2015

15.How are the wave front and wave tail time controlled in impulse generator circuit.(nov-2015)

16.mention the necessity of generating high dc voltage.Dec-16

UNIT-4

TWO MARKS

1. **What are the different methods used for measurement of D.C voltages?**
   - Series resistance microammeter
   - Resistance potential divider
   - Generation voltmeters
   - Sphere and other spark gaps
2. ***What are the different methods used for measurement of A.C Voltages?***
   - Series impedance ammeters
   - Potential dividers
   - Potential transformers
   - Electrostatic voltmeter
   - Sphere gap
3. ***What are the problems involved in high voltage measurements?***

Problem involved in H.V. (1000 KV or more) measurements are:

- Large power dissipation.
- Large leakage current.
- Limitation of voltage stress per unit length.
- Change in resistance due to temperature variations, Etc.

4. ***What are the limitations of using series resistances?(OR) what are the draw backs of series resistance micro-ammeter technique in HVAC measurements.NOV-2015***

The limitations of using series resistance are:

- Power dissipation and source loading.
- Temperature effects and long time stability.
- Voltage dependence of resistive elements.
- Sensitivity to mechanical stresses.

5. ***What is the principle behind the operation of generation voltmeter? APRIL/MAY-15***

A generating voltmeter is a variable capacitor electrostatic voltage generator which generated 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.

6. ***What are the advantages of generation voltmeters?(Dec-16)***
   - Scale is linear and extension of voltage range is easy.

- It can measure wide range of voltages.
- Source is zero.
- There is no direct connection to H.V electrode.

7. ***What are the limitations of using generation voltmeters?***
    - Need calibration
    - Careful construction is needed.
    - Any disturbances due to position and mounting of the electrodes make the calibration invalid.
8. ***What are the problems involved in pure resistance used for A.C voltage measurements?***
    - Power losses more.
    - Variation of resistance varies the temperature. So it is a problem.
    - Residual inductance of the resistance gives rise to an impedance different from its ohmic resistance.
9. ***What do you mean CVT?***

Capacitance voltage transformer Is a device used in power system to measure voltages. It consists of capacitor divider with a suitable matching or isolating potential transformer tuned for resonance condition.

10. ***What are the advantages of CVT?Nov/Dec-17***
    - Design is simple
    - Installation is easy.
    - CVT can be used as a voltage measuring device for meters.
    - In power line carrier communications, CVT can be used.
    - It provides isolation between H.V. terminal and low voltage metering. So it can be used for relaying purpose.
    - Voltage distribution is independent of frequency.

11.What are the disadvantages of CVT?

- Voltage ratio is susceptible to temperature variations.
- In the presence of capacitance and choke, the problem of ferro-resonance occurs in power systems.

12.Which 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 electrodes, for which the field gradient E is the same across the area and perpendicular to the surface.

13.What are the advantages of electrostatic voltmeter?

- Low leading effect, as only electric fields have to be built up.
- High pressure gas or vacuum between electrodes provide very high resistivity. Therefore the active power losses are negligibly small.
- Voltage source loading is limited to the reactive power needed to charge the system capacitance. i.e., for 1 volt voltmeter- capacitance value is few picofarad.

14.What are the disadvantages of the electrostatic voltmeter?

For a constant distance d, $F \alpha V^2_{rms}$, the sensitivity is small. This can be overcome by varying the gap distance d in appropriate steps.

15.Why is peak value instrument needed in high voltage measurement?

Necessity of peak value instrument for an A.C waveform

In sinusoidal waveform,

Peak value of an A.C. waveform = RMS value * $\sqrt{2}$

but to obtain the maximum dielectric strength of insulating solids, the waveform is not sinusoidal.

Peak value $\neq$ RMS value * $\sqrt{2}$

Therefore, a separate peak value instrument is needed in high voltage applications.

16.What are the types of peak reading A.C. voltmeters?

- Series capacitor peak voltmeter (Chubb-Fortscue method for peak voltage measurement)
- Digital peak voltmeter.
- Peak voltmeter with potential dividers.

17. What are the advantages of spark gap measurement for high D.C, A.C, impulse voltages?

- High reliability.
- Simplicity
- More accurate if electronic circuits are applied for measurements.

18. List the factors that are influencing the peak voltage measurement using sphere gap?

Factors that affect the sparkover or disruptive voltages are:

- Nearby earthed objects.
- Atmospheric conditions.
- Influence of humidity.
- Irradiation.
- Polarity and rise time of voltage waveform.
- Switching surges.

19. What are the advantages of uniform field electrode spark gap?

- No influence of nearby earthed objects.
- No polarity effect.

20. What are the disadvantages of uniform field electrode spark gap?

- Very accurate mechanical finish of the electrode is required. Otherwise measurement is not accurate.
- Two electrodes are properly allligned in parallel.
- Dust or greeze influences erratic breakdown of the gap.
- Accuracy is less.

21.What is the use of rod gaps?

Rod gaps are used to measure peak value of impulse voltage and power frequency.

22. Name the types of potential divider circuits?

- Resistive
- Capacitive
- Mixed

23.What are the disadvantages of pure capacitance voltage divider?

A small disturbance in the location of C_2 or H.V. electrode or the presence of any stray object nearby changes the capacitance C_1 and hence the voltage ratio of the divider will be affected.

24. What are the uses of L-peaking?

By using L-peaking, the response is very fast and overshoot is reduced. L-peaking in low voltage arm.

25. What are the uses of peak reading voltmeters for impulse voltages?

Peak reading voltmeters are used to measure impulse voltage wave and routine impulse testing work. The wave shape of impulse voltage might be low or fixed by the source.

26. What are the general methods used for measurement of high frequency and impulse currents?(May-2014,MAY-17,Nov/Dec-17)

- Resistive shunts
- Magnetic potentiometers or probes
- Magnetic links
- Hall generator
- Faraday generator

27. What is the high direct current measurement techniques used?

Current transformer with electro-optical technique.

28.For what measurement are Hall generators techniques used?

- Measurement of high direct currents.
- Measurement of high frequency and impulse currents.

29.Define Hall Effect?April-18

Whenever an electric current flow through a metal plate placed in a magnetic field perpendicular to it, Lorenz force will deflect the electrons in the metal plate in a direction perpendicular to both the magnetic fields and the flow of current. The change in displacement generates an e.m.f. called the Hall Effect.

30.Which type of measuring device is preferred for measurement of high frequency A.C?

Current transformer with electro-optical signal generator.

31. What are the disadvantages of using only current transformer?

- Currents shunts involve unnecessary power loss.
- C.T. provides electrical isolation between H.V and L.V. side of current transformer in power system.
- Current transformers used for extra high voltage systems are kept in very high voltages with respect to the ground.

32. Why are measurements of high frequency and impulse currents needed?

- Impulse currents occur during lightning discharge which causes severe faults.
- Electrical arcs and post arc phenomenon studies with circuit breakers.
- Electric discharge studies with plasma physics.

33. What types of measuring devices are preferred for measurement of high frequency impulse current?

- Resistive shunts
- Magnetic potentiometers or probes.
- Faraday and hall-effect devices.

34. How is the resistance shunt designed?

- Bifilar flat strip design.

- Coaxial tube or park's shunt design.
- Coaxial squirrel cage design.

35. Define Faraday Effect

When a linearly polarized light beam passes through a transparent crystal in the presence of a magnetic field, the plane or polarization of the light beam undergoes rotation. This rotation of plane of polarizations proportional to the current.

Angle of rotation α Bl

Angle of rotation = VBl

Where, V= constant of the crystal depends on the wavelength of the light.

B= magnetic flux density.

L= length of the crystal.

36. What are the advantages of using faraday generator?(Dec-16)

- No electric connection between the source and the device.
- No thermal problems even for large currents of several kA.
- No insulation problem arises for EHV system, because signal transmission is through optical system.

37. Which type of measuring device is used for measurement of impulse voltages and currents?

Cathode ray oscilloscope.

38) Define CVT? (**MAY-JUNE 2013**)

Capacitance voltage transformer is a device used in power system to measure voltages. it consists of capacitor divider with a suitable matching or isolating potential transformer tuned for resonance conditions.

39) Give the advantages of electrostatic voltmeter? (**MAY-JUNE 2013**)

- Low loading effect
- High pressure gas or vacuum between electrodes provide very high resistivity, therefore active power losses are negatively small.
- Voltage source loading is limited to the reactive power needed to charge the system capacitance.
- Voltage up to 600 KV can be measured.

40)**what is the effect of dust particles on the measurements using sphere gaps(DEC-2013)**

When a dust particle is floating between the gap this results into erratic breakdown in homogeneous or slightly inhomogenous electrode configurations. When the dust particle comes in contact with one electrode under the application of d.c. voltage, it gets charged to the polarity of the electrode and gets attracted by the opposite electrode due to the field forces and the breakdown is triggered shortly before arrival. Gaps subjected to a.c. voltages are also sensitive to dust particles but the probability of erratic breakdown is less. Under d.c. voltages erratic breakdowns occur within a few minutes even for voltages as low as 80% of the nominal breakdown voltages. This is a major problem, with high d.c. voltage measurements with sphere gap

41) **What are the advantages and limitations of generating voltmeter?(DEC-2013)**

Advantage:

(i) Scale is linear and extension of voltage range is easy
(ii) Source loading is zero
(III)It can measure wide range of voltages
(iv) There is no connection to H.V electrode
Disadvantage:

(i) need calibration,
(ii) Careful construction is needed,
(iii) Disturbance In Position And Mounting Electrode Make Calibration Unvalied.

42) Give the procedure for DC and Ac peak voltage measurements using sphere gap.(May-14)

- ✓ Spark over voltage of 30KV peak at 1cm spacing in air at 20˚ and 760 toor pressures
- ✓ Value of resistance 0.1to 1MΩ for DC and ac power frequency.
- ✓ Value of R less than500Ω for impulse voltage
- ✓ 10cm diameter used for <50KV

43) What are the condition to be satisfied by potential divider for impulse work?(Dec-14)

The condition to be satisfied here is ωCR »1

***44)* What is the significance of atmospheric (Air) correction factor in HV testing?(Dec-14,MAY-17)**

The standard atmospheric conditions are an air temperature of t_0=20˙c, an air pressure of b_0=1013mbar and an absolute humidity of h_0=11g/m^3. b_0 is standard atmospheric pressure ,b is actual pressure at the instant of measurement with t the actual pressure at the instant of measurement with t the actual temperature. The atmospheric correction factor $k_t$has two parts Air density factor K_1 and humidity factor K_2.

$$K_1=\delta^m$$

Where δ is given by the equation

$$\delta = \frac{b}{b_0}\frac{273+t_0}{273+t}$$

45) Calculate the correction factors for atmospheric conditions, if the laboratory temperature is 37^{0}C, the atmospheric pressure is 750 mm Hg, and the wet bulb temperature is 27^{0}C.APRIL/MAY-2015

SOLUTION:

At t=37^{0}C

Air density factor

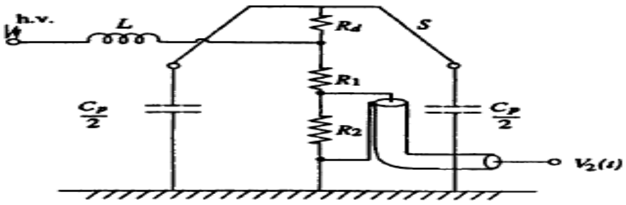
$$d = \frac{P}{760}\frac{293}{273+t}$$

$$= 0.9327$$

(Note: No humidity correction is needed for sphere gaps.)

46)How the stray effect of capacitance potential divider is minimized for impulse measurements? (NOV-2015,April-18)

The electrostatic or capacitive field distribution of a shield or guard ring placed over a resistive divider to enforce a uniform field in the neighbourhood and along the divider may be adopted for high voltage measurements and reduce stray effect.



R_d — Damping resistor
L — Lead inductance
C_P — Capacitance of the shield to ground
S — Shield

47. What are the problems associated with measurements of very high impulse voltages?May-2017

Electromagnetic interference is a serious problem in impulse voltage and current measurements, and it has to be avoided or minimized.

PART B

1. ***Explain briefly different types of DC voltage measurements?NOV- 2011,May-2013,2015 (OR)***

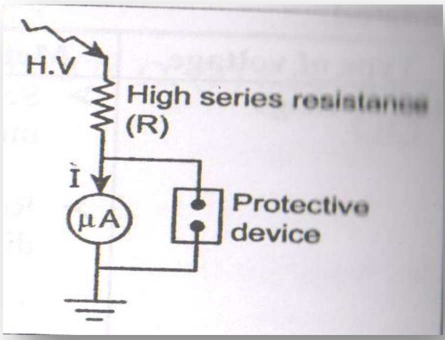
Describe the construction, principle of operation of a generating voltmeter and give its application and limitations.(May-2014,17,Nov/Dec-17)

DC voltage measurements types:

- Series resistance micro ammeter.
- Resistance potential divider.
- Generating voltmeters.
- Sphere and other spark gaps.

High ohmic series resistance with micro ammeters:

- A very high resistance i.e., few hundreds of mega ohms is connected in series with a micro ammeter (µA) is shown.
- A protective device like paper gap, a neon glow tube or zener diode with a suitable series resistance is connected across the micro-ammeter. It is used to protect the meter against high voltage (H.V) occurs due to the failure of high series resistance R or flashover.



The resistance value of R is chosen such that:

- ✓ A current of 1 to 10 μA is allowed for one full-scale deflection.
- ✓ It consists of large number of wire wound resistors in series.
- ✓ To provide corona free termination.
- ✓ Temperature coefficient < 10^{-4} /˚C , so element is made up of carbon-alloy.
- ✓ To maintain very good temperature stability. So, resistance chain is placed in airtight, transformer oil filled PVC tube for 100 kV operations.

Limitations in series resistance design:

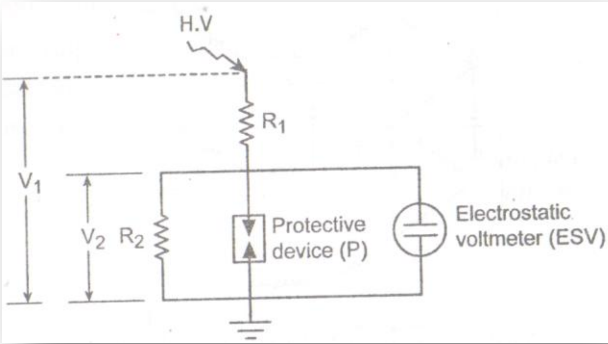
- ✓ Power dissipation and source loading
- ✓ Temperature effects and long time stability.
- ✓ Voltage dependence of resistive elements.
- ✓ Sensitivity to mechanical stresses.

Operation:

- Current I flowing through resistance R is measured using micro ammeter.
- Voltage or the source V=IR
- If any overvoltage or flashover occurs, the protective device will come into action to bypass the current.
- Series resistance meters can operate up to 500kV (D.C)
- Accuracy = ±0.2%

ii)Resistance potential dividers:

A resistance potential divider for D.C. voltage measurement with an electrostatic voltmeter as shown in fig



Let V_2 be the d.c. voltage across resistance R_2 (low voltage)

We know, $V_2 = v_1 * \frac{R_2}{R_{1+R_2}}$

High voltage magnitude, $V_1 = \frac{R_{1+R_2}}{R_2} . V_2$

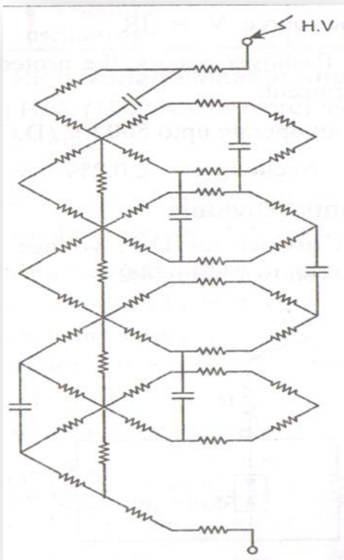
<u>Sudden voltage changes occur during transient period due to:</u>

- ✓ Switching operation
- ✓ Flashover of test objects.
- ✓ Damage may occur to the diverter elements due to stray capacitance across the elements and due to ground capacitance.

<u>Transient voltages can be avoided by:</u>

- ✓ Connecting voltage controlling capacitor across the element.
- ✓ Corona free termination,

For linearizing transient potential distribution, a series resistor is connected with a parallel capacitor as shown



The potential divider accuracy corresponding to the voltage is given in the table

Voltage	Accuracy
Upto 100 Kv	0.05 %
Upto 300 Kv	0.1 %
Upto 500 Kv	0.5 %

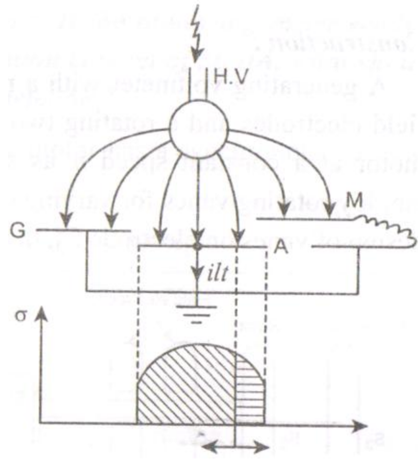
iii)Generating voltmeter:

- ✓ In H.V. D.C. measurement, the generating principle is used when source loading is not permitted or when direct connection to the high voltage source is to be avoided
- ✓ A generating voltmeter is a variable capacitor electrostatic 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.

Principle of operation:

- ✓ High voltage electrode excites the electrostatic field within a highly insulating medium (gas or vacuum) and ground potential.

- ✓ The earthed electrodes are subdivided into a sensing or pick-up electrode (A), guard electrode (G) and movable electrode (M), all are kept at same potential. Every field line ending at these electrodes binds free charges.
- ✓ For measuring purpose, surface area of electrode A is considered. Let q be the charge stored.



$$i = \frac{dq}{dt} = \frac{d(VC)}{dt}$$

$$= V.\frac{dC}{dt} + C.\frac{dV}{dt}$$

Consider the electrode M is fixed or for D.C. voltage,

$$\frac{dV}{dt} = 0; i = V\frac{dC}{dt}$$

If the capacitance C varies between limits C_0 and $(C_0 + C_m)$, then

$$C = C_0 + C_m \sin \omega t$$

$$i = V\frac{dC}{dt} = V \,.\, \mathrm{Cm} \cos \omega t \times \omega$$

$$= V \,.\, C_m \,\omega \cos \omega t = i_m \cos \omega t$$

Where, $i_m = V .C_m \,\omega$,

$$I_{r.m.s} = \frac{V\mathrm{Cm}\ \omega}{\sqrt{2}}$$

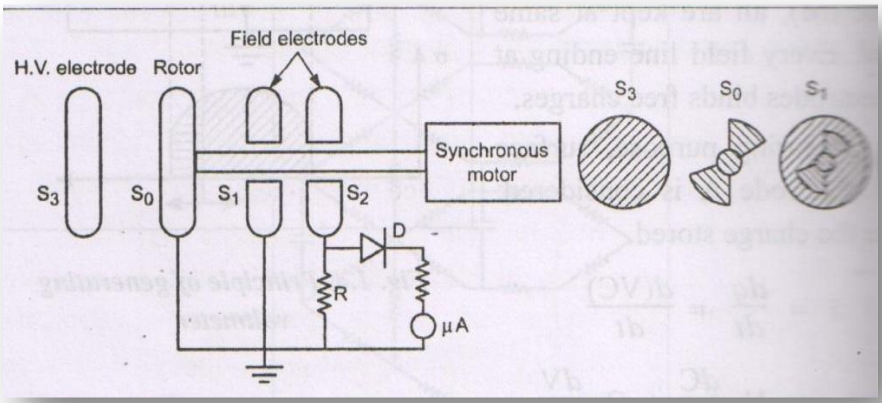
If the capacitance varies linearly with time and reaches its peak value C_m in time $\frac{Tc}{2}$ and vice versa.

$i = V.\ C_m .\ f = V.\ C_m .\frac{2}{60}\ n = \frac{n}{30}\ V.\ C_m$

[let n r.p.m be the synchrounous speed , $T_c = \frac{60}{n}$]

Construction:

- A generating voltmeter with a rotating cylinder consists of two exciting field electrodes and a rotating two pole rotor (S_0) driven by a synchronous motor at a constant speed n as shown.
- Generating voltmeters employ rotating vanes for varying capacitance between S_2 and S_3.By proper design of vanes on electrodes S_0, the capacitance can be varied.H.V. source is connected to a disc electrode S_3 and is kept at a fixed distance from all other electrodes.



Operation:

- ✓ The generated A.C. current through the resistance R is rectified by using diode and read by a moving coil micro ammeter. If the current is small, an amplifier may be used before the current is measured.
- ✓ This instrument is calibrated using potential divider or sphere gap.
- ✓ Generating voltmeters can be used to measure wide range of voltages.

Advantages:

- ✓ Scale is linear and extension of voltage is easy.
- ✓ It can measure wide range of voltages.
- ✓ Source leading is zero.
- ✓ There is no direct connection to H.V. electrode.

Limitations:

- ✓ Need calibration.
- ✓ Careful construction is needed.

- ✓ Any disturbances due to position and mounting of the electrodes make the calibration invalid.

2) *Explain briefly different types of AC voltage measurement?APR-MAY 2011,May-2013*

(or)

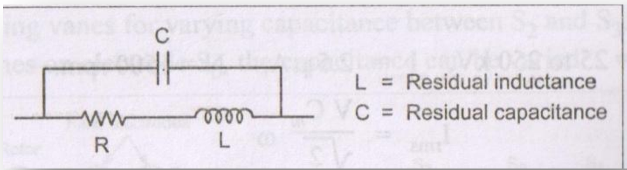
With neat sketch explain in detail the various methods used to measure the RMS and peak values of high AC voltages? APRIL/MAY-2015

i) Series impedance Voltmeter :

Problems Involved in Pure resistance Used for A.C. Voltage Measurement

- Power losses more.
- Variations of resistance vary the temperature. So it is problem.
- Residual inductance of the resistance gives rise to an impedance different from its ohmic resistance.

A simplified lumped parameter equivalent circuit of a high ohmic resistance R is given in Fig.



R+j$X_L$is connected in parallel with -jX_C.

$$Z = \frac{(R+j\omega L)X\frac{1}{j\omega C}}{R+j\omega L+\frac{1}{j\omega C}} = \frac{R+k\omega L}{1-\omega^2 LC+j\omega CR}$$

If ωL and $\omega C$are small compared to R.

$$Z = \frac{R+j\omega L}{1+j\omega CR}$$

Multiplying by complex conjugate of the denominator to the numerator and denominator, we get

$$Z = \frac{R+j\omega L}{1+J\omega CR}\frac{(1-j\omega CR)}{(1-j\omega CR)}$$

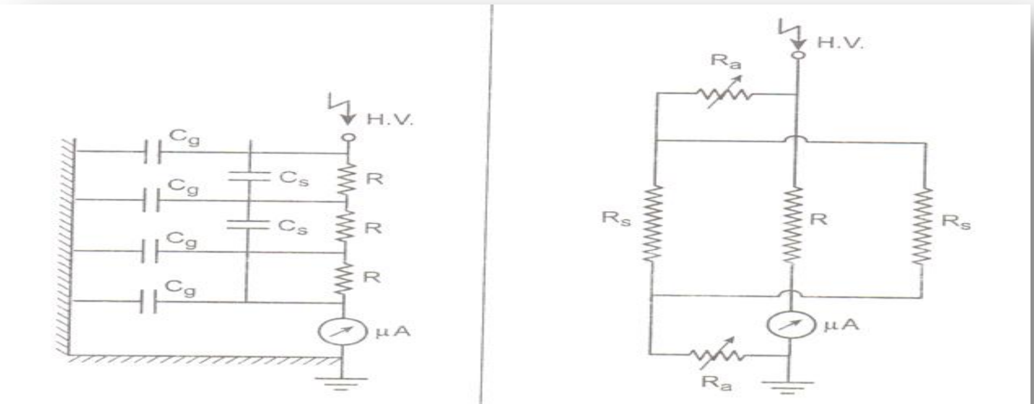
$$= \frac{R+j\omega L-j\omega R^2C+\omega^2 RLC}{1+\omega^2 R^2C^2}$$

$$= R[\ 1+\frac{j\omega L}{R} - j\omega CR\ ] = R\ [\ 1+j\ (\frac{\omega L}{R}-\omega CR)\ ]$$

Phase angle = tan Φ = $\frac{\omega L}{R} - \omega CR$

Extended Series Resistance Voltmeter:

The extended series resistance neglecting inductance is as shown in Fig b



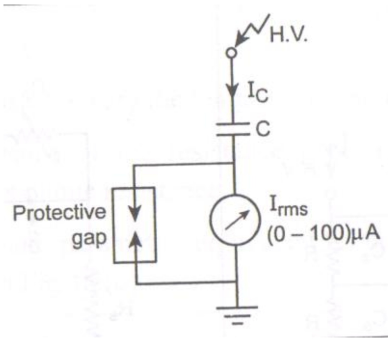
(b) Extended series resistance with inductance neglected

(c) Series resistance with guard (R_s) and tuning (R_a) resistance

- ✓ For calculating the effective resistance, the resistor unit can be taken as the equivalent circuit of transmission line and neglecting inductance. The ground capacitance C_g or stray capacitance influences current flowing in the unit, so the meter reading has error.
- ✓ The series resistance with guard and tuning resistance is as shown in Fig in c
- ✓ Stray and ground capacitance effects can be removed by shielding the resistor R by a second surrounding spiral R_s. $R_s$is connected across R and does not contribute the current through the instrument.
- ✓ Tuning resistance R_a is tuned to adjust the shielding resistor end potentials with respect to the actual measuring resistor. Therefore minimum phase angle can be provided between shield and the measuring resistors.

Series Capacitance Voltmeter:

A series capacitor is used instead of a resistor for A.C. high voltage measurements as shown in Fig.



Let C be the capacitance of the series capacitor.

Let V be the applied A.C. high voltage.

Let ω be the angular frequency.

If A.C. voltages are not pure sinusoidal, it contains harmonics. If an A.C. voltage contains harmonics, error in the measurement occurs due to changes in series impedance.

$V_{RMS} = \sqrt{V_1^2 + V_2^2 + \cdots \ldots\ldots\ldots\ldots + V_n^2}$

Where, V_1 = RMS value of fundamental.

V_2 = RMS value of second harmonic.

V_3 = RMS value of third harmonic.

V_n= RMS value of n^{th} harmonic.

The currents due to V_1, V_2 , ………,V_n are

$I_1 = \omega C V_1$

$I_2 = 2\ \omega\ C\ V_2$

$I_n = n\ \omega\ C V_n$

$I_{rms} = \omega\ C\ \sqrt{V_1^2 + (\ 2V_2)^2 +\ \ldots (nV_n)^2}$

$I_{rms} = \omega\ C\sqrt{V_1^2 +\ 4V_2^2 +\ \ldots\ldots. + n^2V_n^2}$

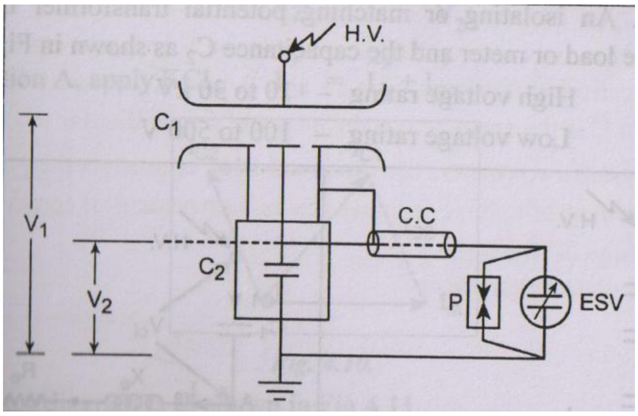
- ✓ Series capacitance voltmeters were used with cascade transformers for measuring rms values upto 1000KV.
- ✓ A series capacitance was formed between high voltage terminal of the transformer and ground. A rectifies ammeter is used as an indicating instrument, which reads rms value of high voltage A.C.

ii)Capacitance Potential Divider:

Capacitance potential divider can be used to eliminate errors due to harmonics with an electrostatic voltmeter or a high impedance meter. It requires high impedance meter like electrostatic voltmeter.

Construction:

A standard compressed air or condensed gas is used for C_1 and the large value capacitor C_2 has insulating media lime mica, paper, etc. C_1 is a three terminal capacitor and is connected to C_2 through a shielded cable. If long cable is connected, the capacitance value is taken into account. To avoid stray capacitance, C_2 is shielded in a box. A protective device is connected across electrostatic voltmeter. Capacitance potential divider is as shown in Fig.



Operation:

- ✓ When high voltage source is applied, it can be measured using electrostatic voltmeter. Some drop in voltage occurs due to the capacitance C_1, C_2, and also the capacitance of the cable and wire.
- ✓ Applied voltage V_1 can be calculated from the electrostatic voltmeter V_2 reading as,

$$V_1 = V_2 \left[\frac{C_1 + C_2 + C_m}{C_1}\right]$$

Where, C_m = Capacitance of meter and cable.

C_1 = Standard compressed gas h.v.

C_2 = Standard low voltage condenser.

V_2 = Meter rating.

P = Protective gap C.C = Connecting cable.

Capacitance Voltage Transformer (CVT).Dec-16)

Capacitance voltage transformer is a device used in power system to measure voltages. It consists of capacitor divider with a suitable matching or isolating potential transformer tuned for resonance condition.

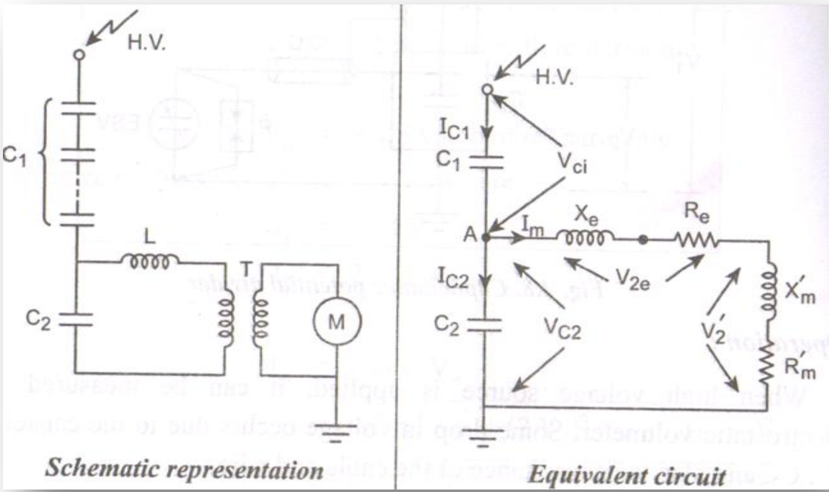
It can be connected to low impedance devices like a pressure coil of wattmeter or a relay coil. It can supply a load of few volt amperes.

Construction:

Capacitance divider has two sections C_1 and C_2, C_1 is made up of few units of high voltage condensers and has the total capacitance of about 1000 pico farad. An isolating or matching potential transformer is connected between the load or meter and the capacitance C_2 as shown in Fig.

High voltage rating – 10 to 30 KV

Low voltage rating – 100 to 500 V



Operating:

Choke L is connected to the primary side of potential transformer used to bring resonance condition or purely resistive by tuning.

Resonance condition is, $X_L = X_C$

$\omega(L + L_T) = \frac{1}{\omega(C_1 + C_2)}$

Where L = Inductance of the choke.

L_T = Equivalent inductance of the transformer referred to H.V. side.

Phasor Diagram:

The meter is taken as a resistive load and $X_m^{'}$ is neglected.

Let $V_2^{'}$ be the voltage across the meter.

$V_2^{'} = I_m R_m^{'}$

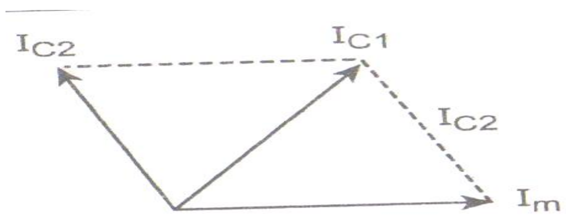
$V_{C2} = V_2^{'} + V_{2n} = V_2^{'} + I_m\ (R_e +\ X_e\ )$

Where R_e , X_e is the resistance and leakage reactance of P.T.

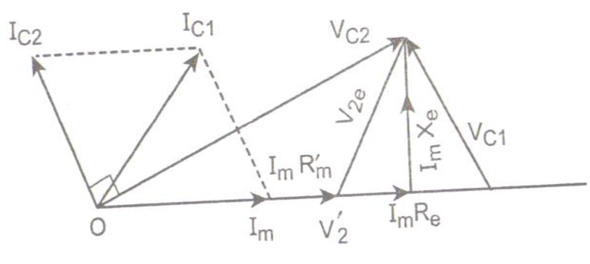
Input voltage $V_1 = V_{C1} + V_{C2}$ and inphase with $V_2^{'}$.

Voltage ratio, a= $\frac{V_1}{V_2} = \frac{V_{C1} + V_{2e} + V_2^{'}}{V'_2}$

At junction A, apply KCL, $\underset{I_{C1}}{\rightarrow} = \vec{I}_{C1} = \vec{I}_m + \vec{I}_{C2}$



The vector diagram is as shown in Fig.



Draw reference line V'_2. Mark $V'_2 = I_m R'_m$ neglecting $i_m X'_m$. From V'_2, mark $I_m R_e$ in the same line. Draw perpendicular line for $I_m X_e$. Join from 0 gives V_{C2} by 90°. The vector sum of $I_m and I_{C2}$gives I_{C1}. From V_{C2}, draw perpendicular line for I_{C1}, which is V_{C1}i.e., I_{C1} leads $V_{C1}$by 90°.

Advantages:

- Design is simple.
- Installation is easy.
- CVT can be used as a voltage measuring device for meters.
- In power line carrier communications, CVT can be used.
- It provides isolation between H.V. terminal and low voltage metering. So it can be used for relaying purposes.
- Voltage distribution is independent of frequency.

Disadvantages:

- Voltage ratio is susceptible to temperature variations.
- In the presence of capacitance and choke, the problem of ferro resonance occurs in power system.

iii) Electrostatic Voltmeter: (Explain the operation of Electrostatic voltmeter with neat sketch and give its advantages and limitations)Nov/Dec-17

Principle:

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.

Attractive force between the

Parallel plate electrodes $F = \left|\frac{-\partial W}{\partial S}\right|$

$$= \left|\frac{\partial}{\partial S}\left(\frac{1}{2}CV^{2}\right)\right|$$

$$= \left|\frac{1}{2}V^2\frac{\partial C}{\partial S}\right| = \left|\frac{1}{2}V^2\frac{\partial}{\partial s}\left(\frac{\varepsilon_0 A}{d}\right)\right|$$

$$= \frac{1}{2}\varepsilon_0 V^2\frac{A}{d^2}$$

V = Applied voltage between plates.

C = Capacitance between the plates

A = Area of cross section of the plates

D = Distance between the plates

ε_0 = Permittivity of the insulating medium.

Since the two plates are oppositely charged, there is attraction force between them.

Measured of voltage = Mean of the force

$$= \frac{1}{T}\int_0^T F(t).dt = \frac{1}{T}\int_0^T \frac{1}{2}\varepsilon_0 \frac{V^2(t)A}{d^2} dt$$

$$= \frac{1}{2}\varepsilon_0 \frac{A}{d^2}.\frac{1}{T}\int V^2(t)dt = \frac{1}{2}\varepsilon_0 \frac{A}{d^2} V_{rms}^2$$

In electrostatic voltmeters, one of the plates is fixed and the other is movable. The force on the plate can be measured by:

- Suspension of moving electrodes on one arm of a balance.
- Suspension of the moving electrode on a spring.
- Pendulous suspension of the moving electrode.
- Torsonal suspension of the moving electrode.

For high voltage measurements, a small displacement of one of the electrodes by a fraction of a millimeter to a few millimeters is sufficient.

As F$\propto V_{rms}^2$, The meter can be used to measure both A.C. and D.C. voltages.

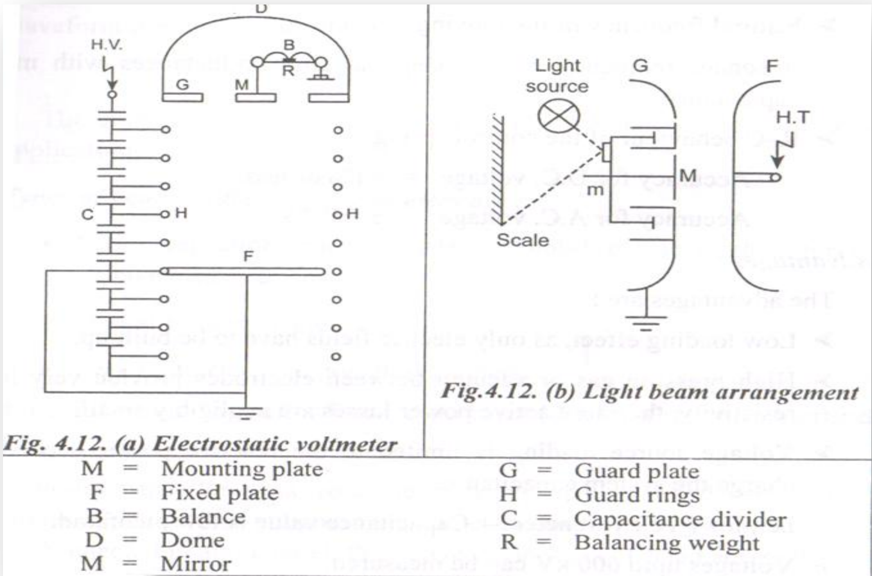


Fig. 4.12. (a) Electrostatic voltmeter

Fig.4.12. (b) Light beam arrangement

Construction:

Absolute electrostatic voltmeter is as shown in Fig. (a).

It consists of parallel plate disc electrodes. The moving disc M forms the central core of the guard ring G, which has the same dimension as that of fixed plate F. The guard rings are used to make the electric field uniform in the central region and to avoid corona. The controlling torque is provided by a balancing weight (B). The cap or dome D encloses a balance and a moving.

Operation:

The balance beam carries a mirror which reflects a beam of light. The movement of the moving electrode is amplified through optical arrangement as shown in Fig. (b)

To measure the given voltage with precision, the disc diameter is to be increased, and the gap distance between the electrodes is to be minimized. As the gap distance is more, the uniformity of electric field is maintained by guard rings H placed between electrodes F and M by using capacitance divider (C).

The upper frequency limit for A.C. application is determined from:

- Natural frequency of the moving system.
- Resonant frequency of the lead and stray inductances with meter capacitance.
- R-C behavior of the control spring.

Accuracy for D.C. voltage = $\pm$1% or less.

Accuracy for A.C. voltage = $\pm$0.25%

<u>Advantages:</u>

The advantages are:

- Low loading effect, as only electric field have to be built up.
- High pressure gas or vacuum between electrodes provide very high resistivity, therefore active power losses are negligibly small.
- Voltage source loading is limited to the reactive power needed to charge the system capacitance.

i.e., for 1 volt voltmeter – Capacitance value is few picofarad.

- Voltages upto 600KV can be measured.

<u>Disadvantages:</u>

For a constant distance d, F $\propto V_{rms}^2$, the sensitivity is small. This can be overcome by varying the gap distance d in appropriate steps.

<u>Restriction of electrostatic voltmeters:</u>

- ✓ For D.C. voltage measurements, the electrostatic voltmeters compete with resistor voltage dividers or measuring resistors, as the very high impedance is not necessary
- ✓ For A.C. voltage measurements, the R.M.S. value is either of minor importance for dielectric testing or capacitance voltage dividers. Thus use of electrostatic voltmeters is restricted.

3) Explain briefly various types of peak reading voltmeters?

<u>Necessity of peak value instrument for an AC waveform</u>

In sinusoidal waveform,

Peak value of an A.C. waveform = RMS value * $\sqrt{2}$

But to obtain the maximum dielectric strength of insulating solids, the waveform is not sinusoidal.

Peak value RMS value $\neq$* $\sqrt{2}$

Therefore a separate peak value instrument is needed in high voltage applications.

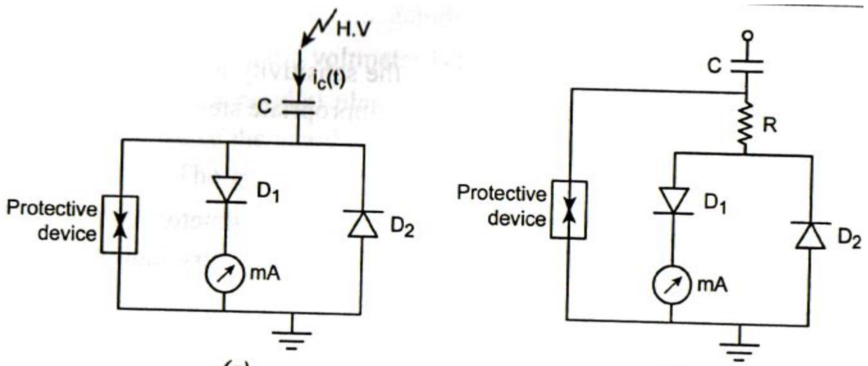
Types of peak reading A.C. voltmeters are:

- Series capacitor peak voltmeter (Chubb- Frotscue method for peak voltage measurement.)
- Digital peak voltmeter.
- Peak voltmeter with potential dividers.

i) *Explain Series capacitor peak voltmeter (Chubb- Frotscue method for peak voltage measurement.(Dec-14)*

Construction:

Series capacitor peak voltmeter consists of a standard capacitor, two diodes and a current integrating ammeter as shown in fig The diodes are connected in antiparallel.Protective device is connected across the diode to protect the equipment.



Operation:

When a sinusoidal voltage source is connected to a capacitor, charging current proportional to the voltage to be measured flows is given by,

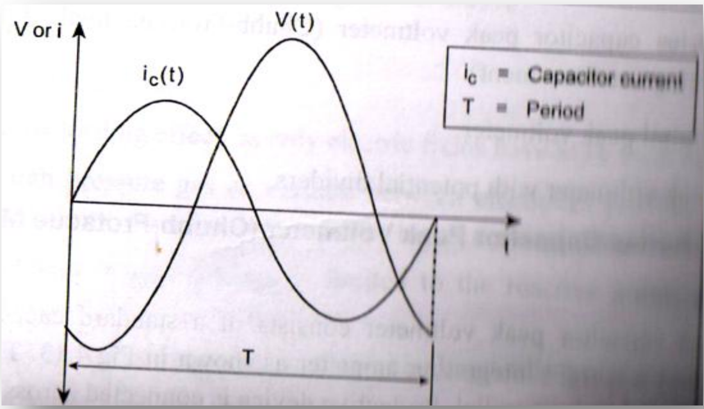
I = $C\int_0^t Vdt$ = $j\omega CV$

Where ω= angular velocity,

V= rms value of voltage.

I = D.C. current read by the mili ammeter

- During positive half cycle, diode D_2 conducts and during negative half cycle, diode D_1 conducts and ;used to rectify the A.C. current.
- Wave form is suitable sinusoidal A.C. only
- i.e., both half cycles are symmetrical and equal. Ammeter reads the mean value of current and voltage drop across the diodes (1 v for Si) can be neglected.



- When the waveform is not sinusoidal, the peak value may occur more than once in a half cycle as shown.
- Standard A.C. voltages for testing should not have any harmonics.
- But A.C. voltages for testing should have pre-discharge currents, causing very short duration voltage drops which introduce error in meter reading.
- This problem can be overcome by introducing a damping resistance R in series with capacitor and diode circuit as shown.

% Error due to resistance $\frac{\Delta V}{V} = \frac{V - V_m}{V}$ = (1- $\left(1 - \frac{1}{1+\omega^2 C^2 R^2}\right)$

Where, V = actual value.

V_m = measured value.

Errors occur due to:

- Imperfect rectifiers,
- Non-sinusoidal voltage, waveform, etc.

Advantages:

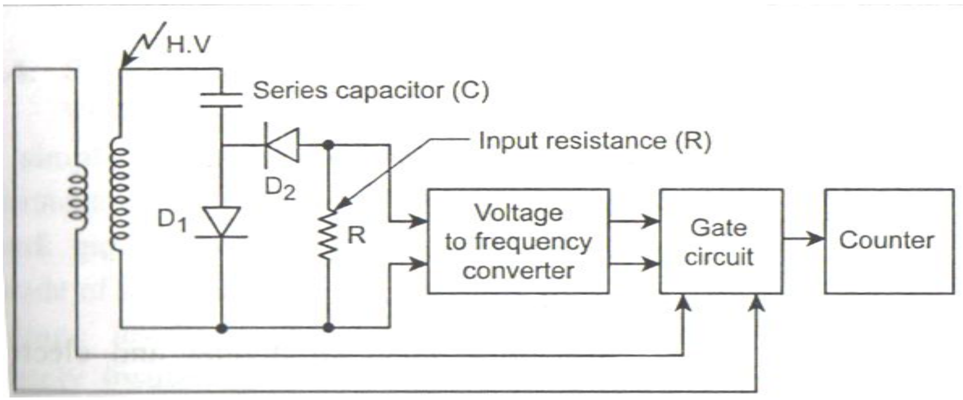
When sinusoidal waveform is used, the measurement is accurate and used for the calibration of the other peak voltage measuring devices.

ii)Digital peak voltmeter:Dec-16

Construction:

- ✓ A digital peak voltmeter is as shown.in fig.
- ✓ A.C. voltage is given to the capacitor and diode circuit. Then output of the rectifier is a voltage signal proportional to the rectified charging current and is given to the voltage to frequency converter.

- ✓ Now analog voltage signal is converted into a proportional medium frequency f_m.Then the output is given to gate circuit which was controlled by a.c. power frequency (f).The frequency $\frac{f_m}{f}$ is measured in gage circuit and is given to counter.
- ✓ The counter opens for an adjustable number of periods $\Delta t = \frac{P}{f}$Where, P = instrument constant.Number of impulse counted n = $\Delta t \,.\, f_m = \frac{P}{f} f_m$



Where,

Voltage to frequency conversion factor, A = $\frac{f_m}{Ri_m} = \frac{f_m}{R\, 2\, V_{mfC}}$

$= \frac{f_m}{f} . \frac{1}{2\, RV_{mC}}$

n = 2 PC V_m A R

Where, i_m = Rectified current through R

= $\frac{V_m}{X_c}$ = V_m 2 $\boldsymbol{\Pi}$fC∝2 V_mfC

By choosing proper value of R and P, voltage can be measured immediately.

Accuracy < 0.35%

Merits:

- ✓ Scale in linear and extension
- ✓ Measure wide range
- ✓ Source loading is zero.

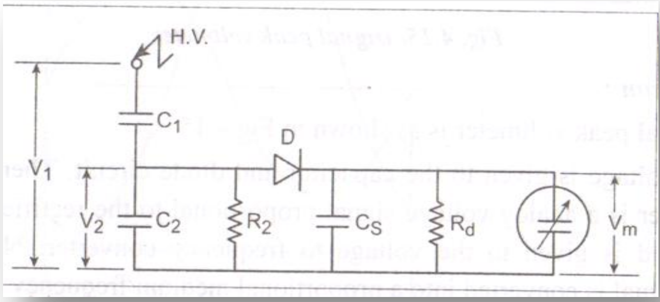
Demerits:

- ✓ Need calibrations
- ✓ Careful construction is needed

iii)Peak voltmeters with potential dividers:

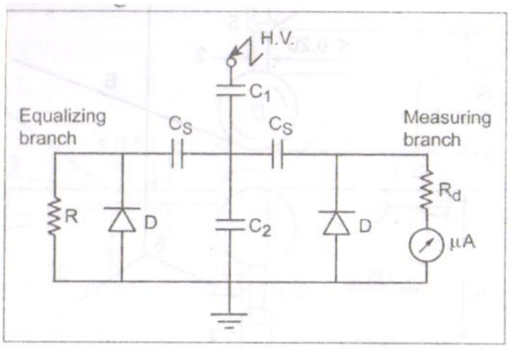
- ✓ Peak voltmeter with a capacitance potential divider and electrostatic voltmeter is as shown in fig
- ✓ Diode D is used for rectification.The voltage across C_2 is used to charge the capacitor C_3.
- ✓ R_d is the discharge resistor used to permit the variation of V_m when V_2 is reduced.

Electrostatic voltmeter is used as an indicating meter.



Voltage across the capacitor $C_s \propto$ Peak value to be measured.
Discharge time constant = $C_s R_d \approx 1$ to 10 sec
This gives discharge error, which depends on frequency of the supply.

Modified peak voltmeter
For compensating discharge error, the circuit can be modified as shown in fig
The indicating instrument used is microammeter.The circuit has equivalizing and measuring branches.



4)Explain various spark gap measurement of high D.C., A.C and impulse voltages (Peak values)?NOV-DEC 2011,May-2013,17,DEC-2013,Dec-14,15,16.

- ✓ Spark gaps insulated by atmospheric air can be used to measure the amplitude of a voltage above 10 kV.Voltage level can be determined by a fast transition from either completely insulating or still higher insulating state of a gap to the high conducting arc state.

- ✓ A complete short circuit is the result of a spark and the voltage source must be capable to allow for short circuit.

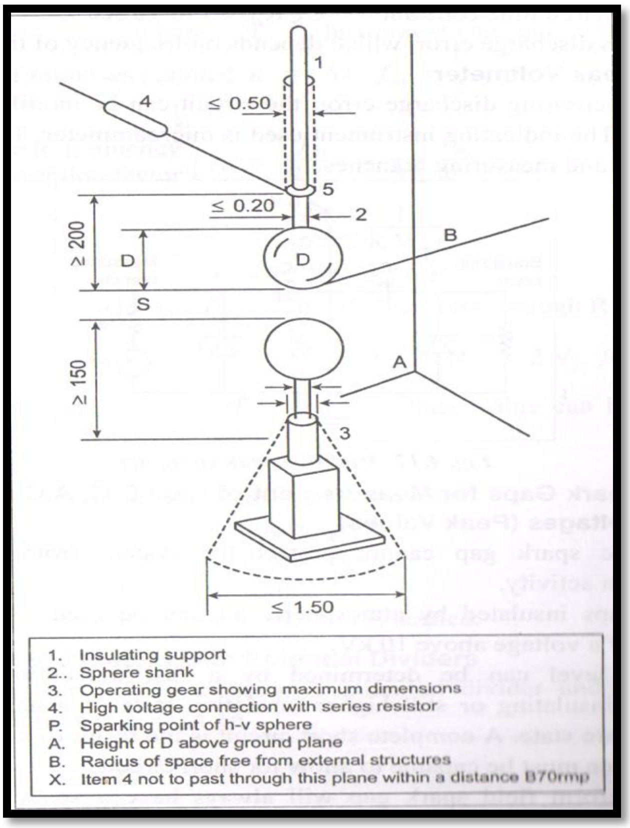
- ✓ **A** uniform field spark gap will always have a spark over voltage within a known tolerance under constant atmospheric conditions.
- ✓ Measurements are reliable only for the certain gap configuration.
- ✓ Accuracy is less.

Advantages:

- High reliability
- Simplicity.
- More accurate if electronic circuits are applied for measurements.

i)Sphere gap measurements:MAY-17

Sphere gaps are used for the measurement of voltage (D.C, A.C, impulse) and radio frequency A.C. peak voltage if the distance of the gap is known.A spark over voltage 30 kV (peak) at 1 cm spacing in air at 20°C and 760 torr pressure occurs for a sphere gap.



Construction:

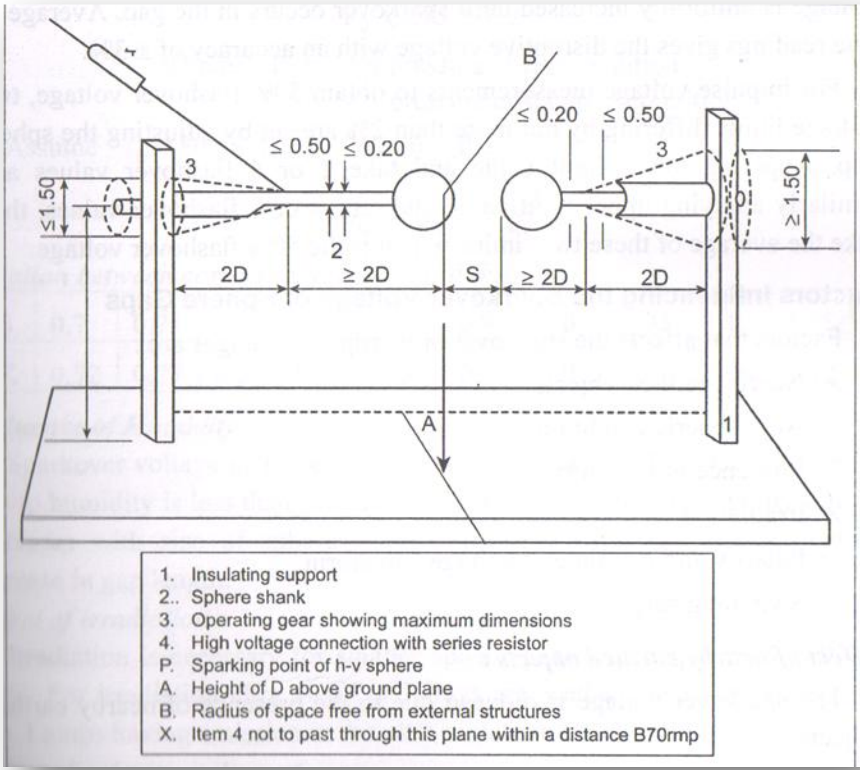
- ➢ Sphere gaps are arranged either vertically with lower sphere grounded or horizontally with both spheres connected to the source and one sphere grounded.Spheresare made us of copper, aluminum or brass.
- ➢ Spheres have identical size and shape, uniform surface, free from dust smooth

- Sphere gaps are made with two metal spheres of identical diameters with their shanks, operating gear, and insulator support dimensions are as shown in fig

- A series resistance is connected outside the shanks at a distance of 2D away form sparking point to limit the breakdown current and to suppress unwanted oscillations I n the source voltage when breakdown occurs.

- Value of resistance = 0.1 to 1 MΩ for D.C and A.C power frequency voltages.

- Value of resistance ≯500Ω for impulse voltage.



Sphere shanks should be in line and the shanks of the high voltage sphere should be free from sharp edges or corners.

Diameter of shank ≯0.2D

Irradiation of sphere gap is needed when measurements of voltages < 50 kV made with sphere gaps of 10 cm diameter of less. Irradiation may be obtained from a quartz tube mercury vapor lamp of 40 W rating.

Working:

- The voltage to be measured is applied between the two spheres and the distance of spacing S between them gives a measure of the spark over voltage.
- The ability to respond to peak values of voltages, if the duration of the peak region is not too short in time (1 – 3 μsec).

- This lag time is required for an electron to initiate electron avalanche and streamer breakdown to form spark.The gap distance is provided in such a way that no predischarge or corona occurs before breakdown.
- For D.C. voltage and A.C. peak voltage measurements, the applied voltage is uniformly increased until spark over occurs in the gap.Average of five readings gives the disruptive voltage with an accuracy of ±3%
- For impulse voltage measurements to obtain 50% flashover voltage, two voltages limits differing by not more than 2% are set by adjusting the sphere gap.

- Applying lower limit value and take 2 or 4 flashover values and similarly applying upper limit value and take 6 or 8 flashover values, then take the average of these two limits, which is the 50 flashover voltages.

Factors influence with the spark over voltage of sphere gaps:(NOV/DEC-15)

Factors that affects the spark over or disruptive voltages are(Dec-14)

- Nearby earthed objects.
- Atmospheric conditions.
- Influence of humidity.
- Irradiation.
- Polarity and rise time of voltage waveform.
- Switching surges.

Effects if nearby earthed objects:

The spark over voltage is reduced due to the presence of nearby earthed objects.

Voltage reduction ΔV = m log $\left(\frac{B}{D}\right)$ + C

Where, B= diameter of earthed enclosing cylinder.

D = diameter of the spheres.

S = gap distance between spheres.

m, C = constants.

For $\frac{S}{D} \leq 0.5$, $\frac{B}{D} \geq 0.8$, percentage reduction = 2%

For $\frac{S}{D} = 1.0$, $\frac{B}{D} \geq 1.0$, percentage reduction = 3%

Reduction voltage is within accuracy limit when $\frac{S}{D} < 0.6$

Effect of atmospheric condition:

Actual air density during measurements differs due to temperature and pressure variations. So spark over voltage depends on air density factor.

Spark over voltage $V = K\, V_0$

Where, K = correction factor related to air density factor

V_0 = spark over voltage under standard temperature and pressure.

$\delta = \frac{P}{P_0}\left(\frac{273+t_0}{273+T}\right)$

Where, P = air pressure at test condition.

P_0 = air pressure at standard condition.

Assume t_0 = 20°C, P_0 = 760 torr, then

$\delta = \frac{P}{P_0}\left(\frac{293}{273+T}\right)$

<u>Relation between correction factor K and δ:</u>

δ	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**	**0.95**	**1.0**	**1.05**	**1.1**	**1.15**
K	0.72	0.77	0.82	0.86	0.91	0.95	1.0	1.05	1.09	1.12

<u>Influence of humidity:</u>

Spark over voltage increases with humidity. Increase of spark over voltage due to humidity is less that 3%. So it may be neglected. The humidity effect increases with size of spheres, partial pressure of water vapour in air, increase in gap length.

Effect of irradiation:

Irradiation is necessary for smaller sphere gaps of gap spacing less than 1 cm. for irradiation ultra violet or X-rays are used to ionize the air int the gap.

Lamps having emission in the ultra violet are efficient.

<u>Effect of polarity and waveform:</u>

Spark over voltages of positive and negative impulse are different.

<u>For D.C.,</u>

Positive minus negative voltage $\ngtr$ 1% for gap length of 6.25 to 25 cm diameter..

For impulse of $\frac{1}{50}\mu s$ waveform,

Positive minus negative voltage = 8% for gap length < 2 cm diameter

Wave front and wave fail duration of the waveforms influence the spark over voltage. Sphere gap measurements are not used where

Wave front <0.5 μs and wave fail < 5 μs

Switching surges:

Spark over voltages was varied by switching surges.

ii) Uniform Field Electrode Spark Gaps(DEC-2013)

Uniform field spark gaps are used upto a voltage of 600 kv. We could not say that the sparking always takes place along the uniform field.

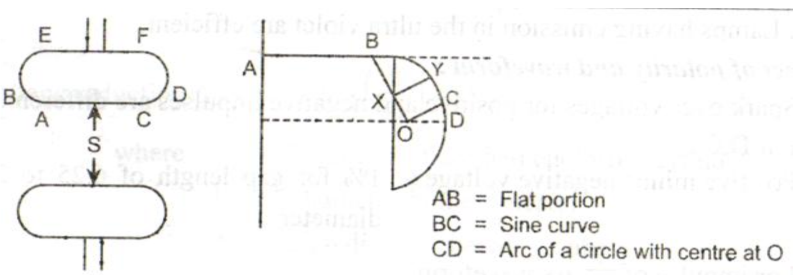
Rogowaski presented a design and the spark over voltage in a uniform field is given by,

$$V = As + B\int s$$

Where, A,B = Constants.

s = Gap spacing in cm.

Typical uniform field spark gap is as shown in Fig



For T = 25℃ , pressure = 260 torr, A = 24.4, B = 7.5.

$$V = 24.4\delta S + 7.5\int \delta S$$

According to Bruce, uniform field spark gaps are used for 140, 280 and 420 KV respectively.

Spark over voltage $V = 6.66\int \delta S + 24.55 + 0.41(0.1\ e - 1)\delta S$

Where, δ = Air density factor.

e = Vapour pressure of water in air.

Advantages:

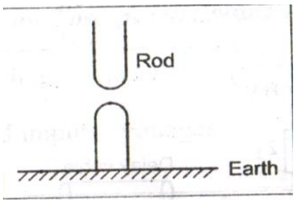
- No influence of nearby earthed objects.
- No polarity effect.

Disadvantages:

- Very accurate mechanical finish of the electrode is required. Otherwise measurement is not accurate.
- Two electrodes are properly aligned in parallel.
- Dust or greeze influences erratic breakdown of the gap.
- Accuracy is less.

iii)Rod Gaps

Rod gaps are used to measure peak value of impulse voltage and power frequency. The rod gap is as shown in Fig



For 50% flashover voltage, the procedure is same as that of sphere gap.

For T = 25℃ , Pressure = 760 torr

Breakdown voltage, V = δ(A + Bs)$4\sqrt{5.1\ X10^{-2}(h+8.65)}$ KV

Where, A = 20KV for positive polarity.

= 15KV for negative polarity.

B = 5.1KV/cm

H = Absolute humidity in gm/m^3(4 to 20)

Accuracy is about $\pm$2% for this method.

5)Explain with neat diagram various Impulse Voltage Measurements Using Voltage Dividers or Potential Dividers?(DEC-2013)

Discuss and compare the performance of resistance capacitance and mixed R-C potential divider for measurement of impulse voltage.(May-2014)

Give the schematic arrangement of an impulse potential divider with an oscilloscope connected for measuring impulse voltages. Explain the arrangement used to minimize errors.NOV/DEC-2015

What are the requirements of a digital storage oscilloscope for impulse and high frequency measurements in HV test circuits?NOV/DEC-15

Potential or voltage dividers are used to measure impulse voltages or high frequency A.C. or fast rising transient voltage measurements.

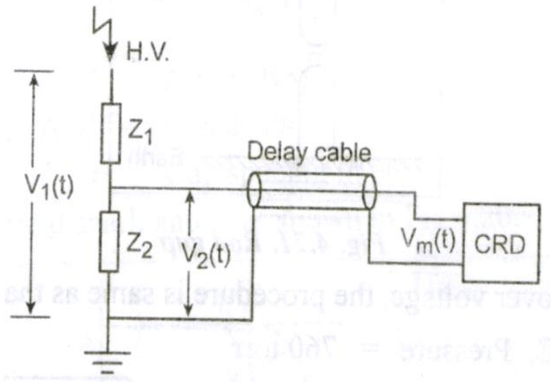
Types of potential divider circuit

- Resistive

- Capacitive
- Mixed

i)General Potential Divider:

The schematic diagram of potential divider with a delay cable and oscilloscope is as shown in Fig..$Z_1$is resistor or a series of resistors in the resistance potential divider or series of capacitors in the case of capacitive potential divider or combination of both. The low voltage arm of the divider is connected to a fast recording oscillograph or a peak reading instrument through a delay cable.



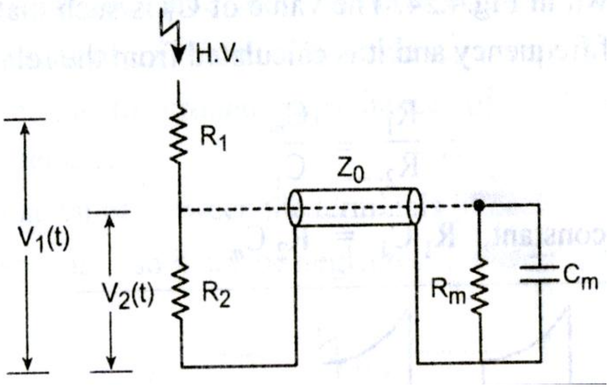
$Z_2$is a resistor or a capacitor or R – C impedance depends on the type. Each element has self resistance or capacitance. The resistive elements have residual inductances, stray capacitance to ground and terminal to terminal capacitances.

Errors arise due to the following elements are:

- Residual inductance in the element.
- Stray capacitance.
- Impedance.
- Parasitic oscillations due to lead and cable inductance and capacitance of high voltage terminal to ground.

Resistance Potential Divider for very Low Impulse Voltages and Fast Rising Pulses:

It consists of two resistances $R_1 and R_2$ in series ($R_1 \gg R_2$). The element R_2 is connected through the coaxial cable to the oscilloscope. The surge impedance of cable (Z_0) is connected in parallel with the input impedance of oscilloscope (R_M, C_m) as shown in Fig.



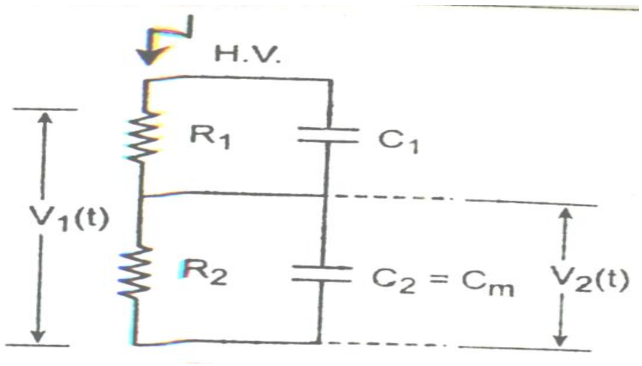
Attenuation factor or voltage ratio 'a' = $\frac{V_1(t)}{V_s(t)} = \frac{R_1 + R_2}{R_2} = 1 + \frac{R_1}{R_2}$

For high frequency and impulse voltages,

$$A = \frac{V_1}{V_2} = \frac{R_2 + R_1}{(R_2)//\frac{1}{j\omega\, C_m}} = \frac{\frac{R_2+R_1}{R_2}}{\frac{j\omega\, C_m}{R_2+\frac{1}{j\omega\, C_m}}}$$

$$= \frac{\frac{R_1 + R_1}{R_2}}{1+j\omega\, C_m R_2}$$

$$= 1 + \frac{R_1(1+j\omega\, C_m R_2)}{R_2}$$

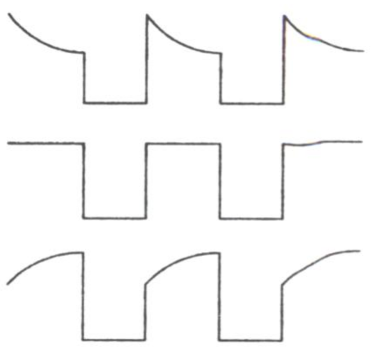


$$R_m > 1M\boldsymbol{\Omega}, C_m = 10\ to\ 50\ p.f$$

Value of 'a' depends on frequency. To avoid frequency dependence of 'a' , the divider is compensated by adding an additional capacitance C_1 across R_1as shown in Fig.. The value of C_1 is such that voltage divider is independent of frequency and it is calculated from the relation.

$$\frac{R_1}{R_s} = \frac{C_m}{C_1}$$

Time constant, $R_1\, C_1$ = $R_2 C_m$



The waveform of compensated divider is as shown in Fig.

Time constants of compensated divider $\tau = R_{eq} C_{eq}$

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \; (R_1 || R_2)$$

$$C_{eq} = C_1 + C_2$$

$\tau = R_{eq} C_{eq} = \frac{R_1 R_2}{R_1 + R_2} (C_1 + C_m)$

If C_1> Correct compensation, τ is large.

An charging time is high, and exponential decay occurs as shown in Fig.

If charging time is high, an undershoot occurs with an exponential decay occurs as shown in fig.4.25(c).

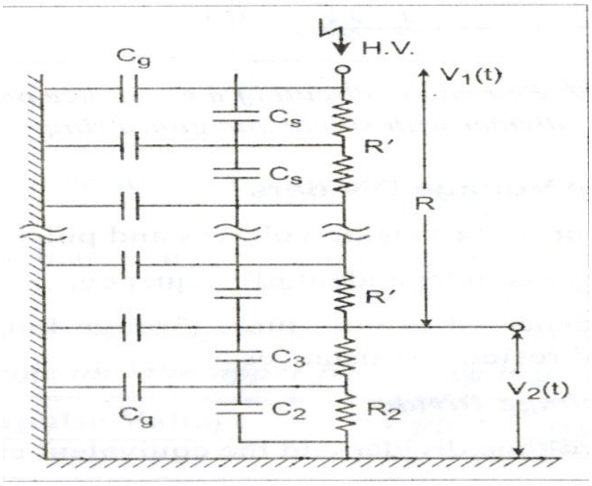
<u>iii) Potential Dividers used for High Voltage Impulse Measurement:</u>

For voltages above 100KV, single resistor R_1 cannot be used. So an equivalent distributed network with its terminal to ground capacitances and inter – sectional series capacitances as shown in Fig.4.26.

Resistor R_1 consists of n – resistors of value R'_1(i.e.,) $R_1 = nR'_1$.

C_g – Terminal to ground capacitance of each of the resistor elements R'_1.

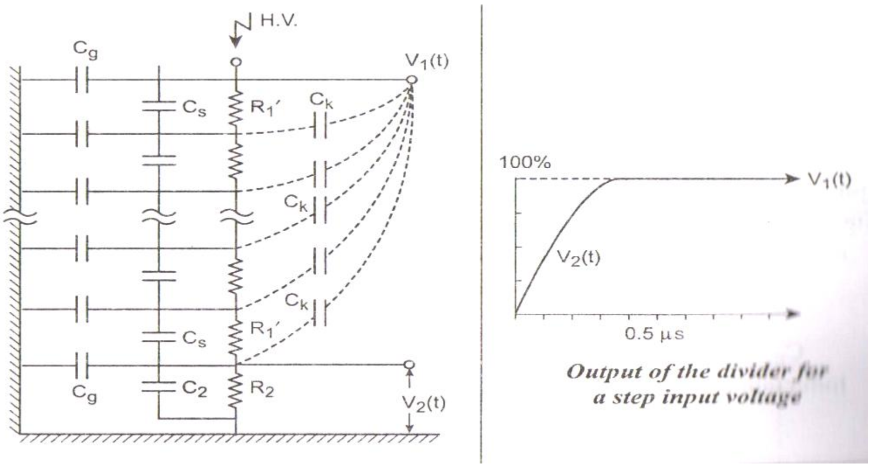
C_S - Capacitance between the terminals of each section Inductance is so small, so it can be neglected in the circuit.



It produces a non-linear voltage distribution along its length and acts like an R-C filter.

To make linear distribution along its length, and reduce distortion introduced by the divider, arrange guard rings at various elemental points and are shown in Fig.

C_h - Stray capacitance introduced between the high voltage lead and the guard element.



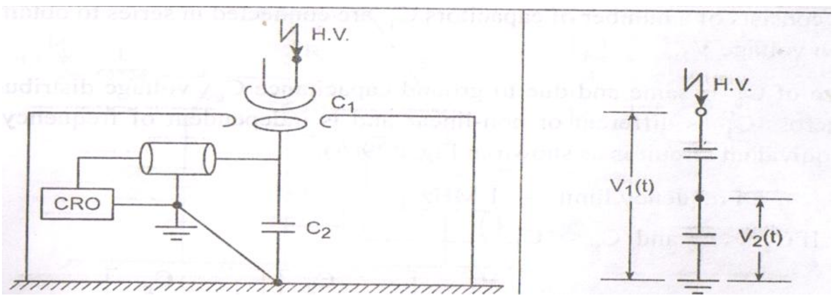
iv) Capacitance Voltage Dividers:

It is used for measuring fast rising voltages and pulses.

- Capacitance ratio is independent of frequency.
- Dividers are connected to the source through long leads which gives inductances and residual resistances.

a)Pure Capacitance Voltage Divider

Pure capacitance voltage divider and the equivalent circuit is as shown in Fig.



H.V. supply is given to the high voltage terminal. CRO is placed within the shielded screen surrounding capacitance C_2.

C_1 = Capacitance between H.V. terminal and test object.

C_2 = {Capacitance used + Lead capacitance + Capacitance of CRO + Ground capacitance

Voltage ratio 'a' = $\frac{V_1(t)}{V_2(t)} = \frac{C_1 + C_2}{C_1 C_2}$ X C_2 = 1+ $\frac{C_2}{C_1}$

$C_1\ inserieswith C_2$; $C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$

Advantages:

- The loading on the source is negligible.

Disadvantages

- A small disturbance in the location of C_2 or H.V. electrode or the presence of any stray object nearby changes the capacitance C_1, and hence the voltage ratio of the divider will be affected.

Impulse voltage range and the upper frequency is given in Table

Impulse Voltage	Upper Frequency
350KV	10MHz
Upto 100KV	200MHz

v) Capacitance voltage divider with distributed network:

Capacitance voltage divider with distributed network or string insulator unit structure is as shown in fig

C_1 consists of a number of capacitance are connected in series to obtain a given voltage V_1.

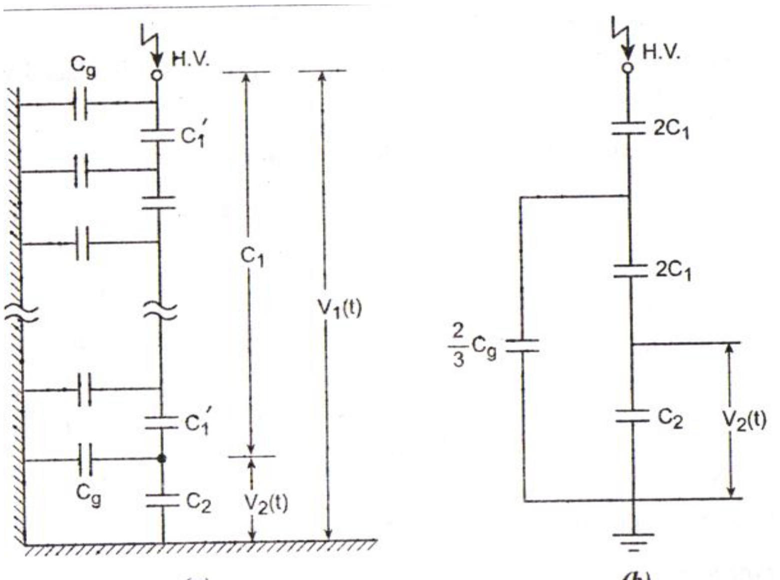
Size of C_1' is same and due to ground capacitance c_g, voltage distribution across is different or non-linear and is independent of frequency.

The equivalent circuit is as shown.

Frequency limit – 1MHz

If $C_1 << C_2$ and $C_g << C_1$

Voltage ratio a=$\frac{V_1}{V_2} = \left[1 + \frac{C_2}{C_1}\right]\left[1 + \frac{C_g}{6C_1}\right]$

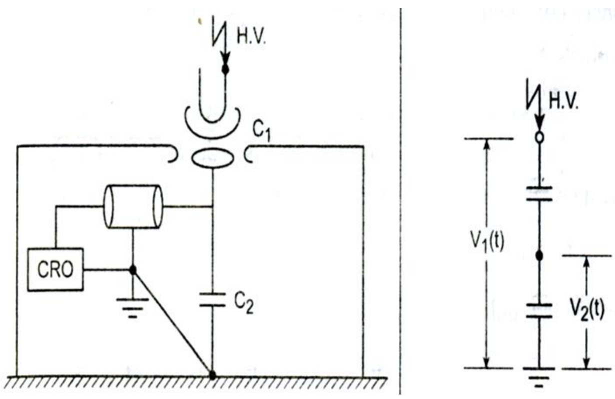


(a) *(b)*

Vi) Field controlled voltage dividers:

To achieve uniform field in the neighborhood and along the divider, the electrostatic or capacitive field distribution of a shield or guard ring is placed over a resistive divider. This arrangement is used to measure high voltage.

The field controlled voltage divider with damping resistor is as shown. The shield has cone like structure.



Oscillations will be produced due to R_2 together with the lead inductance and shunt capacitance.

Damping resistance R_d is used to reduce the oscillations. This type is constructed for measuring very high voltages up to 2 MV.

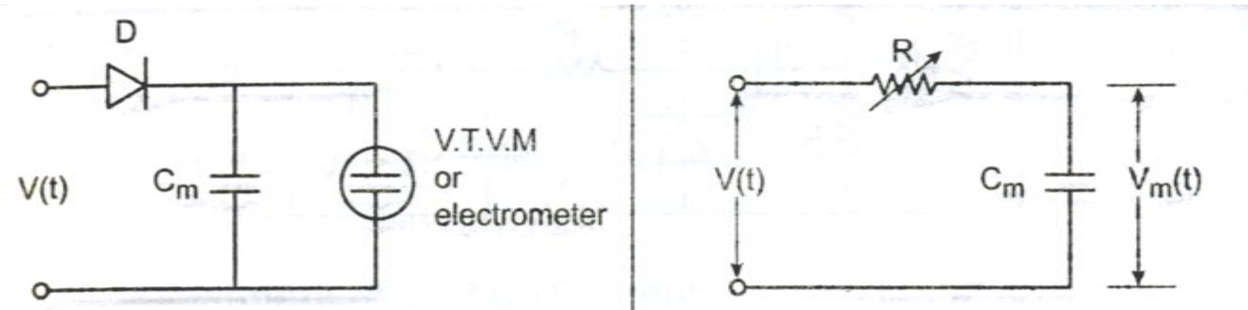
Response time < $30 * 10^{-9}$ sec

Advantages:

- The capacitance per unit length is small and hence loading effect is reduced.
- Response time is less and overshoot is reduced by using damping resistors.

Vii) Peak reading voltmeters for impulse voltages:

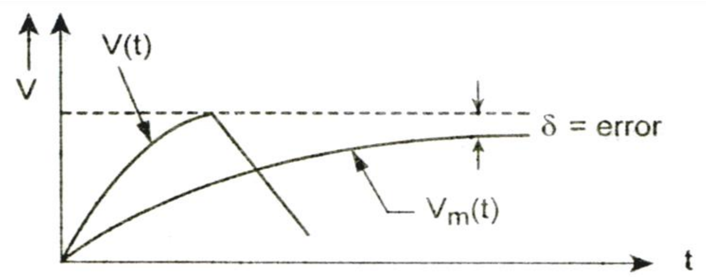
Peak reading voltmeters are used to measure Impulse voltage wave and routing impulse testing work. The wave shape of impulse voltage might be known or fixed by the source.Measuring instrument is connected to the low voltage side of the potential divider and the equivalent circuit is as shown.

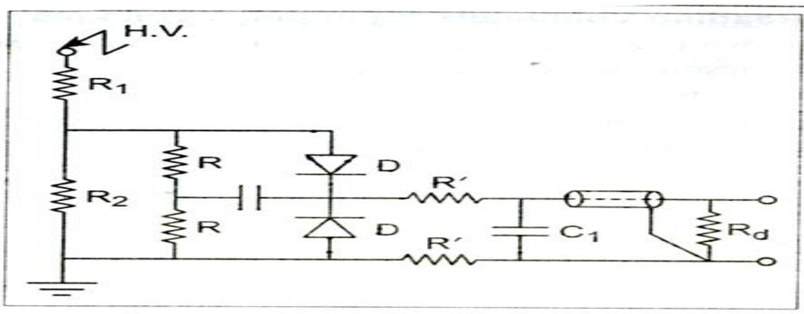


Basic circuit *Equivalent circuit of basic circuit*

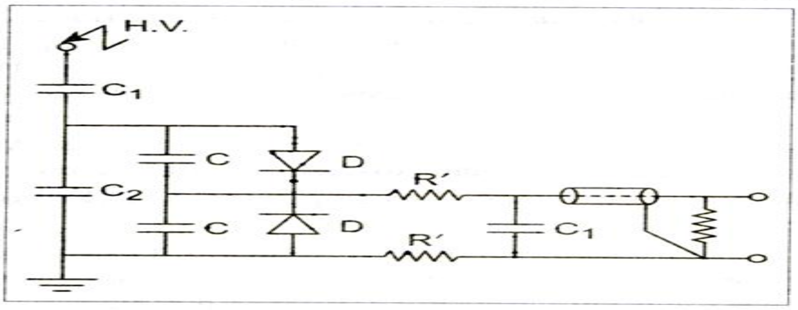
During positive half cycle, diode D conducts and a impulse voltageV(t) appears across the low voltage arm of the potential divider. The capacitor C_m charges to the peak value. Forward resistance of the diode is assumed to be finite.

During negative half cycle, diode D is reverse biased. Amplitude of the signal starts decreasing and prevents discharging of capacitor $C_{m.}$Now measured voltage < actual peak valueThe circuit can be modified using R-C network to measure peak voltage accurately. The error is as shown. The error can be estimated if the waveform is known.





(a) Peak reading voltmeter for either polarity with resistance divider



(b) Peak reading voltmeter for either polarity with a capacitive divider

To estimate the forward resistance of the diode is difficult, so meter can be calibrated by using oscilloscope.

For measuring peak reading for either polarity, we can use resistance potential divider or capacitive resistance as shown.

In this circuit, voltage of positive and negative polarity is transferred into a proportional positive measuring signal.

Advantages:

- Fast rising pulses or impulse waves can be measured.
- Capacitor is used to prevent the build-up of D.C. charge.
-

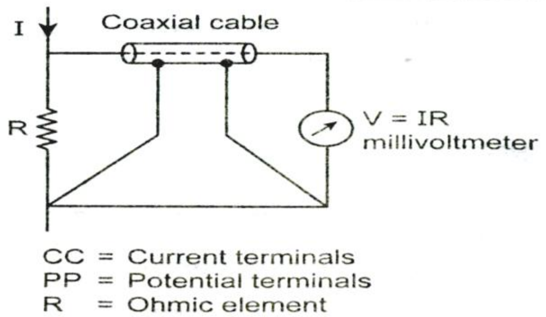
6) Write a shorts notes on Measurement of high direct currents? *MAY-2013*

There are two methods used to measure high direct currents. They are:

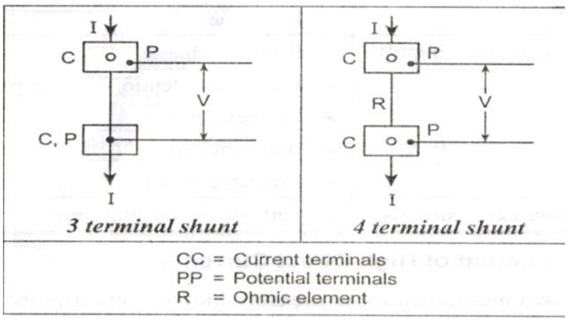
- Resistive shunts
- Hall generators

i) Resistive shunts:

Resistance shunts for high magnitude D.C measurement is shown High current whose magnitude is to be measured is passed through a resistive shunt of low ohmicvalue.The voltage drop across the shunt resistance is measured with the help of milli voltmeter, which is connected through a coaxial cable.



Value of shunt resistance = 10 μΩ to 13 μΩ depends on heating effect and loading effect.Voltage drop < 1 volt in power circuits.High current resistors are oil immersed type and are made as three or four terminal shunt as shown

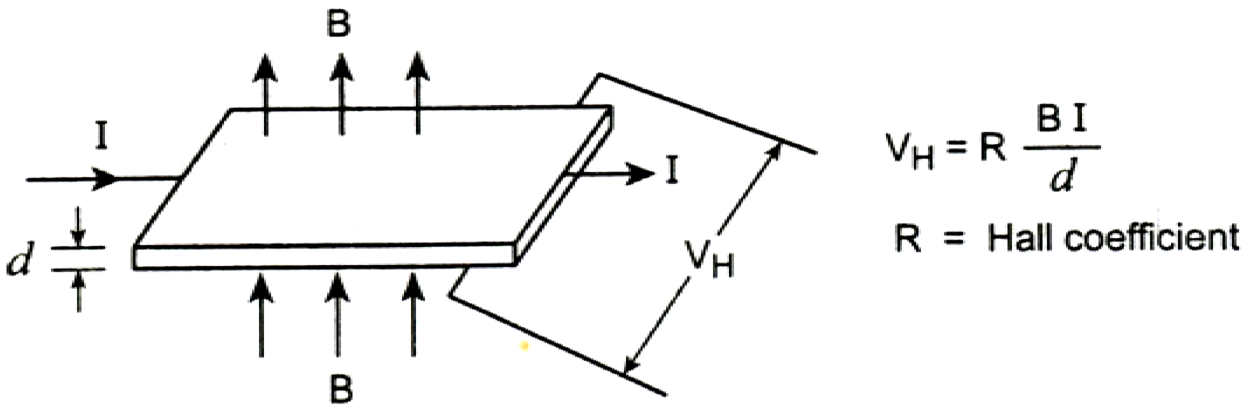


ii)Hall generator or D.C. measurements:

Hall effect is used for the measurements of high direct current as shown.

HALL EFFECT:

Whenever electric current flows through a metal plate placed in a magnetic field perpendicular to it, Lorenz force will deflect the electrons in the metal plate in a direction perpendicular to both the magnetic field and the flow of current. The change in displacement generates an e.m.f called the "Hall Voltage".



Hall voltage $V_H \alpha \frac{BI}{d}$

V_H = R.$\frac{BI}{d}$

Where, B= magnetic flux density,

I=Current,

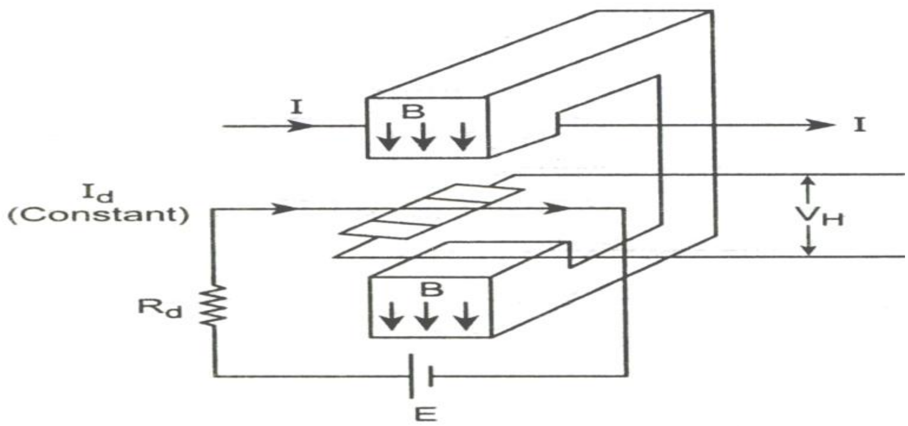
d=thickness of the metal plate,

R= hall coefficient.

Hall coefficient (R) depends on the material of the plate and temperature. Value of hall coefficient is very small for metals and high for semiconductor materials.

<u>Construction of hall generators:</u>

The D.C current which is to be measured is passed through the conductor. The conductor is wound on an iron cored magnetic circuit as shown. The magnetic circuit produces magnetic field in the air gap.



Magnetic field intensity, $H=\frac{1}{\delta}$

Where, δ = air gap distance or depth.

The hall element or metal plate is placed in the air gap formed by the iron core magnetic circuit. It is connected in series with resistor and a battery.A small d.c. current (I_d) is passed through this Hall element.

According to Faraday's law, whenever a current carrying conductor is placed in a magnetic field, an e.m.f. is induced in it.

The voltage or e.m.f. is developed across the hall element (V_H),

$V_H = R.\frac{BI}{d}$

R is the hall coefficient, which depends on the temperature and high magnetic field strengths and compensation provided for measuring high currents.

8)Write a shorts notes on Measurement of high power frequency alternating currents(A.C)?

<u>Measurement of high power frequency current using current transformer:</u>

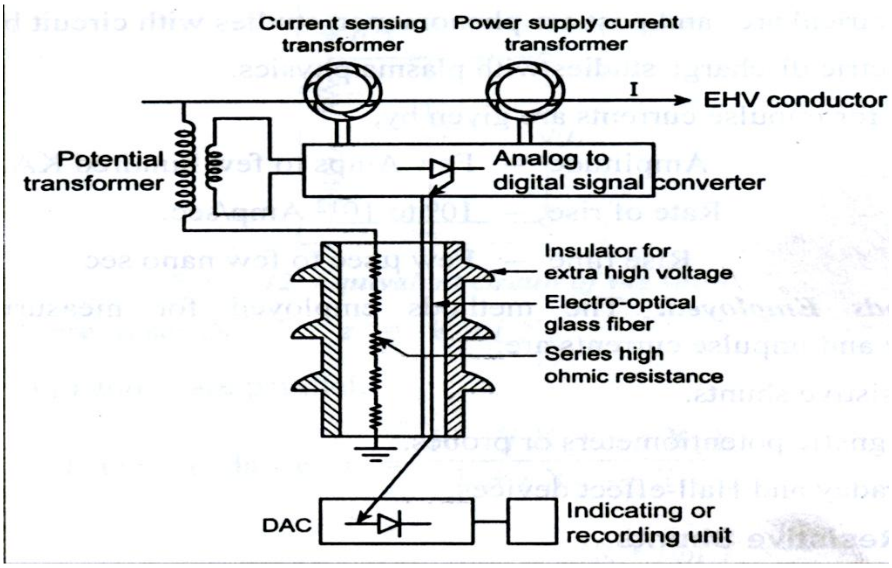
Current transformers are normally used to measure high power frequency current, but it has some disadvantages.

<u>Disadvantages of using only current transformers:</u>

- Current shunts involve unnecessary power loss.
- C.T. provides electrical isolation between H.V. and L.V. side of current transformers in power systems.
- Current transformers used for extra high voltage systems are kept at very high voltages with respect to the ground.
- So, we are using current transformer with electro-optical technique for measuring high alternating currents.

<u>Current transformer with electro-optical signal converter for EHV system:</u>

Current transformer with electro-optical signal converter for EHV system consists of current sensing transformer, power supply current transformer, potential transformer, analog-digital signal converter, and electro optical glass fiber, digital to analog converter as shown.



Operation:

- A voltage signal proportional to the measuring current is passed though the EHV conductor.Current transformer is used in the power circuit to stop down the current to a very low value.
- Potential transformer is used in the power circuit to step down the voltage to a very low value (measurable value).EHV conductor acts as primary side of current transformer. Potential transformer primary is connected between the EHV conductor and the ground through high series resistance.
- The secondary side of current transformers and potential transformers (power to signal converter) are given to the analog to digital converter which converts the analog signal into digital signal.
- This digital signal is given to the digital to analog converter converts the digital signal into analog signal. This analog signal is given to the recording unit.
- Accuracy = ±5% at rated current

9) Write a shorts notes on Measurement of high frequency and impulse currents?April-18

Amplitude and waveform of high frequency and impulse current is necessary because of:

- Impulse currents occur during lightning discharge which causes severe faults.
- Electrical arcs and post arc phenomenon studies with circuit breakers.
- Electric discharge studies with plasma physics.

Range of impulse currents are given by,

Amplitude- Few Amps to few hundred KA.

Rate of rise- 10^6 to 10^{12} Amp/sec.

Rise time- Few µ sec to few nano sec.

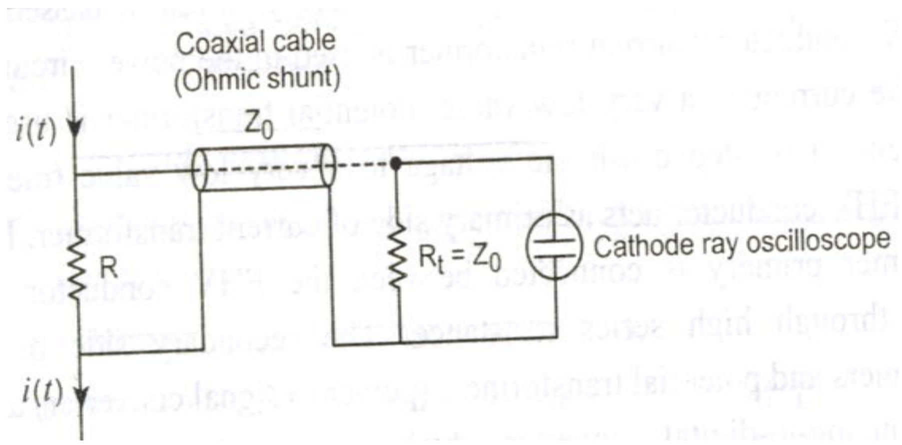
Methods Employed:

The methods employed for measuring high frequency and impulse currents are:

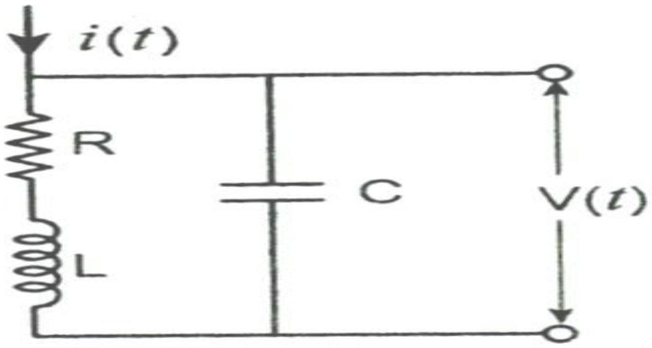
- Resistive shunts.
- Magnetic potentiometers or probes.
- Faraday and hall- effect devices.

i) Resistive shunts:

- The high impulse current which is to be measured is passed through a low ohmic pure resistance as shown.



- The current passed through the low resistance shunt element R produces a voltage drop R i(t) across it.The voltage signal generated is transmitted to a cathode ray oscilloscope through a coaxial cable of surge impedance z_0.
- The oscilloscope end is terminated by a resistance z_0 which is equal to the internal resistance to avoid reflections.The resistance element has a residual inductance L and a terminal capacitance C and the corresponding equivalent circuit as shown.



R and L are in series.

$z = R + j X_L$

($R + j X_L$) and C are parallel.

Total impedance, $z = \frac{(R + j XL)(-jXc)}{R + j XL - Xc}$

(or) $V(t) = z \; i(t) = \frac{(R+j\omega L)\frac{1}{j\omega C}}{R+j\omega L+\frac{1}{j\omega C}} \; i(t)$

$= \frac{R+j\omega L}{1+(j\omega)^2 LC+j\omega RC} * i(t)$

Taking Laplace transform on both sides, we get

$V(s) = \frac{(R+Ls)}{1+LCs^2+RCs} I(s)$

Where, s= complex frequency,

$s=j\omega$

Value of L and C become significant for a frequency above 1 MHz.

Resistance value= 10 μΩ to few milliohm. (Value can determine by thermal capacity and heat dissipation of the shunt)

Voltage drop = usually about a few volts

When the value of C is neglected, then

$V(s) = (R+Ls) I(s)$

Accuracy = 1 to 10%

Voltage drop is usually about a few volts.

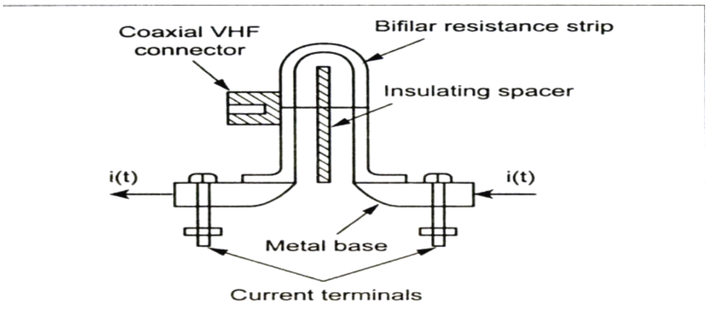
For better frequency response of the shunt, the stray inductance and capacitance should be as small as possible.

To reduce stray effects, the resistance shunt is designed as follows:

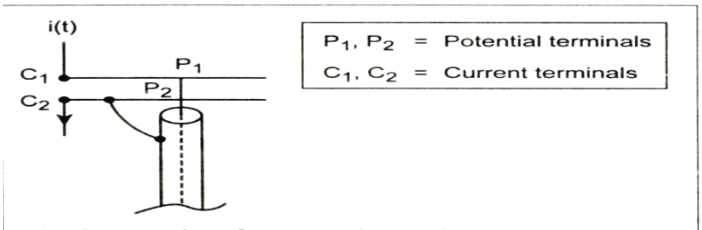
- Bifilar flat strip design.
- Coaxial tube or park's shunt design.
- Coaxial squirrel cage design

a)Bifilar flat strip shunt:

- The bifilar flat shunt design as shown. It consists of resistor elements which are wound in opposite directions and folded back.The both ends are insulated by Teflon, or other high quality insulation. The ultra high frequency voltage signal is collected by a coaxial connector.



(a) Schematic arrangement of bifilar flat strip shunt



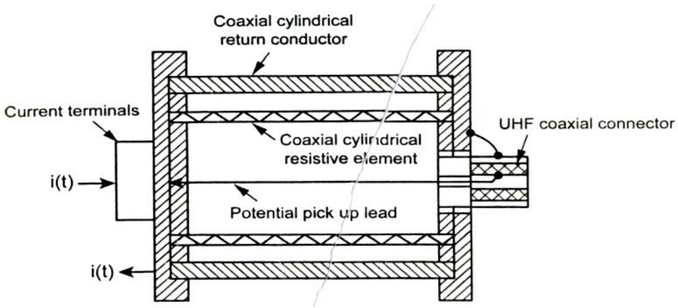
(b) Connection for potential and current terminals

Disadvantages:

- Shunt element is affected by stray inductance.
- Potential leads are linked to a small part of the magnetic flux generated by the current which is to be measured.

To overcome this, coaxial tabular shunts are used.

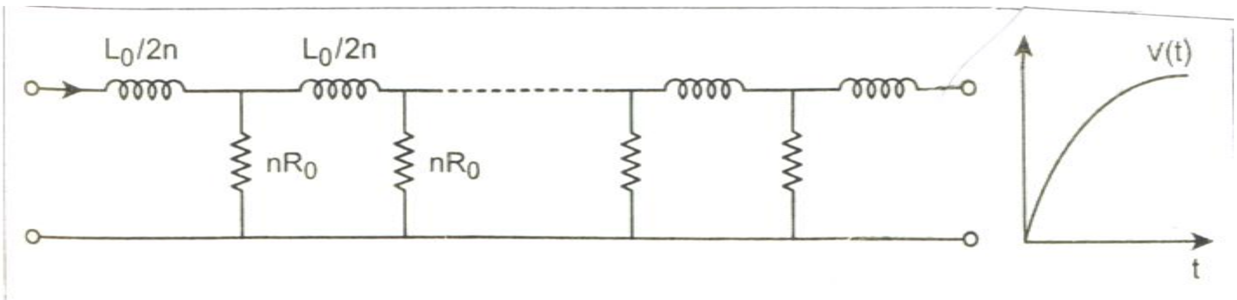
b)**Coaxial tubular or park's shunt:** The coaxial ohmic shunt arrangement as shown.



- Current is passed through the pick-up point or an inner cylinder or resistive element and is made to return through an outer case or outer conducting cylinder.The outer conducting cylinder is made up of copper or brass.
- The space between the inner and the outer cylinder is filled with air and acts as a pure insulator. The voltage drop across the resistive element is measured between the pick-up point and the outer case.
  - ✓ Maximum frequency limit: 1000 MHz.
  - ✓ Response time: few nano sec.

Upper frequency limit is governed by the skin effect in the resistive element (when A.C. is passed through the resistive element, the concentration of alternating current near the outer surface is called as skin effect)

The equivalent circuit is as shown.



Inductance $L_0 = \frac{\mu\ dI}{2\pi r}$

Where, n = number of sections per unit length

$\mu = \mu_0\mu_r$

$\mu_0 = 4\pi * 10^{-7}$

d = thickness of the cylindrical tube,

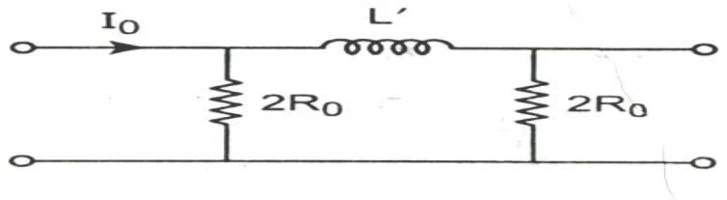
l= length of the cylindrical tube,

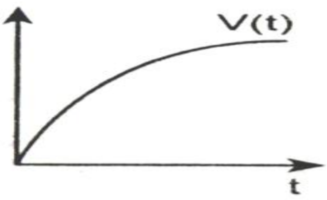
r= radius of the cylindrical tube.

Effective resistance R= $\frac{V(t)}{I_0}$

Where, R_0 = d.c. resistance

The simplified equilavalent circuit is as shown.





The step response and the corresponding frequency response is as shown

Rise time, T = $0.237 \frac{\mu d^2}{\rho}$

Skin depth, d = $\frac{1}{\sqrt{\pi f \mu \sigma}}$

Where, σ= conductivity of material.

f = frequency.

Bandwidth, B = $\frac{1.46\ R}{L_0} = \frac{1.46\ \rho}{\mu d^2}$

Where, ρ = resisticity.

Maximum current = 200 kA

Rate of rise of current $\frac{di}{dt}$ = $5 * 10^{10}$ A/s

Induced voltage < 50V

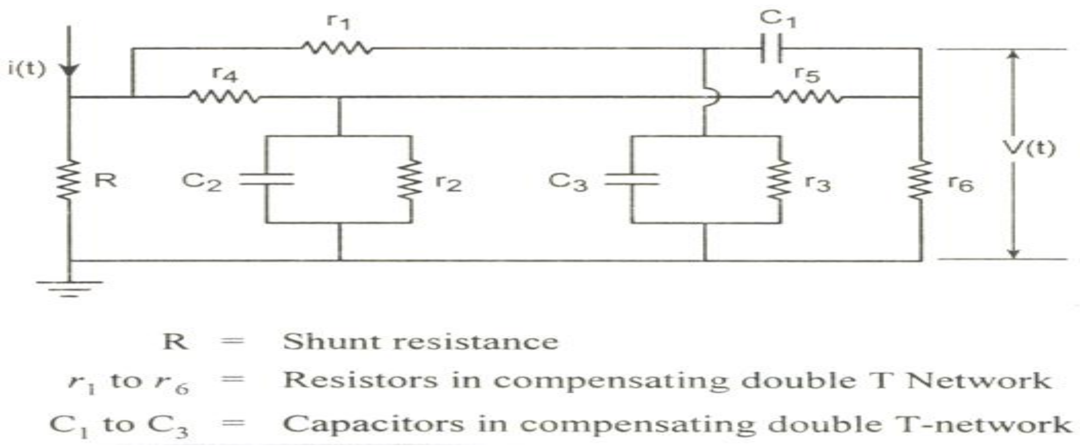
Voltage drop across the shunt = 100 V

In post arc current measurements, tubular shunts are not suitable. Due to heat dissipation, skin effect occurs**.**

c) Squirrel cage shunts:

The equivalent circuit of squirrel cage shunts as shown,

- To overcome the problem of heat dissipation and skin effect, the resistive cylinder is replaced by thick rods or strips. This construction is similar to that of the rotor of double cage induction motor. So, it is called as squirrel cage shunt.
- Squirrel cage shunts are high ohmic shunts which can dissipate large energy. The step response of squirrel cage shunt is large.Therefore, compensating network is used in conjunction with the shunt to improve frequency response.



10) Explain with nean diagram various Measurement techinique of high impulse currents? (DEC-13)

Explain with neat diagram of Rogowskicoils ,the principle of operation for measurement of high impulse current (Dec-14)

<u>i) Magnetic potentiometers (Rogowski coils):NOV-DEC 2010</u>

Principle: when a coil is wound surrounding a current carrying conductor, the voltage is induced in the coil.

Voltage induced in the coil is V(t) = M $\frac{di(t)}{dt}$

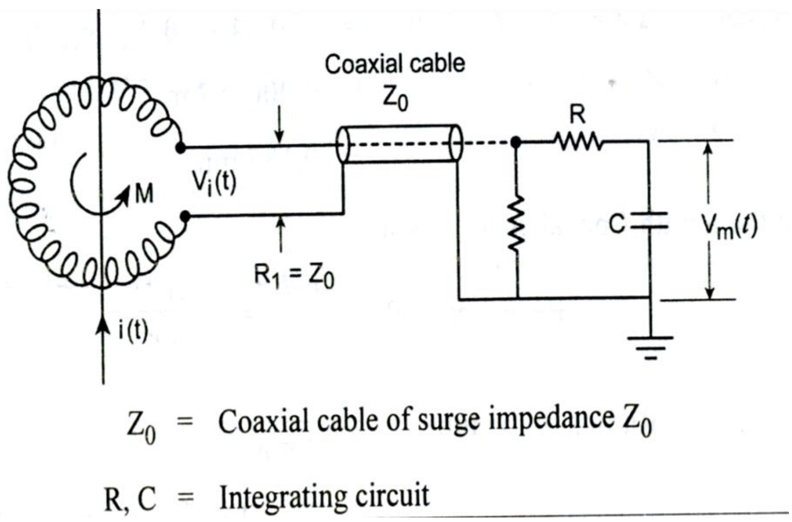
Where M= mutual inductance between the conductor and the coil.

I(t) = current flowing through the conductor.

Construction:

The coil is wound on a non-magnetic former of toroidal shape and is placed surrounding the current carrying conductor.

- To reduce the leakage reactance, the coil is wound crosswire.
- To get enough signals induced, the number of turns on the coil is chosen to be large.



The rogowski coil with integrating circuit is as shown,

Output voltage $V_m(t) = \frac{1}{RC}\int_0^t V_i\ (t) = \frac{1}{RC}\int_0^t M.\frac{di(t)}{dt}$ …(1)

Where RC = time constant of the integrating circuit

Integrating equation (1), we get

$V_m(t) = \frac{M}{CR}$ i(t)

Voltage signal ∝ current to be measured

For higher frequency above 100 MHz, the response is affected by,

- Capacitance per unit length along the coil.
- Skin effect.
- Electromagnetic interference.

For ultra high frequency measurement, miniature probes with response time are nano sec and made up of few turns of copper strips are used.

ii)Magnetic links:

Magnetic links are used for the measurement of peak value of impulse currents but it is not used to give impulse wave shape.

Construction:

- Magnetic link consists of steel strips having high retentivity and are arranged on a circular wheel. These strips are used for the measurement of peak value of impulse current because it has the property of permanent magnetism for a current pulse of 0.5/5 sec is same as that caused by a D.C. current of same value.

Operation:

- The strips were kept at a known distance from the current carrying conductor and placed parallel to it.The peak value of current is measured by measuring the permanent magnetism.
- By increasing the number of strips for accurate measurement of peak value.

Uses:

Estimating the lightning current on the transmission lines and towers.

ii) Hall generators:

Hall Effect is used to measure very high impulse current.

Hall voltage $\propto \frac{BI}{d}$

$V_H = R \frac{BI}{d}$

- Hall voltage developed is directly proportional to the current.
- Whenever electric current flows through a metal plate placed in a magnetic field perpendicular to it, a force will deflect the electrons In a direction perpendicular to both magnetic field and current.

Bandwidth = 50 MHz

<u>iv)Faraday generator or magneto optic method:</u>

Principle: Faraday Effect:

When a linearly polarized light beam passes through a transparent crystal in the presence of a magnetic field, the plane or polarization of the light beam undergoes rotation. These rotation of plane of polarization Is proportional to the current.

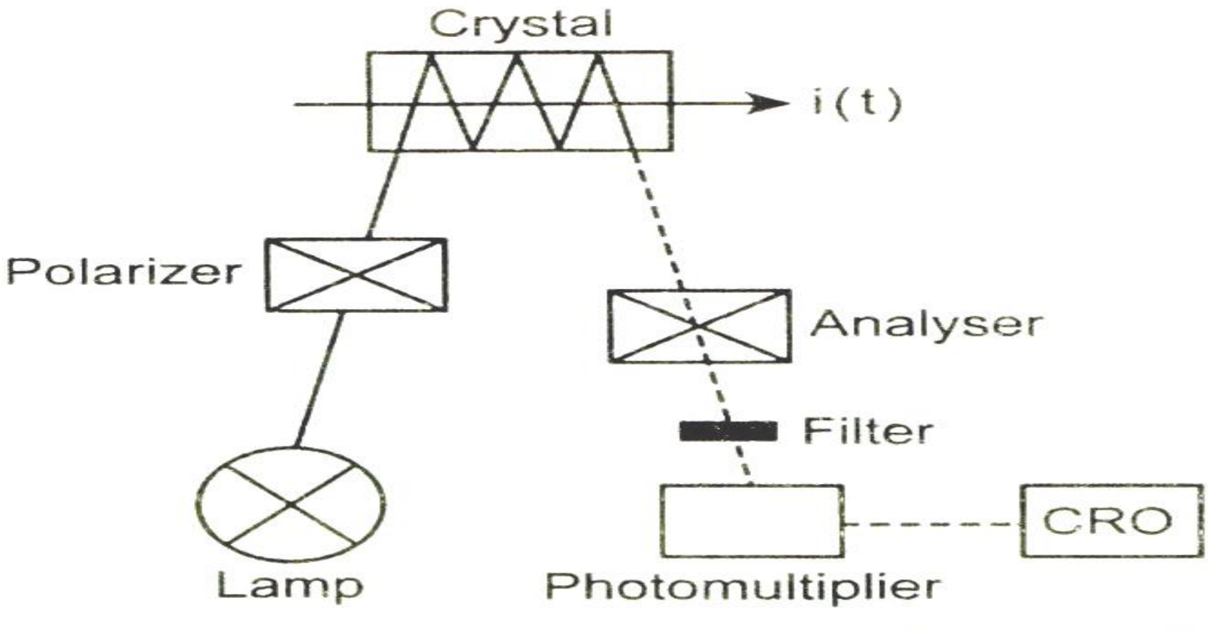
Angle of rotation $\propto$ B l

Angle of rotation = VB l

Where, V= constant of the crystal depends on the wavelength of the light,

B= magnetic flux density,

l = length of the crystal



Construction and operation:

- A stabilized light source (lamp) emits beam of light. These beams of light are felt on the crystal though a polarizer.
- The crystal is placed parallel to the magnetic field produced by the current i(t). Due to faraday's effect, light beam undergoes rotation of its plane of polarization.
- The beam is now passed through the analyzer, then filtered by using filter to allow only monochromatic light and is passed to the CRO through photo-multiplier.
- By seeing the output display of oscillograph, the current can be measured.
- This device cannot be operated for D.C. circuits.

Advantages:

- No electric connection between the source and the device.
- No thermal problems even for large currents of several kA.
- No insulation problem arises for EHV system, because signal transmission is through optical system.

PROBLEM:1

A coaxial shunt is to be designed to measure an impulse current of 50kA. If the bandwidth of the shunt is to be at least 10MHz and if the voltage drop across the shunt should not exceed 50V, find the ohmic value of the shunt and its dimensions. MAY-2017,18

Solution: Resistance of the shunt (max) R=$\frac{50}{50\times10^{2}} = 1m\Omega$

Taking the simplified equivalent circuit of the shunt as given in Fig.7.49(b)

Bandwidth $B = \frac{1.46R}{L_0} = 10MHz$

or, $L_0 = \frac{1.46R}{B} = \frac{1.46X10^{-2}}{10X10^6}$

$= 1.46 \times 10^{-10} H$ or 0.146 nH

d, the thickness of the cylindrical resistive tube is taken from the consideration of the bandwidth as

$$B=\frac{1.46\rho}{\mu d^2}$$

where r = resistivity of the material

$\mu = \mu_0 = 4\pi \times 10^{-7}$ H/m, and

d=thickness of the tube in meters

r = radius of the resistive tube,

l = length of the resistive tube,

d = thickness of the resistive tube, and

ρ = resistivity of the tube material.

Then the bandwidth $B=\frac{1.46\rho}{\mu d^2}$

where, $\mu = \mu_0\mu_r = \mu_0$

Substituting $B = 10^7$ Hz

$$\rho = 30 \times 10^{-8} \Omega m$$

$$\mu_0 = 4\pi \times 10^{-7}$$

$$d = \sqrt{\frac{1.46\rho}{\mu B}} = \sqrt{\frac{1.46 \times 30 \times^{-8}}{4\pi \times 10^{-7} \times 10^7}}$$

$$= 0.187 \times 10^{-3} m = 0.187 mm$$

Let the length *l* be taken as 10cm or 10^{-1}m;

then, $R=\frac{\rho l}{A} = \frac{\rho l}{(2\pi r)d} = 1 m\Omega$

or, $r = \frac{\rho l}{2\pi R d} = \frac{30 \times 10^{-8} \times 10^{-1}}{2\pi \times 10^{-3} \times 0.187 \times 10^{-3}}$

$= 25.5 \times 10^{-3} m$ or 25.5mm.

For the return conductor the outer tube can be taken to have a length = 10cm, radius = 30mm, and thickness = 1mm, and it can be made from copper or brass.

UNIVERSITY QUESTIONS

PART-A

1. What are the general methods used for measurement of high frequency and impulse currents?***(MAY-2014)***
2. Define CVT? ***(MAY-JUNE 2013)***
3. Give the advantages of electrostatic voltmeter? ***(MAY-JUNE 2013)***
4. what is the effect of dust particles on the measurements using sphere gaps***(DEC-2013)***
5. What are the advantages and limitations of generating voltmeter?***(DEC-2013)***
6. Give the procedure for DC and Ac peak voltage measurements using sphere gap***.(M-14)***
7. What are the condiction to be satisfied by potential divider for impulse work?***(Dec-14)***
8. What is the significance of atmospheric correction factor in HV testing?***(Dec-14)***
9. *What is the principle behind the operation of generation voltmeter? APRIL/MAY-15*
10. Calculate the correction factors for atmospheric conditions, if the laboratory temperature is 37^0C, the atmospheric pressure is 750 mm Hg, and the wet bulb temperature is 27^0C.APRIL/MAY-2015

11.*what are the draw backs of series resistance micro-ammeter technique in HVAC measurements.**NOV-15***

12.*What is the principle behind the operation of generation voltmeter? **APRIL/MAY-15***

13) How the stray effect of capacitance potential divider is minimized for impulse measurements? (NOV-2015)

14)What are the advantages of generation voltmeters?(Dec-16)

15) What are the advantages of using faraday generator?(Dec-16)

PART-B

1. Explain the sphere gap measurement and compare it with rod gap measurement of high voltage**.(NOV/DEC-2004, NOV/DEC-2004, NOV/DEC-2008,MAY/JUN-2009)**
2. Explain the principle of operation of electrostatic voltmeter.
3. What are the different types of resistive shunt used for impulse current measurement**?(NOV/DEC-2008)**
4. Explain the capacitive voltage transformer with neat diagram.
5. Explain potentiometers(Rogowski coil)
6. Explain the Faraday generator**(May/june-2012)**
7. Explain with diagram the extended series resistance for high voltage AC measurements**.(APR/MAY-2005)**

8. Describe a new scheme of current transformer measurements introducing electro-optical technique for EHV systems**(APR/MAY-2005)**

9. Describe the generating voltmeter method for measurement of high DC voltage**(APR/MAY-2005)**

10. Explain with neat diagram the principle of operation of an electrostatic voltmeter. Discuss its advantage and limitation for high voltage measurements**.(APR/MAY-2011,MAY/JUNE-2012)**

11. Explain with nean diagram various Measurement techinique of high impulse currents?

(DEC-2013)

12. Explain briefly different types of DC voltage measurements**? May-2013,15**

13. Explain briefly different types of AC voltage measurement? **May-2013**

14. Explain various spark gap measurements of high D.C., A.C and impulse voltages (Peak values)? **DEC-2013,Dec14,15,16**

15. Explain with neat diagram various Impulse Voltage Measurements Using Voltage Dividers or Potential Dividers**? (DEC-2013)**

16) Describe the construction, principle of operation of a generating voltmeter and give its application and limitations**.(May-2014)**

17) Explain Series capacitor peak voltmeter (Chubb- Frotscue method for peak voltage measurement**.(Dec-2014)**

18) Discuss and compare the performance of resistance capacitance and mixed R-C potential divider for measurement of impulse voltage**.(May-2014)**

19) Explain with neat diagram of Rogowskicoils ,the principle of operation for measurement of high impulse current **(Dec-2014)**

20). What is mean by 50 percent disruptive discharge as applieD to impulse voltages. Didcuss any one method**(MAY/JUN-2009)**

21) Explain briefly different types of DC voltage measurements?NOV- 2011,May-2013,2015

22) *With neat sketch explain in detail the various methods used to measure the RMS and peak values of high AC voltages? APRIL/MAY-2015*

23)What are the requirements of a digital storage oscilloscope for impulse and high frequency measurements in HV test circuits?NOV/DEC-15

24)Capacitance Voltage Transformer (CVT).Dec-16)
25)Digital peak voltmeter:Dec-16

UNIT-5

1. **Why is testing for over voltages needed?**

High voltage testing of electrical apparatus is essential to ensure that the electrical equipment is capable of withstanding the over voltages.The over voltages may be either due to natural causes like lightning o switching or power frequency transient voltages.

2. **Define disruptive discharge voltage.Nov/Dec-17**

It is defined as the voltage which produces the loss of dielectric strength of insulation. It is that voltage at which the electrical stress in the insulation causes a failure which includes the collapse of voltage and passage of current.

3. **Distinguish between flashover and puncture.(MAY14,NOV15)**

When a discharge takes place between two electrodes in gas or a liquid over a solid surface in air, it is called flash over. If the discharge occurs through a solid insulation, it is called puncture.

4. **Define withstand voltage.(APRIL 2005)**

The voltage which has to be applied to a test object under specified condition in a withstand test is called withstand voltage.

5. **Define 50% flashover voltage.Dec-16**

The voltage which has a probability of 50% of flash over, when applied to a test Object.

This is normally applied in impulse test in which the loss of insulation strength is temporary.

6. **Define 100% flashover voltage.**

The voltage, that causes a flash over at each of its application under specified condition when applied to test objects as specified, is hundred percent flash over voltage.

7. **Define creepage distance.(Dec-14)**

It is the shortest distance on the contour of the external surface of the insulator unit or between two metal fittings on the insulator.

8. **Define front time in impulse wave.**

The time to front(t_f) is defined as 1.67times to time between 30% and 90% of the peak value in the rising portion of the wave.

9. **Define standard impulse wave.**

The standard impulse wave is defined one with t_f=1.2μs,t_t=50μs.

10. **Write the standard atmospheric conditions for H.V testing as per Indian Standard.**

Temperature : 27c

Pressure :1013millibars(or 760torr)

Absolute humidity :17gm/m3

11. What are insulators?

Insulators are the elements which provide necessary insulation between line conductors and supports(towers) and thus prevent any leakage current from conductors to earth.

12. What are the types of insulators?

Types of insulators are:

i)Pin type insulators
ii)Suspension type insulators
iii)Strain insulators
iv)Shackle insulators
v)Stay insulators
vi)Stack insulators

13. What are the tests conducted on insulators?(NOV-DEC 2009,MAY-2013,DEC-2013)

High voltage tests include:

i)The power frequency tests, and

ii)Impulse test.

All the insulators are tested for both categories of test.

14. Differntiate type test and routine test.(MAY/JUNE 2012,MAY-2013,DEC-2013)

Type test:

These tests are intended to prove or check the design features and the quality.

Type tests are done on samples when new design or design changes are introduced.

Routine test:

The routine tests are intended to check the quality of the individual test piece. The routine tests are done to ensure the reliability of the individual test objects and quality and consistency of the materials used in their manufacture.

15. How is dry flash over test carried?

If the test is conducted under normal conditions without any rain or precipitation, it is called dry flash over test.

16. How is wet flashover test carried?

If the test is carried under condition of artificial rain, it is called wet flash over test.

17.What are impulse tests?(NOV/DEC 2008)

Impulse tests are:

i)impulse withstand voltage test.
ii)50% dry impulse flash over test.
Iii)pollution testing

18. How is impulse withstand voltage test carries?(April-2005,May-14)

This test is done by applying standard impulse voltage of 1/50µs wave under dry conditions with both positive and negative polarities of the wave.

i)If five consecutive waves do not cause of flash over or puncture ,the insulator is deemed to have passed the test.

ii)If two applications cause flash over, the insulator is deemed to have failed.

19. How is 50% dry impulse flashover test carried?

50% dry impulse flash over test is done by applying standard impulse voltage of specified value under dry condition with both positive and negative polarities of the wave. Here the probability of failure is determined for 40% and 60% failure values or 20% and 80% failure values, since it is difficult to adjust the test voltage for the exact 50% flash over values. The average value of the upper and lower limits is taken.

The insulator surface should not be damaged by these tests, but slight marking on its surface or chipping off of the cement is allowed.

20. What is an isolator?

Isolator is a mechanical switching device which provides in the open position, an isolating distance in accordance with special requirements. An isolator is capable of carrying currents under normal circuit conditions.

21. What are the tests conducted on isolators and circuit breakers?

The tests are:

i)Dielectric test or over voltage test(power frequency test and impulse test)
ii)Temperature rise and mechanical test

iii)Short circuit test.

22. What are the tests conducted on transformers?(MAY/JUNE 2009,Dec-16)

The tests are:

i)Induced overvoltage test

ii)Partial discharge test

iii)Impulse test.

23. What are the uses of induced overvoltage test on transformers?

i)Reduce core saturation
ii)Limit the charging current necessary
iii)Check the insulation withstand strength.

24. What is partial discharge?

The weak points in an insulation like voids, cracks and other imperfections lead to internal discharges in the insulation. These imperfections were considered as power loss. An electrical discharge that partially bridges the dielectric or insulating medium between two conductors is called as partial discharge. It may be internal discharge, surface discharge and corona discharge.

25. What is surge arrester?

A surge arrester or lightning arrester is a device used to protect the power system against transient voltages due to lightning and switching surges.

26. What are the tests conducted on surge arresters?(MAY/JUNE 2009)

i)Power frequency spark over test

ii)100% standard impulse spark over test

iii)Front of wave spark over test

iv)Residual voltage test

v)High current impulse test and other tests.

27. What are the tests conducted on cables?

Different tests are conducted on cable are:

i)Mechanical tests

a) Bending test

b)Dripping and drainage test

c)Fire resistance test

d)Corrosion test

ii)Thermal duty test

iii)Dielectric power factor test

iv)Power frequency withstand voltage test

v)Impulse withstand voltage test

vi)Partial discharge test

vii)Life expectancy test.

28. What are the tests conducted on bushings?(NOV/DEC2009,MAY-17)

i)Power frequency tests

ii)Impuse voltage tests

iii)Thermal tests

29. What is insulation coordination?(Dec-2008,May-2008,Dec-14,17,April-18)

The selection of suitable values for the insulation levels of the various components in any electrical system and their arrangement in a rational manner is called insulation coordination.

30. What is insulation level of an apparatus?

It is defined as that combination of voltage values which characterize its insulation with regard to its capability of withstanding the dielectric stresses.

31. Why is insulation coordination needed?(MAY/JUNE 2012)

i)To ensure reliability and continuity to the utility concerns.

ii)To minimize the number of failures of lines and substations due to over voltages.

iii)To minimize the cost involved in the design, installation, and operation of protective devices.

32. On what factor does insulation problem occur?

i)Determination of line insulation

ii)Selection of Basic Impulse Level (BIL) and insulation levels of other equipment.

iii)Selection of lightning arresters.

33. What are the ideal requirements of a protective device?

i) It should not usually flash over for power frequency over voltages.

ii) The volt-time characteristics of the devices must lie below the withstand voltage of the protected apparatus or insulation.

iii) It should be capable of discharging high energies contained in surges and recover insulation strength quickly.

34. On what factors, does the surge arrester voltage rating fort EHV and UHV system depend?

The rate of rise of voltage

Type of system

i)Effectively grounding

ii)Grounded through an impedance Operating characteristics

35. What are the advantages of using Z_nO arresters for EHV system?

i)Simple in construction

ii)Flat V-I characteristic over a wide current range

iii)The absence of a spark gap that produces steep voltage gradients when sparking occurs.

36. What are the disadvantages of Z_nO arresters for EHV system?

i)Continuous flow of power frequency current ii)Power loss is high.

37. On what factors does equipment insulation level depend?

i)Distance from the arrester location

ii)Steepness of the wave front

iii)Electrical apparatus.

38. State the principles that are followed in the insulation design of EHV and UHV substations.

Stations have transformers and other valuable equipment that have non-self restoring insulation.

The protective levels for lightning surges and switching surges are almost equal and even overlap. If BIL for the equipment or the system is chosen, then this level cannot give protection against the switching impulses. Hence, a separate surge impedance loading(SIL) has to be chosen.

$$SIL = V_{RL}^2/Z$$

Where $Z=\sqrt{L/C}$

V_{RL}=line voltage

It is therefore, desirable to use protective devices for limiting both lightning and switching over voltages. As such the SIL above the controlled switching surge level has to be adopted, so that the surge arrestors operate only rarely on switching over voltages where the controls of the control devices for switching devices fail.

39.What are called Type Tests? APRIL/MAY-2015

1. Short circuit tests
2. Dielectric tests
3. Thermal test
4. Mechanical test

40.What is BIL? APRIL/MAY-2015

The lightning impulse withstand level known as the Basic Impulse Level (BIL) is established for each system nominal voltage for different apparatus. Various equipment and their component parts should have their BIL above the system protective level, by a suitable margin. This margin is usually determined with respect to air insulation by statistical methods. For non self-restoring insulation like the transformer insulation, the margin limit is fixed using conventional methods.

41.Define safety margin as applied to insulation coordination.(NOV 2015)

For proper insulation co-ordination, a certain margin of safety has to be provided by properly choosing the 'protective level" for protective devices, such as spark gaps and surge diverters, and proper insulation level for the equipment and the apparatus.

***42)* What is the significance of atmospheric (Air) correction factor in HV testing?(Dec-14,MAY-17)**

The standard atmospheric conditions are an air temperature of t_0=20·c, an air pressure of b_0=1013mbar and an absolute humidity of h_0=11g/m^3. b_0 is standard atmospheric pressure ,b is actual pressure at the instant of measurement with t the actual pressure at the instant of measurement with t the actual temperature. The atmospheric correction factor $k_t$has two parts Air density factor K_1 and humidity factor K_2.

$$K_1=\delta^m$$

Where δ is given by the equation

$$\delta = \frac{b}{b_0}\frac{273+t_0}{273+t}$$

43.what is the significance of power factor test.April/May-18

A proactive approach is the key to monitoring the integrity of the insulation system and preventing or at least anticipating such failures. **Power factor** diagnostic **testing**is an **important** tool in determining the quality of the insulation and estimating its remaining healthy life.

PART -B

1.What are the different tests conducted on insulator? Explain any one of them. (MAY/JUNE-2009, MAY/JUNE -2013,18,2015,DEC-2013)

Arrangement of Insulators for Test:

- String insulator unit should be hung by a suspension eye from an earthed metal cross arm.
- The test voltage is applied between the cross arm and the conductor hung vertically down from the metal part on the lower side of the insulator unit.
- Suspension string with all its accessories as in service should be hung from an earthed metal cross arm. The length of the cross arm should be at least 1.5 times the length of the string being tested and should be at least equal to 0.9 m on either side of the axis of the string.
- No other earthed object should be nearer to the insulator string then 0.9 m or 1.5 times the length of the string whichever is greater.
- A conductor of actual size to be used in service or of diameter not less than 1 cm and length 1.5 times the length of the string is secured in the suspension clamp and should lie in a horizontal plane.
- The test voltage is applied between the conductor and the cross arm and connection from the impulse generator is made with a length of wire to one end of the conductor.
- For higher operating voltages where the length of the string is large, it is advisable to sacrifice the length of the conductor as stipulated above. Instead, it is desirable to bend the ends of the conductor over in a large radius.

- For tension insulators the arrangement is more or less same as in suspension insulator except that it should be held in an approximately horizontal position under a suitable tension (about 1000 Kg.).

- For testing pin insulators or line post insulators, these should be mounted on the insulator pin or line post shank with which they are to be used in service. The pin or the shank should be fixed in a vertical position to a horizontal earthed metal cross arm situated 0.9 m above the floor of the laboratory.

- A conductor of 1 cm diameter is to be laid horizontally in the top groove of the insulator and secured by at least one turn of tie-wire, not less than 0.3 cm diameter in the tie-wire groove.

- The length of the wire should be at least 1.5 times the length of the insulator and should over hang the insulator at least 0.9 m on either side in a direction at right angles to the cross arm. The test voltage is applied to one end of the conductor.

<u>High voltage testing of electrical equipment requires two types of tests:</u>
(i)Type tests,
(ii)Routine test.

Type tests involves quality testing of equipment at the design and development level i.e. samples of the product are taken and are tested when a new product is being developed and designed or an old product is to be redesigned and developed whereas the routine tests are meant to check thequality of the individual test piece. This is carried out to ensure quality and reliability of individual test objects.

<u>Various types of overhead line insulators are:</u>

- ✓ Pin type
- ✓ Post type
- ✓ String insulator unit
- ✓ Suspension insulator string
- ✓ Tension insulator.
- ✓ High voltage tests include
- ✓ Power frequency tests and
- ✓ Impulse tests.

<u>These tests are carried out on all insulators:</u>

- ✓ 50% dry impulse flash over test.
- ✓ Impulse withstand test.
- ✓ Dry flash over and dry one minute test.
- ✓ Wet flash over and one minute rain test.
- ✓ Temperature cycle test.
- ✓ Electro-mechanical test.
- ✓ Mechanical test.
- ✓ Porosity test.
- ✓ Puncture test.
- ✓ Mechanical routine test.

(i) 50% dry impulse flash over test:

- ✓ The test is carried out on a clean insulator mounted as in a normal working condition. An impulse voltage of 1/50µsec. wave shape and of an amplitude which can cause 50% flash over of the insulator, is applied, i.e.of the impulses applied 50% of the impulses should cause flash over.
- ✓ The polarity of the impulse is then reversed and procedure repeated. There must be at least 20 applications of the impulse in each case and the insulator must not be damaged. The magnitude of the impulse voltage should not be less than that specified in standard specifications.

ii)Impulse withstand test :

- ✓ The insulator is subjected to standard impulse of 1/50 µsec. wave of specified value under dry conditions with both positive and negative polarities.
- ✓ If five consecutive applications do not cause any flash over or puncture, the insulator is deemed to have passed the impulse withstand test. If out of five, two applications cause flash over, the insulator is deemed to have filed the test.

iii)Dry flash over and dry one minute test :

- ✓ Power frequency voltage is applied to the insulator and the voltage increased to the specified value and maintained for one minute.
- ✓ The voltage is then increased gradually until flash over occurs. The insulator is then flashed over at least four more times, the voltage is raised gradually to reach flash over in about 10 seconds.
- ✓ The mean of at least five consecutive flash over voltages must not be less than the value specified in specifications.

(iv) Wet flash over and one minute rain test :

- ✓ If the test is carried out under artificial rain, it is called wet flash over test. The insulator is subjected to spray of water of following characteristics:
- ✓ Precipitation rate: 3 ±10% mm/min.
- ✓ Direction: 45° to the vertical
- ✓ Conductivity of water: 100 micro Siemens ±10%
- ✓ Temperature of water ambient +15°C the insulator with 50% of the one-min.
- ✓ rain test voltage applied to it, is then sprayed for two minutes, the voltage raised to the one minute test voltage in approximately 10 sec. and maintained there for one minute.
- ✓ The voltage is then increased gradually till flash over occurs and the insulator is then flashed at least four more times, the time taken to reach flash over voltage being in each case about 10 sec. The flash over voltage must not be less than the value specified in specifications.

(v) Temperature cycle test :

- ✓ The insulator is immersed in a hot water bath whose temperature is 70° higher than normal water bath for Tminutes.
- ✓ It is then taken out and immediately immersed in normal water bath for T minutes. After Tminutes the insulator is again immersed in hot water bath for Tminutes.

- ✓ The cycle is repeated three times and it is expected that the insulator should withstand the test without damage to the insulator or glaze. Here T = (15 + W/1.36) where Wis the weight of the insulator in kgs.

(vi) Electro-mechanical test :

- ✓ The test is carried out only on suspension or tension type of insulator. The insulator is subjected to a 2½ times the specified maximum working tension maintained for one minute.
- ✓ Also, simultaneously 75% of the dry flash over voltage is applied. The insulator should withstand this test without any damage.

(vii) Mechanical test :

- ✓ This is a bending test applicable to pin type and line-post insulators. The insulator is subjected to a load three times the specified maximum breaking load for one minute.
- ✓ There should be no damage to the insulator and in case of post insulator the permanent set must be less than 1%. However, in case of post insulator, the load is then raised to three times and there should not be any damage to the insulator and its pin.

(viii) Porosity test:

The insulator is broken and immersed in a 0.5% alcohol solution of fuchsin under a pressure of 13800 kN/m^2 for 24 hours. The broken insulator is taken out and further broken. It should not show any sign of impregnation.

(ix) Puncture test:

- ✓ An impulse over voltage is applied between the pin and the lead foil bound over the top and side grooves in case of pin type and post insulator and between the metal fittings in case of suspension type insulators. The voltage is 1/50 µsec.

- ✓ wave with amplitude twice the 50% impulse flash over voltage and negative polarity. Twenty such applications are applied. The procedure is repeated for 2.5, 3, 3.5 times the 50% impulse flash over voltage and continued till the insulator is punctured.

- ✓ The insulator must not puncture if the voltage applied is equal to the one specified in the specification.

(x) Mechanical routine test :

- ✓ The string in insulator is suspended vertically or horizontally and a tensile load 20% in excess of the maximum specified working load is applied for one minute and no damage to the string should occur.

2. What are the different tests conducted on cable? Explain any one of them. (May/June-2012, May/June-2013,DEC-2013)

- ➢ The cable sample has to be carefully prepared for performing various tests especially electrical tests.

- This is essential to avoid any excessive leakage or end flashovers which otherwise may occur during testing and hence may give wrong information regarding the quality of cables.
- The length of the sample cable varies between 50 cms to 10 m. The terminations are usually made by shielding the ends of the cable with stress shields so as to relieve the ends from excessive high electrical stresses.

A cable is subjected to following tests:

- ✓ Bending tests.
- ✓ Loading cycle test.
- ✓ Thermal stability test.
- ✓ Dielectric thermal resistance test.
- ✓ Life expectancy test.
- ✓ Dielectric power factor test.
- ✓ Power frequency withstand voltage test.
- ✓ Impulse withstand voltage test.
- ✓ Partial discharge test.

(i) ***Bending tests:*** It is to be noted that a voltage test should be made before and after a bending test. The cable is bent round a cylinder of specified diameter to make one complete turn. It is then unwound and rewound in the opposite direction. The cycle is to be repeated three times.

(ii) Loading cycle test :A test loop, consisting of cable and its accessories is subjected to 20 load cycles with a minimum conductor temperature 5°C in excess of the design value and the cable is energized to 1.5 times the working voltage. The cable should not show any sign of damage.

(iii) Thermal stability test: After test as at (ii), the cable is energized with a voltage 1.5 times the working voltage for a cable of 132 kV rating (the multiplying factor decreases with increases in operating voltage) and the loading current is so adjusted that the temperature of the core of the cable is 5°C higher than its specified permissible temperature. The current should be maintained at this value for six hours.

(iv) Dielectric thermal resistance test: The ratio of the temperature difference between the core and sheath of the cable and the heat flow from the cable gives the thermal resistance of the sample of the cable. It should be within the limits specified in the specifications.

(v) Life expectancy test: In order to estimate life of a cable, an accelerated life test is carried out by subjecting the cable to a voltage stress higher than the normal working stress. It has been observed that the relation between the expected life of the cable in hours and the voltage stress is given by

$$g = \frac{K}{n\sqrt{t}}$$

where*K*is a constant which depends on material .
nis the life index depending again on the material.

(vi) Dielectric power factor test:

- ✓ High Voltage Schering Bridge is used to perform dielectric power factor test on the cable sample. The power factor is measured for different values of voltages *e.g.* 0.5, 1.0, 1.5 and 2.0 times the rated operating voltages.
- ✓ The maximum value of power factor at normal working voltage does not exceed a specified value (usually 0.01) at a series of temperatures ranging from 15°C to 65°C. The difference in the power factor between rated voltage and 1.5 times the rated voltage and the rated voltage and twice the rated voltage does not exceed a specified value.
- ✓ Sometimes the source is not able to supply charging current required by the test cable, a suitable choke in series with the test cable help sin tiding over the situation.

(vii) Power frequency withstand voltage test :

- ✓ Cables are tested for power frequency a.c. and d.c. voltages. During manufacture the entire cable is passed through a higher voltage test and the rated voltage to check the continuity of the cable.
- ✓ As a routine test the cable is subjected to a voltage 2.5 times the working voltage for 10 min without damaging the insulation of the cable. HV d.c. of 1.8 times the rated d.c. voltage of negative polarity for 30 min.
- ✓ is applied and the cable is said to have withstood the test if no insulation failure takes place.

viii) Impulse withstand voltage test:

- ✓ The test cable is subjected to 10 positive and 10 negative impulse voltage of magnitude as specified in specification, the cable should withstand 5 applications without any damage.
- ✓ Usually, after the impulse test, the power frequency dielectric power factor test is carried out to ensure that no failure Occurred during the impulse test.

(ix) Partial discharge test:

- ✓ Partial discharge measurement of cables is very important as it gives an indication of expected life of the cable and it gives location of fault, if any, in the cable.
- ✓ When a cable is subjected to high voltage and if there is a void in the cable, the void breaks down and a discharge takes place. As a result, there is a sudden dip in voltage in the form of an impulse.
- ✓ This impulse travels along the cable as explained in detail in Chapter VI. The duration between the normal pulse and the discharge pulse is measured on the oscilloscope and this distance gives the location of the void from the test end of the cable.
- ✓ However, the shape of the pulse gives the nature and intensity of the discharge.
- ✓ In order to scan the entire length of the cable against voids or other imperfections, it is passed through a tube of insulating material filled with distilled water.
- ✓ Four electrodes, two at the end and two in the middle of the tube are arranged. The middle electrodes are located at a stipulated distance and these are energized with high voltage.
- ✓ The two end electrodes and cable conductor are grounded. As the cable is passed between the middle electrodes, if a discharge is seen on the oscilloscope, a defect in this part of the cable is stipulated and hence this part of the cable is removed from the rest of the cable.

3. What are the test conducted on circuit breaker and isolator? Explain any one method for each.(may/june-2012,Dec-14,16)

An Equipment when designed to certain specification and is fabricated, needs testing for its performance. The general design is tried and the results of such tests conducted on one selected breaker and are thus applicable to all others of identical construction. These tests are called the type tests. These tests are classified as follows:

1.Short circuit tests:

- ✓ Making capacity test.
- ✓ Breaking capacity test.
- ✓ Short time current test.
- ✓ Operating duty test

2. Dielectric tests:

(i) Power frequency test:

- ✓ One minute dry withstand test.
- ✓ One minute wet withstand test.

(ii) Impulse voltage dry withstand test.

3. Thermal test:

4. Mechanical test:

- ✓ Once a particular design is found satisfactory, a large number of similar C.Bs. are manufactured for marketing. Every piece of C.B. is then tested before putting into service. These tests are known as routine tests.
- ✓ With these tests it is possible to find out if incorrect assembly or inferior quality material has been used for a proven design equipment. These tests are classified as
  - operation tests,
  - Millivoltdrop tests,
  - (iii)power frequency voltage tests at manufacturer's premises, and
  - power

Frequency voltage tests after erection on site. We will discuss first the type tests. In that also we will discuss the short circuit tests after the other three tests.

Dielectric Tests:

- ✓ The general dielectric characteristics of any circuit breaker or switchgear unit depend upon the basic design i.e. clearances, bushing materials, etc. upon correctness and accuracy in assembly and upon the quality of materials used. For a C.B.
- ✓ These factors are checked from the viewpoint of their ability to

Withstand over voltages at the normal service voltage and abnormal voltages during lightning or other phenomenon.

The test voltage is applied for a period of one minute between

- phases with the breaker closed,
- phases and earth with C.B. open,
- Across the terminals with breaker open.

- ✓ With this the breaker must not flash over or puncture. These tests are normally made on indoor switchgear. For such C.Bs the impulse tests generally are unnecessary because it is not exposed to impulse voltage of a very high order.

- ✓ The high frequency switching surges do occur but the effect of these in cable systems used for indoor switchgear are found to be safely withstood by the switchgear if it has withstood the normal frequency test. Since the outdoor switchgear is electrically exposed, they will be subjected to over voltages caused by lightning.
- ✓ The effect of these voltages is much more serious than the power frequency voltages in service. Therefore, this class of switchgear is subjected in addition to power frequency tests, the impulse voltage tests.

- ✓ The test voltage should be a standard 1/50 µsec wave, the peak value of which is specified according to the rated voltage of the breaker.

- ✓ A higher impulse voltage is specified for non-effectively grounded system than those for solidly grounded system. The test voltages are applied between

(i) Eachpole and earth in turn with the breaker closed and remaining phases earthed,
(ii) Between all terminals on one side of the breaker and all the other terminals earthed, with the breaker open.

- ✓ The specified voltages are withstanding values i.e.the breaker should not flash over for 10 applications of the wave.
- ✓ Normally this test is carried out with waves of both the polarities. The wet dielectric test is used for outdoor switchgear.
- ✓ In this, the external insulation is sprayed for two minutes while the rated service voltage is applied; the test overvoltage is then maintained for
- ✓ 30 seconds during which no flash over should occur.

The effect of rain on external insulation is partly beneficial, insofar as the surface is thereby cleaned, but is also harmful if the rain contains impurities

Thermal Tests:

- ✓ These tests are made to check the thermal behaviour of the breakers. In this test the rated current through all three phases of the switchgear is passed continuously for a period long enough to achieve steady state conditions.
- ✓ Temperature readings are obtained by means of thermocouples whose hot junctions are placed in appropriate positions. The temperature rise above ambient, of conductors, must normally not exceed 40°C when the rated normal current is less than 800 amps and 50°C if it is 800 amps and above.
- ✓ An additional requirement in the type test is the measurement of the contact resistances between the isolating contacts and between the moving and fixed contacts.
- ✓ These points are generally the main sources of excessive heat generation. The voltage drop across the breaker pole is measured for different
- ✓ values of d.c. current which is a measure of the resistance of current carrying parts and hence that of contacts.

Mechanical Tests:

- ✓ A C.B. must open and close at the correct speed and perform such operations without mechanical failure. The breaker mechanism is, therefore, subjected to a mechanical endurance type test involving repeated opening and closing of the breaker.
- ✓ B.S. 116: 1952 requires 500 such operations without failure and with no adjustment of the mechanism. Some manufacture feel that as many as 20,000 operations may be

reached before any useful information regarding the possible causes of failure may be obtained.

- ✓ A resulting change in the material or dimensions of a particular component may considerably improve the life and efficiency of the mechanism.

<u>Short Circuit Tests:</u>

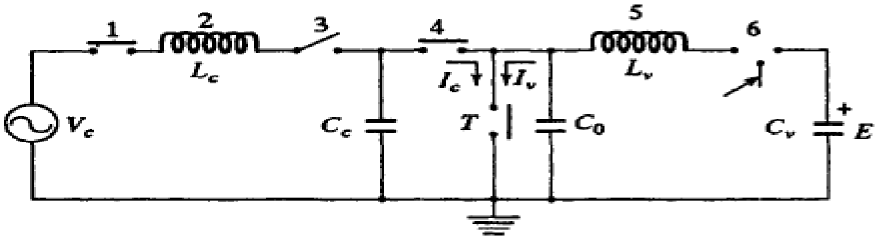
These tests are carried out in short circuit testing stations to prove the ratings of the C.Bs. Before discussing the tests it is proper to discuss about the short circuit testing stations.
There are two types of testing stations;

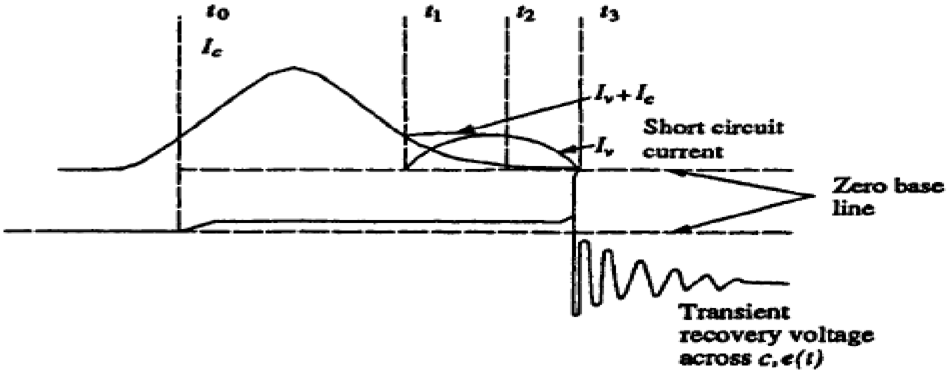
(i) field type,
(ii) Laboratory type.

In case of field type stations the power required for testing is directly taken from a large power system.
The breaker to be tested is connected to the system. Whereas this method of testing is economical for high voltage C.Bs. it suffers from the following drawbacks:
1. The tests cannot be repeatedly carried out for research and development as it disturbs the whole network.
2. The power available depends upon the location of the testing stations, loading conditions, installed capacity, etc.
3. Test conditions like the desired recovery voltage, the RRRV etc. cannot be achieved conveniently. In case of laboratory testing the power required for testing is provided by specially designed generators. This method has the following advantages:
1. Test conditions such as current, voltage, power factor, restriking voltages can be controlled accurately.
2. Several indirect testing methods can be used.
3. Tests can be repeated and hence research and development over the design is possible.
The limitations of this method are the cost and the limited power availability for testing the breakers.

Synthetic Tests-MAY-17, Nov/Dec-17

Synthetic Testing of Circuit Breakers Due to very high interrupting capacities of circuit breakers, it is not economical to have a single source to provide the required short circuit and the rated voltage. Hence, the effect of a short circuit is obtained as regards to the intensity of the current and the recovery voltage as a combination of the effects of two sources, one of which supplies the a.c. current and the other the high voltage. of comparatively high voltage of small current capacity. A schematic diagram of a synthetic testing station is shown in Fig.





With the auxiliary breaker (3) and the test breaker (T) closed, the closing of the
making switch (1) causes the current to flow in the test circuit breaker. At some instant say *to*, the test circuit breaker (T) begins to operate and the master circuit breaker (1) becomes ready to clear the generator circuit. At some times *t.* just before the zero of the generator current, the trigger gap (6) closes and the higher frequency current from the discharging capacitor *Cv*also flows through the arc. At time ^, when the generator Cv which has the required rate of change of current at its zero flowing in the test circuit breaker. At the zero of this current/full test voltage will be available. The closing of gap (6) would be a little earlier in time than shown in Fig. 10.4, but it has been drawn as shown for clarity at current zeros. It is important to see that the high-current source is disconnected and a high-voltage source applied with absolute precision (by means of an auxiliary circuit breaker) at the instant of circuit breaking.

4. Explain the method of impulse testing of high voltage transformer. What is the procedure adopted for locating the failure?(may-2011,17,Dec-14,15)

- ✓ Transformer is one of the most expensive and important equipment in power system. If it is not suitably designed its failure may cause a lengthy and costly outage.
- ✓ Therefore, it is very important to be cautious while designing its insulation, so that it can withstand transient over voltage both due to switching and lightning.
- ✓ The high voltage testing of transformers is, therefore, very important and would be discussed here.
- ✓ Other tests like temperature rise, short circuit, open circuit etc. are not considered here. However, these can be found in the relevant standard specification.

<u>Partial Discharge Test:</u>

- ✓ The test is carried out on the windings of the transformer to assess the magnitude of discharges.
- ✓ The measurements are to be made at all the terminals of the transformer and it is estimated that if the apparent measured charge exceeds 104 picocoulombs, the

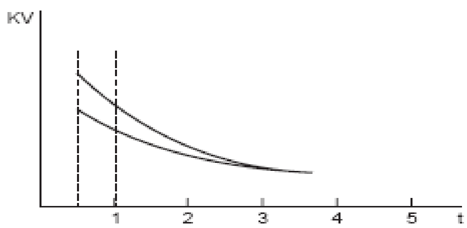
discharge magnitude is considered to be severe and the transformer insulation should be so designed that the discharge measurement should be much below the value of 104 pico-coulombs.

Impulse Testing of Transformer:

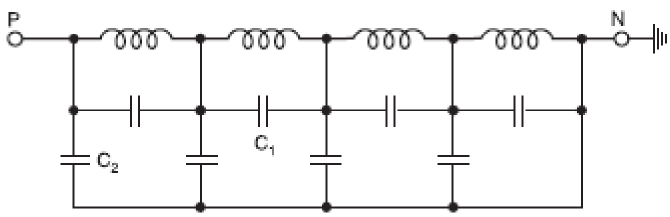
- ✓ The impulse level of a transformer is determined by the breakdown voltage of its minor insulation (Insulation between turn and between windings), breakdown voltage of its major insulation (insulation between windings and tank) and the flash over voltage of its bushings or a combination of these.

- ✓ The impulse characteristics of internal insulation in a transformer differ from flash over in air in two main respects.

- ✓ Firstly the impulse ratio of the transformer insulation is higher (varies from 2.1 to 2.2) than that of bushing (1.5 for bushings, insulators etc.). Secondly, the impulse breakdown of transformer



- ✓ Volt time curve of typical major insulation in transformer insulation in practically constant and is independent of time of application of impulse voltage. Figshows that after three micro seconds the flash over voltage is substantially constant.
- ✓ The voltage stressbetween the turns of the same winding and between different windings of the transformer dependsupon the steepness of the surge wave front.
- ✓ The voltage stress may further get aggravated by the pilingup action of the wave if the length of the surge wave is large. In fact, due to high steepness of the surgewaves, the first few turns of the winding are overstressed and that is why the modern practice is toprovide extra insulation to the first few turns of the winding. Fig below shows the equivalent circuit of a transformer winding for impulse voltage.



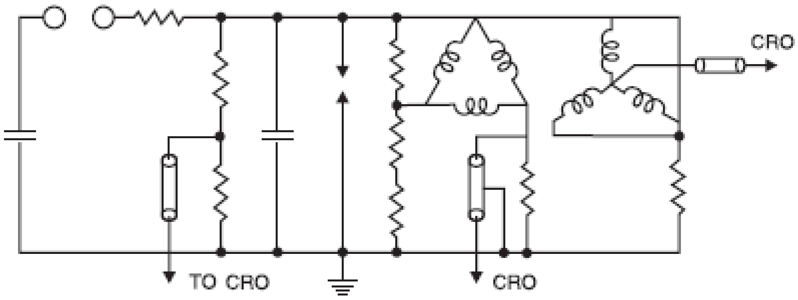
Equivalent circuit of a transformer for impulse voltage
Here C_1 represents inter-turn capacitance
C_2 capacitance between winding and the ground(tank).

- ✓ In order that the minor insulation will be able to withstand the impulse voltage, the winding issubjected to chopped impulse wave of higher peak voltage than the full wave.
- ✓ This chopped wave isproduced by flash over of a rod gap or bushing in parallel with the transformer insulation. The choppingtime is usually 3 to 6 micro seconds.
- ✓ While impulse voltage is applied between one phase andground, high voltages would be induced in the secondary of the transformer. To avoid this, the secondary windings are short-circuited and finally connected to ground.
- ✓ The short circuiting, however, decreases the impedance of the transformer and hence poses problem in adjusting the wave front and wave tail timings of wave. Also, the minimum value of the impulse capacitance required is given by

$$Co = \frac{\mathrm{P} * 10\text{^}8}{\mathrm{Z} * \mathrm{V}\text{^}2} microfarad$$

whereP= rated MVA of the transformer
Z = per cent impedance of transformer.
V = rated voltage of transformer.

Fig. bellow shows the arrangement of the transformer for impulse testing. CRO forms an integral part of the transformer impulse testing circuit. It is required to record to wave forms of the applied voltage and current through the winding under test.



Arrangement for impulse testing of transformer

<u>Impulse testing consists of the following steps:</u>

- o Application of impulse of magnitude 75% of the Basic Impulse Level (BIL) of the transformer under test.
- o One full wave of 100% of BIL.
- o Two chopped wave of 115% of BIL.
- o One full wave of 100% BIL
- o One full wave of 75% of BIL.

- ✓ During impulse testing the fault can be located by general observation like noise in the tank or smoke or bubble in the breather. If there is a fault, it appears on the Oscilloscope as a partial of complete collapse of the applied voltage.
- ✓ Study of the wave form of the neutral current also indicated the type of fault. If an arc occurs between the turns or form turn to the ground, a train of high frequency pulses are seen on the oscilloscope and wave shape of impulse changes.
- ✓ If it is a partial discharge only, high frequency oscillations
- ✓ are observed but no change in wave shape occurs.

- ✓ The bushing forms an important and integral part of transformer insulation. Therefore, its impulse flash over must be carefully investigated. The impulse strength of the transformer winding is same for either polarity of wave whereas the flash over voltage for bushing is different for different polarity. The manufacturer, however, while specifying the impulse strength of the transformer takes into consideration the overall impulse characteristic of the transformer.

DETECTION AND LOCATION OF FAULT DURING IMPULSE TESTING(NOV-2015)

The fault in a transformer insulation is located in impulse tests by any one of the following methods.

General observations:The fault can be located by general observations like noise in the tank or smoke or bubbles in breather.

Voltage oscillogrammethod :Fault or failure appears as a partial or complete collapse of the applied voltage wave. Figure 10.14 gives the typical waveform. The sensitivity of this method is low and does not detect faults which occur on less than 5% of the winding.

Neutral current method :In the neutral current method, a record of the impulse current flowing through a resistive shunt between the neutral and ground point is used for detecting the fault. The neutral current oscillogram consists of a high frequency oscillation, a low frequency disturbance, and a current rise due to reflections from the ground end of the windings. When a fault occurs such as arcing between the turns or from turn to the ground, a train of high frequency pulses similar to that in the front of the impulse current wave are observed in the oscillogram and the waveshape changes.

If the fault is local, like a partial discharge, only high frequency oscillations are observed without a change of waveshape. The sensitivity of the method decreases, if other windings not under test are grounded.

Transferred surge current method:In this method, the voltage across a resistive shunt connected between the low voltage winding and the ground is used for fault location. A short high frequency discharge oscillation is capacitively transferred at the event of failure and is recorded. Hence, faults at a further distance from the neutral are also clearly located. The waveshape is distorted depending on the location and type of fault, and hence can be more clearly detected. After the location of the fault, the type of fault can be observed by dismantling the winding and looking for charred insulation or melted parts on the copper winding. This is successful in the case of major faults. Local faults or partial discharges are self healing and escape observation.

5.Explain the power frequency voltage test withstand test on a 66kv insulator.(nov/dec-2007apr,may-2008)

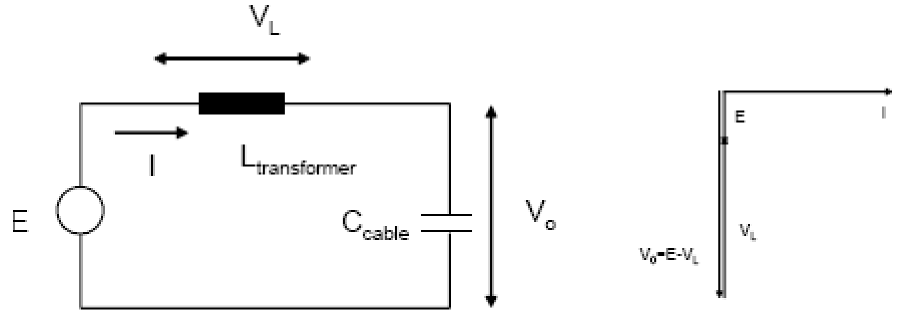
<u>Power frequency overvoltages:</u>

As shown in Table below power system apparatus are specified to operate at Um, which is usually about 5% higher than the nominal operating voltage. There are, however, circumstances where temporary over voltages (TOV's) as high as 50% of the nominal voltage may occur. These over voltages are extremely destructive due to their relatively long duration, as is clear from Table below Temporary over voltages are usually caused or triggered by some abnormal event on the power system. There are a variety of such causes and some are summarised in Table below

Type	**Description**
Earth fault occurrence	Voltage increase due to method of neutral grounding.
Load rejection	Ferranti effect Generator loss of load
Line energizing and autoreclosing Resonance effects	Travelling waves, trapped charge
Resonance effects	Resonance at fundamental frequency or harmonic frequency. Non-linear resonance between line capacitance and transformer magnetising reactance

Load rejection:

The disconnection (shedding) of a large load leads to voltage increases on the system as the series resistive and reactive voltage drops disappear. The capacitance of an unloaded cable, in combination with a transformer or generator inductance may lead to an increase of the voltage at the end of the line, if the cable capacitance and the series inductance are in near resonance, the output voltage can be much higher than the input voltage, as can be seen in the phasor diagram.



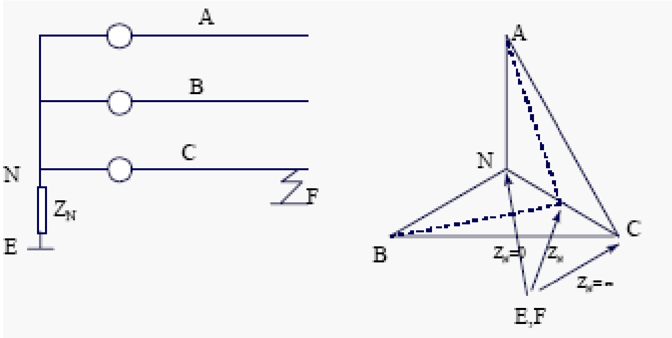
This phenomenon is known as the Ferranti effect and can also be explained, using a distributed parameter model of a transmission line, resulting in the following equation:

V_0/V_1=1/COS (βl)

with$V_0$and $V_1$the sending end and receiving end voltages of the line, respectively, l the line length and β the phase constant of the line (usually 6° per km).

Earth fault occurrence: the effect of neutral earthing:

If a ground fault occurs in a network with a non earthed neutral, the healthy phases will adopt a √3 times higher voltage until the fault is cleared. If the system is earthed through an impedance, the overvoltage depends on the transformer neutral earthing impedance, as indicated in Fig.



Earth Fault on Phase C

A system is classed as an effectively earthed system if $R_0/X_0 < 1$ and $X_0/X_1 < 3$, where:
R_0: zero sequence resistance
X_0: zero sequence reactance
X_1: positive sequence reactance
The overvoltage factor for earth faults (whereby the voltage prior to the fault occurrence has to be multiplied) is given by:

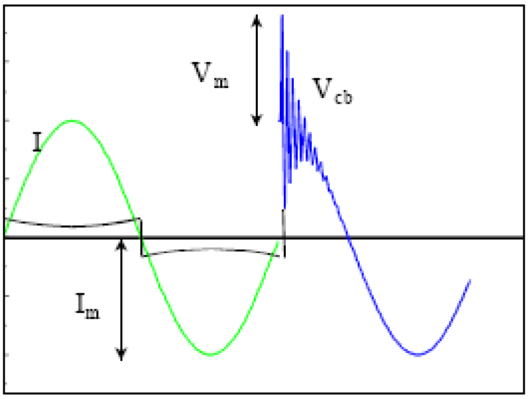
$$K = \sqrt{3}\,\frac{\sqrt{1 + Xo/X1 + (Xo/X1)^2}}{2 + Xo/X1}$$

In the above equation it was assumed that the system resistance can be ignored.

Switching overvoltages:

A power system contains a large number of capacitances (mainly the line shunt capacitances and compensation capacitors) and inductances (e.g. transformer leakage inductances). During disturbances transients occur in the form of damped oscillations. Typical examples are:
- Fault clearing
- Transformer magnetising current
- Capacitance switching
- Energizing of unloaded transmission lines,travelling waves.

- ✓ Only the interruption of fault currents will be dealt with here. Consider the power system in Fig below. Sinusoidal fault current flows, only limited by the reactance L.
- ✓ When the circuit breaker interrupts the fault current at the current zero the voltage across the circuit breaker must recover to follow the supply voltage. The high frequency recovery voltage across the open circuit breaker contacts adds to the power frequency voltage and introduces additional stresses of the insulation of the power system components as is shown in Fig.



- ✓ Clearly, a peak voltage as high as $2V_m$may appear across the circuit breaker and thus also on the equipment, connected to the system.
- ✓ The magnitude of the resulting overvoltage, should the current be "chopped" before the zero crossing, may be estimated by noting that the energy oscillates between Land Cduring the high frequency transient. For example, if the current is "chopped" at the current peak value, I_m, the energy in,

$$L,\ W_L=LI_m^2/2$$

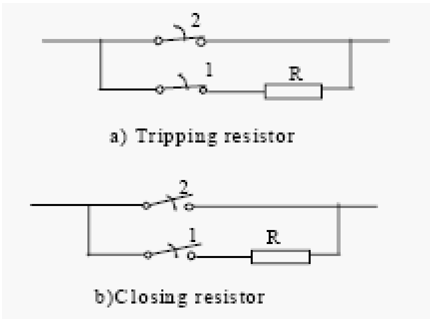
Is transferred to C(ignoring losses), during the first cycle of the transient. The energy in the capacitor is:

$$W_C=Cv_m^2/2$$

Equating $W_L$and W_C, it follows that the maximum voltage across *C* is:

$$V_m=\sqrt{(L/C)}I_m$$

Closing and tripping resistors that are inserted in parallel with the main circuit breaker gap for a short time during tripping, may effectively reduce switching over voltages as is shown in Figure.



The tripping resistors drain trapped charge from the line, while closing resistors damp oscillations that occur on energizing a line.

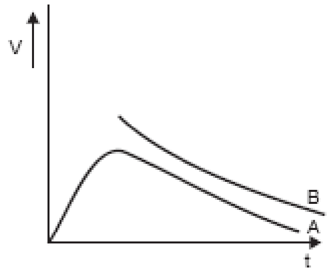
6. Explain different aspects of insulation design and insulation co-ordination adopted for EHV systems.(APR/MAY-2011,17,NOV-2015,17)

What are volt-time curves? Explain the procedure for constructing volt-time curves with neat sketch. Give its significance in power system studies. (May-2014)

<u>Insulation coordination and overvoltage protection:</u>

- ✓ Insulation coordination means the correlation of the insulation of the various equipments in a power system to the insulation of the protective devices used for the protection of those equipments against overvoltages. In a power system various equipments like transformers, circuit breakers, bus supports etc.

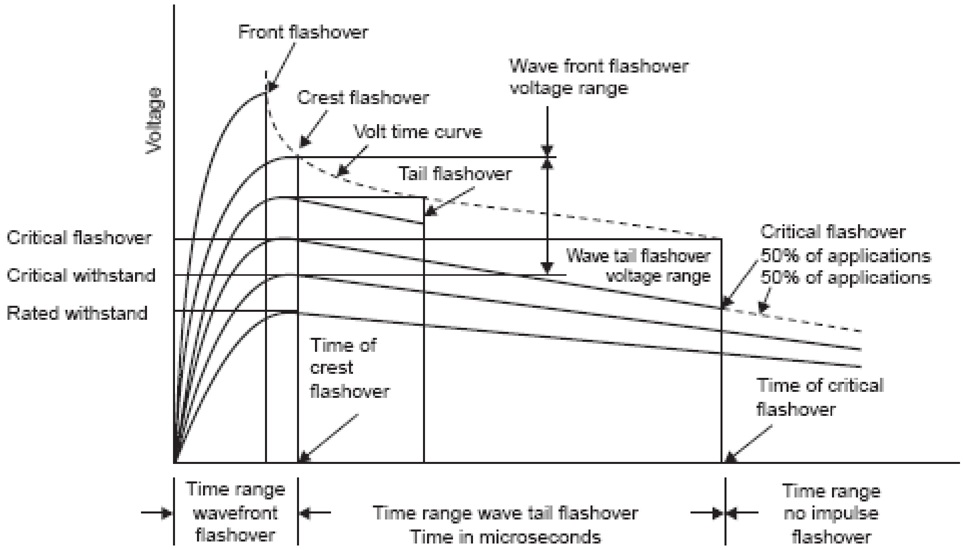
- ✓ have different breakdown voltages and hence the volt-time characteristics. In orderthat all the equipments should be properly protected it is desired that the insulation of the various protective devices must be properly coordinated. The basic concept of insulation coordinationis illustrated in Fig. below.



- ✓ Curve *A* is the volt-time curve of the protective device and *B* the volt-time curve of the equipment to be protected. Fig above shows the desired positions of the volt-time curves of the protecting device and the equipment to be protected.
- ✓ Thus, any insulation having a withstand voltage strength in excess of the insulation strength of curve *B* is protected by the protective device of curve *A*.The 'volt-time curve' expression will be used very frequently in this chapter. It is, therefore, necessary to understand the meaning of this expression.

<u>Volt-Time Curve:</u>

- ✓ The breakdown voltage for a particular insulation of flashover voltage for a gap is a function of both the magnitude of voltage and the time of application of the voltage.
- ✓ The volt-time curve is a graph showing the relation between the crest flashover voltages and the time to flashover for a series of impulse applications of a given wave shape. For the construction of volt-time curve the followingprocedure is adopted.
- ✓ Waves of the same shape but of different peak values are applied to the insulation whose volt-time curve is required. If flashover occurs on the front of the wave, the flashover point gives one point on the volt-time curve. The other possibility is that the flashover occurs just at the peak value
- ✓ of the wave;
- ✓ this gives another point on the *V-T* curve. The third possibility is that the flashover occurs on the tail side of the wave. In this case to find the point on the *V-T* curve, draw a horizontal line from the peak value of this wave and also draw a vertical line passing through the point where the flashovertakes place.
- ✓ The intersection of the horizontal and vertical lines gives the point on the *V-T* curve. This procedure is nicely shown in Fig below.



- ✓ The overvoltages against which coordination is required could be caused on the system due to system faults, switching operation or lightning surges.
- ✓ For lower voltages, normally upto about 345 kV, over voltages caused by system faults or switching operations do not cause damage to equipment insulation although they may be detrimental to protective devices.
- ✓ Overvoltages caused by lightning are of sufficient magnitude to affect the equipment insulation whereas for voltages above 345 kV it is these switching surges which are more dangerous for the equipments than the lightning surges.
- ✓ The problem of coordinating the insulation of the protective equipment involves not only guarding the equipment insulation but also it is desired that the protecting equipment should not be damaged. To assist in the process of insulation coordination, standard insulation levels have been recommended. These insulation levels are defined as follows.

- ✓ Basic impulse insulation levels (BIL) are reference levels expressed in impulse crest voltage with a standard wave not longer than 1.2/50 µsec wave. Apparatus insulation as demonstrated by

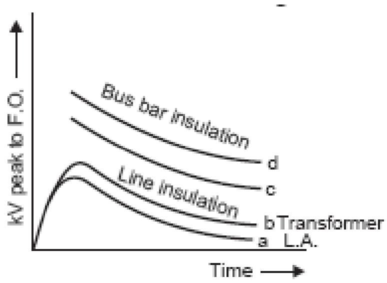
- ✓ Suitable tests shall be equal to or greater than the basic insulation level.

The problem of insulation coordination can be studied under three steps:

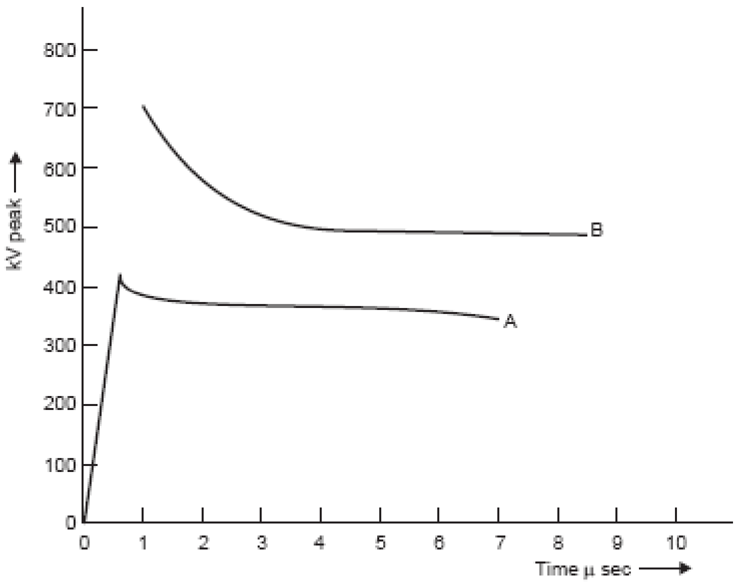
- ✓ Selection of a suitable insulation which is a function of reference class voltage (i.e., 1.05 × operating voltage of the system).
- ✓ The design of the various equipments such that the breakdown or flashover strength of all insulation in the station equals or exceeds the selected level as in Selection of protective devices that will give the apparatus as good protection as can be justified economically.

- ✓ The third column of the table gives the reduced insulation levels which are used for selecting insulation levels of solidly grounded systems and for systems operating above 345 kV where switching surges are of more importance than the lightning surges.
- ✓ At 345 kV, the the ratio of switching voltage to operating voltage is reduced by using the switching resistances between the C.B. contacts. For 500 kV it is has been possible to obtain this ratio as 2.0 and for 765 kV it is 1.7. With further increase in operating voltages, it is hoped that the ratio could be brought to 1.5. So, for switching voltages

the reduced levels in third column are used *i.e.*, for 345 kV, the standard BIL is 1550 kV but if the equipment can withstand even 1425 kV or 1300 kV it will serve the purpose.



- The above Fig, gives the relative position of the volt-time curves of the various equipments in a substation for proper coordination.
- To illustrate the selection of the BIL of a transformer to be operated on a 138 kV system assume that the transformer is of large capacity and its star point is solidly grounded.
- The grounding is such that the line-to-ground voltage of the healthy phase during a ground fault on one of the phases is say 74% of the normal *L-L* voltage. Allowing for 5% overvoltage during operating conditions, the arrester rms operating voltage will be $1.05 \times 0.74 \times 138 = 107.2$ kV. The nearest standard rating is 109 kV. The characteristic of such a L.A. is shown in



- From the figure above the breakdown value of the arrester is 400 kV. Assuming a 15% margin plus 35 kV between the insulation levels of L.A. and the transformer, the insulation level of transformer should be at least equal
- to $400 + 0.15 \times 400 + 35 = 495$ kV. From Fig. 7.30 (or from the table the reduced level of transformer for 138 kV is 550 kV) the insulation level of transformer is 550 kV; therefore a lightning arrester of 109 kV rating can be applied
- It is to be noted that low voltage lines are not as highly insulated as higher voltage lines so that lightning surges coming into the station would normally be much less than in a higher voltage station because the high voltage surges will flashover the line insulation of low voltage line and not reach the station.
- The traditional approach to insulation coordination requires the evaluation of the highest overvoltages to which an equipment may be subjected during operation and

selection of standardized value of withstand impulse voltage with suitable safety margin.

- ✓ However, it is realized that overvoltages are a random phenomenon and it is uneconomical to design plant with such a high degree of safety that they sustain the infrequent ones.
- ✓ It is also known that insulation designed on this basis does not give 100% protection and insulation failure may occur even in well designed plants and, therefore, it is desired to limit the frequency of insulation failures to the most economical value taking into account equipment cost and service continuity. Insulation coordination, therefore, should be based on evaluation and limitation of the risk of failure than on the prior choice of a safety margin.

- ✓ The modern practice, therefore, is to make use of probabilistic concepts and statistical procedures especially for very high voltage equipments which might later on be extended to all cases where a close adjustment of insulation to system conditions proves economical. The statistical methods even though laborious are quite useful.

7. Discuss the various tests carried out in a surge arrester at high voltage laboratories.(May-2014)

To ensure safe operation and an appropriate lifetime of surge arresters, type and routine tests are to be performed. The most important standards covering type and routine testing of surge arresters.

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Type tests

Surge arrester type tests demonstrate the general ability of an arrester design to withstand the electrical, mechanical, thermal and environmental stresses which might occur within the lifetime of a surge arrester. These test are performed once on a certain number of samples and are to be repeated when significant changes of the arrester design are introduced. Apart from test on arrester units (e.g. short circuit test), certain tests on complete arresters (e.g. artificial pollution test) have to be performed.

Routine tests

Surge arrester routine tests are performed on every single arrester unit in order to ensure the correct manufacturing and assembly of the arrester. Thus, routine testing is an important part of the quality assurance system of every manufacturer of surge arresters. As per IEC 60099-4, th

- ❖ Insulation withstand test-- Demonstrates the ability of the arrester housing to withstand voltage stresses under dry and wet conditions
- ❖ Residual voltage test-- Demonstrates the protective level of the arrester.
- ❖ Long duration current impulse withstand test --Demonstrates the ability of the resistor elements to withstand dielectric and energy stresses without puncture or flashover
- ❖ Operating duty test-- Demonstrates the thermal stability of the arrester under defined conditions
- ❖ Short circuit test --Demonstrates the ability of the arrester to withstand short circuit currents without violent shattering of the housing. For polymer housed arresters this test also demonstrates the ability self-extuingish any fire caused by the arc
- ❖ Test of arrester disconnections'-- Usually not applicable for surge arresters for SC banks and HVDC stations, since disconnectors are virtually not used
- ❖ Artificial pollution test for porcelain housed multi unit arresters-- Evaluation of the temperature rise of the internal parts due to a non-linear and transient voltage grading caused by the pollution layer on the surface of the arrester housing Usually only applicable for "A" and "D" arresters of HVDC stations, generally not for SC arresters
- ❖ Internal partial discharge test-- Measures the internal partial discharge rate
- ❖ Seal leak rate test-- Demonstrates the gas and water tightness of the complete system.

- Current distribution test-- for multi column arrester Determination of the current through each column of parallel resistors
- Bending moment test-- Demonstrates the ability of the arrester to withstand the values for bending loads claimed by the manufacturer
- Environmental tests-- Demonstrates that the sealing mechanism and the metal parts of the arrester are not impaired by environmental

8. EXPLAIN THE TYPES OF BUSHING.

I. Types of Bushings

High-voltage bushings for use on transformers and breakers are made in several principal types, as follows:

A. **Composite Bushing**.- A bushing in which insulation consists of two or more coaxial layers of different insulating materials.

B. **Compound-Filled Bushing**.- A bushing in which the space between the major insulation (or conductor where no major insulation is used) and the inside surface of a protective weather casing (usually porcelain) is filled with a compound having insulating properties.

C. **Condenser Bushing.-** A bushing in which cylindrical conducting layers are arranged coaxially with the conductor within the insulating material. The length and diameter of the cylinders are designed to control the distribution of the electric field in and over the outer surface of the bushing. Condenser bushings may be one of several types:

1. Resin-bonded paper insulation;
2. Oil-impregnated paper insulation; or
3. Other.

D. Dry or Unfilled Type Bushing.- Consists of porcelain tube with no filler in the space between the shell and conductor. These are usually rated 25 kV and below.

E. Oil-Filled Bushing.- A bushing in which the space between the major insulation (or the conductor where no major insulation is used) and the inside surface of a protective weather casing (usually porcelain) is filled with insulating oil.

F. Oil Immersed Bushing.- A bushing composed of a system of major insulations totally immersed in a bath of insulating oil.

G. Oil-Impregnated PaperInsulated Bushing.- A bushing in which the internal structure is made of cellulose material impregnated with oil.

H. Resin-Bonded, PaperInsulated Bushing.- A bushing in which the major insulation is provided by cellulose material bonded with resin.

I. Solid (Ceramic) Bushing.- A bushing in which the major insulation Is provided by a ceramic or analogous material.

9.WITH NEAT DIAGRAM EXPLAIN THE VARIOUS HV TESTING'S CARRIED OUT ON BUSHINGS. APRIL/MAY-2015,18

POWER FREQUENCY TESTS

(a) ***Power Factor—Voltage Test***: In this test, the bushing is set up as in service or immersed in oil. It is connected such that the line conductor goes to the high voltage side and the tank or earth portion goes to the detector side of the high voltage Schcringbridge. Voltage is applied up to the line value in increasing steps and then reduced. The capacitance and power factor (or tan 5) are recorded at each step. The

characteristic of power factor or tan 8 versus applied voltage is drawn. This is a normal routine test but sometimes may be conducted on percentage basis.

(b) ***Internal or Partial Discharge Test***: This test is intended to find the deterioration or failure due to internal discharges caused in the composite insulation of the bushing. This is done by using internal or partial discharge arrangement. The voltage versus discharge magnitude as well as the quadratic rate gives an excellent record of the performance of the bushing in service. This is now a routine test for high voltage bushings.

(c) ***Momentary Withstand Test at Power Frequency:***This is done as per the Indian Standard Specifications, IS: 2099, applied to bushings. The test voltage is specified in the specifications. The bushing has to withstand without flashover or puncture for a minimum time (~ 3Os) to measure the voltage. At present this test is replaced by the impulse withstand test.

(d) ***One Minute Wet Withstand Test at Power Frequency***: The most common and routine tests used for all electrical apparatuses are the one minute wet, and dry voltage withstand tests. In wet test, voltage specified is applied to the bushing mounted as in service with the rain arrangement as described earlier. A properly designed bushing has to withstand the voltage without flashover for one minute. This test really does not give any information for its satisfactory performance in service, while impulse and partial discharge tests give more information.

(e) ***Visible Discharge Test at Power Frequency***This test is intended for determining whether the bushing is likely to give radio interference in service, when the voltage specified in IS: 2099 is applied. No discharge other than that from the arcing horns or grading rings should be visible to the observers in a dark room. The test arrangement is the same as that of the withstand test, but the test is conducted in a dark room.

IMPULSE VOLTAGE TESTS

(a) ***Full Wave Withstand Test:***The bushing is tested for either polarity voltages as per the specifications. Five consecutive full waves of standard waveform are applied, and, if two of them cause flashover, the bushing is said to have failed in the test. If only one flashover occurs, ten additional applications are done. The bushing is considered to have passed the test if no flashover occurs in subsequent applications.

(b) ***Chopped Wave Withstand and Switching Surge Tests***The chopped wave lest is sometimes done for high voltage bushings (220 kV and 400 kV and above). Switching surge flashover test of specified value is now-a-days included for high voltage bushings. The tests are carried out similar to full wave withstand tests.

THERMAL TESTS

(a) ***Temperature Rise and Thermal Stability Tests:***The purpose of these tests is to ensure that the bushing in service for long does not have an excessive temperature rise and also does not go into the "thermal runaway" condition of the insulation used.Temperature rise test is carried out in free air with an ambient temperature below 4O^{0}C at a rated power frequency (50 Hz) a.c. current. The steady temperature rise above the ambient air temperature at any part of the bushing should not exceed 45^{0}C.

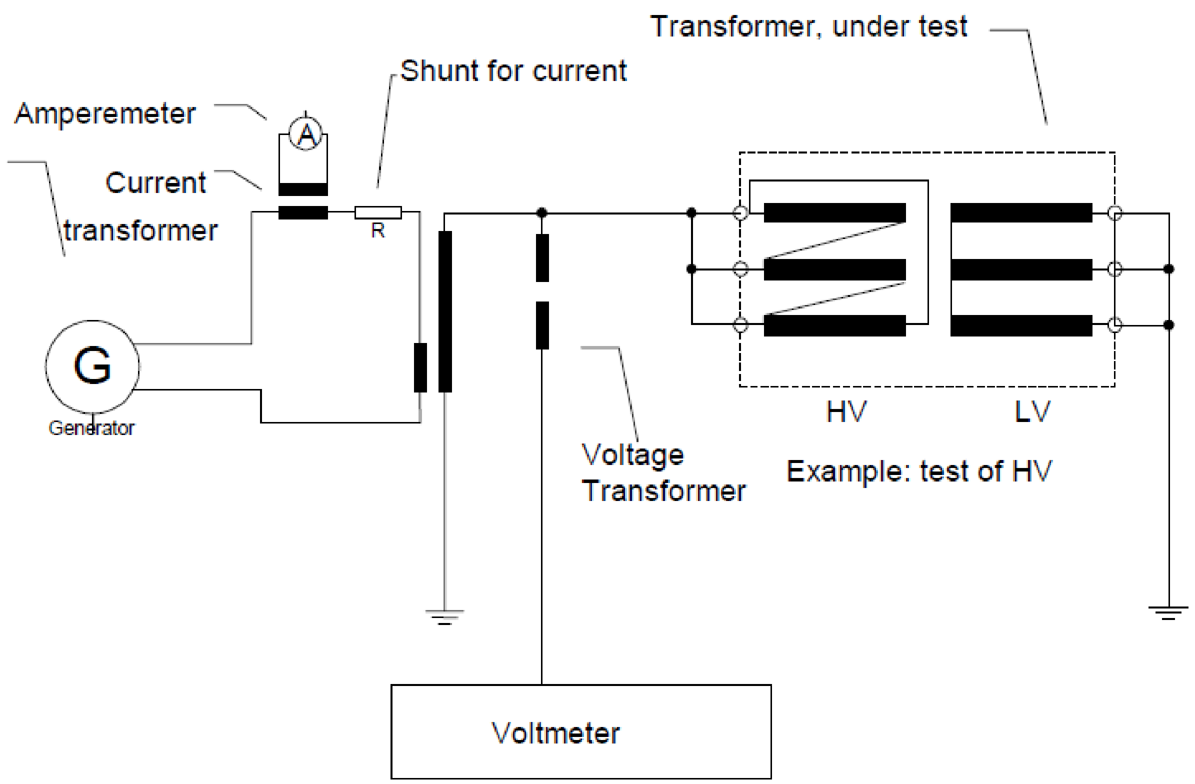
The test is carried out for such a long time till the temperature is substantially constant, i.e. the increase in temperature rate is less than l°C/hr. Sometimes, the bushings have to be operated along with transformers, of which the temperature reached may exceed 8O^{0}C. This temperature is high enough to produce large dielectric losses and thermal instability. For high voltage bushings this is particularly important, and hence the thermal stability test is done for bushings rated for 132 kV and above. The test is carried out with the bushing immersed in oil at a maximum temperature as in service, and the voltage applied is 86% of the nominal system voltage. This is approximately *12* times the working voltage of the bushing and hence the dielectric losses are about double the normal value. The additional losses account for the conductor ohmic losses. It has been considered unnecessary to specify the thermal stability test for oil-impregnated paper bushings of low ratings; but for the large high voltage bushings (1600 A, 400 kV transformer bushings, etc.), the losses in the conductor may be high enough to outweigh the dielectric losses. It may be pointed out here, that the thermal stability tests are type tests. But in the case of large sized high voltage bushings, it may be necessary to make them routine tests.

10.EXPLAIN IN SEQUENCE THE VARIOUS HIGH VOLTAGE TESTE BEING CARRIED OUT IN A POWER TRANSFORMER.APRIL/MAY-2015,Dec-16.

1) DIELECTRIC TESTS – SEPARATE-SOURCE VOLTAGE WITHSTAND TEST

The single-phase applied voltage wave shape shall be approximately sinusoidal. The test must be performed at rated frequency. At the end of the test, the test voltage shall be rapidly reduced up to 1/3 the full voltage before disconnection. The full test voltage shall be applied for 60 seconds between the winding under test and all the remaining windings, magnetic core, frame and enclosure connected to earth. The test shall be performed on all the windings.The test is Successful if no failure occurs at full test voltage.

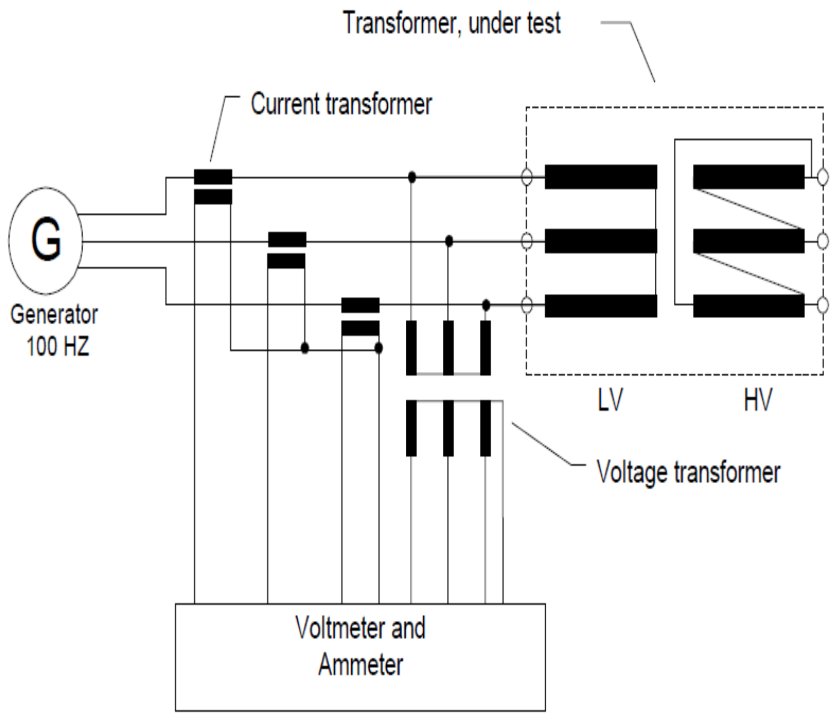
CONNECTION SCHEME:



2) *INDUCED VOLTAGE TEST*

The test voltage shall be twice the value corresponding to the rated voltage; it shall be applied between the terminals of the secondary windings, by maintaining the primary winding open. The duration of the test at full voltage shall be 60 s, and the frequency twice the rated value. The test shall start with a voltage lower than 1/3 the full test voltage, and it shall be quickly increased up to full value. At the end of the test, the voltage shall be rapidly reduced up to 1/3 the rated value before disconnection. The test is successful if no failure occurs at full test voltage.

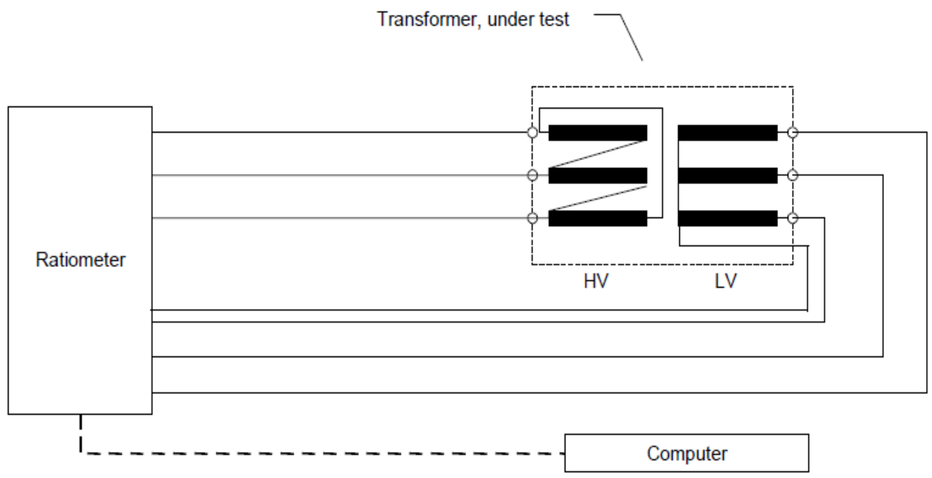
CONNECTION SCHEME:



3) *VOLTAGE RATIO MEASUREMENT AND CHECK OF POLARITIES AND CONNECTIONS*

Voltage ratio measurement and check of polarities and connections shall be performed on all tapchanger positions; the correspondence between the numbers assigned to the tappings and the ratings shall also be checked. Voltage ratio measurement shall be performed phase by phase between the terminals of corresponding windings. Voltage ratio measurement is carried out by use of potentiometric method.

CONNECTION SCHEME:

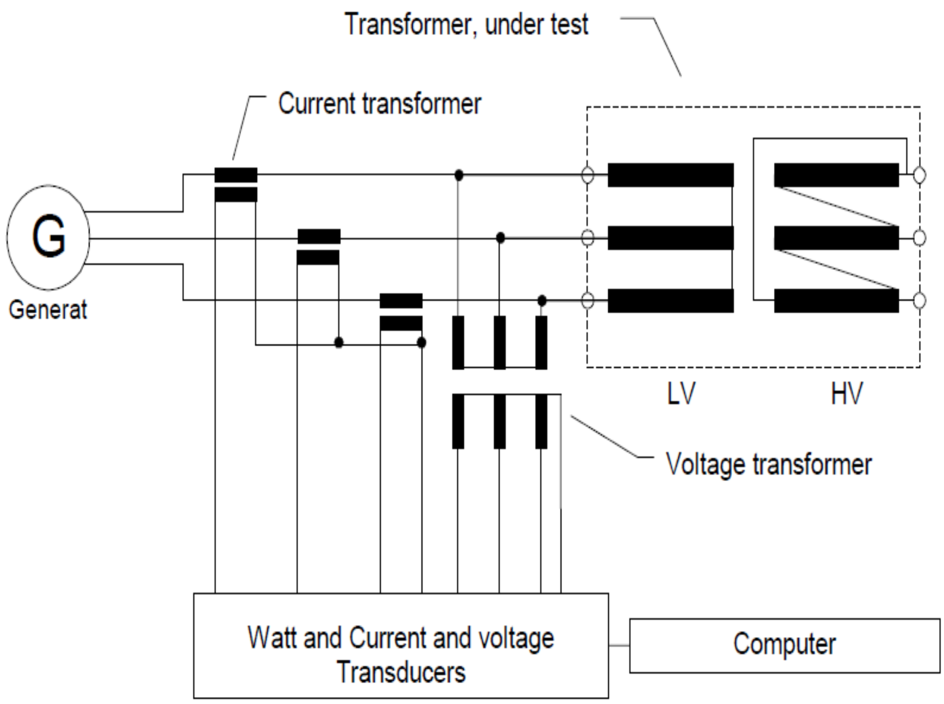


4) *NO-LOAD CURRENT AND NO-LOAD LOSS MEASUREMENT*

This test is performed by supplying LV windings at rated frequency and rated voltage. The wave shape shall be as nearly as possible of the sine-wave and the primary windings shall be open.

The frequency of the test shall not differ from the rated value more than ± 1%. No-load current and loss shall be measured as well as the mean value and the effective value of the voltage. If these two readings are equal, no correction shall be applied on the measurement of no-load loss; otherwise, no-load loss shall be referred to sine-wave condition in accordance with IEC Standards 60076-1. No-load current shall result as the average value of three readings performed by effective value ammeters. Three wattmeters shall be used to measure the power, by using instrument transformers and transducers when necessary.

CONNECTION SCHEME:



5) *WINDING RESISTANCE MEASUREMENT*

Winding resistance measurement shall be performed when the windings are at ambient temperature without supply for a time long enough to achieve this condition. The measurements shall be carried out in direct current between terminals according to the sequence U-V; V-W; WU.Ambient temperature shall also be measured. It shall result as the average value of three measurements performed by apposite thermal sensors.

HV winding resistance measurement

HV winding resistance measurement shall be performed by measuring simultaneously voltage and current. The voltmeter and ammeter must be connected as follows :

• voltmeter terminals must be connected beyond current cables;
• the current shall not exceed 10% of winding rated current;
• the measurement shall be carried out after voltage and current are stable.

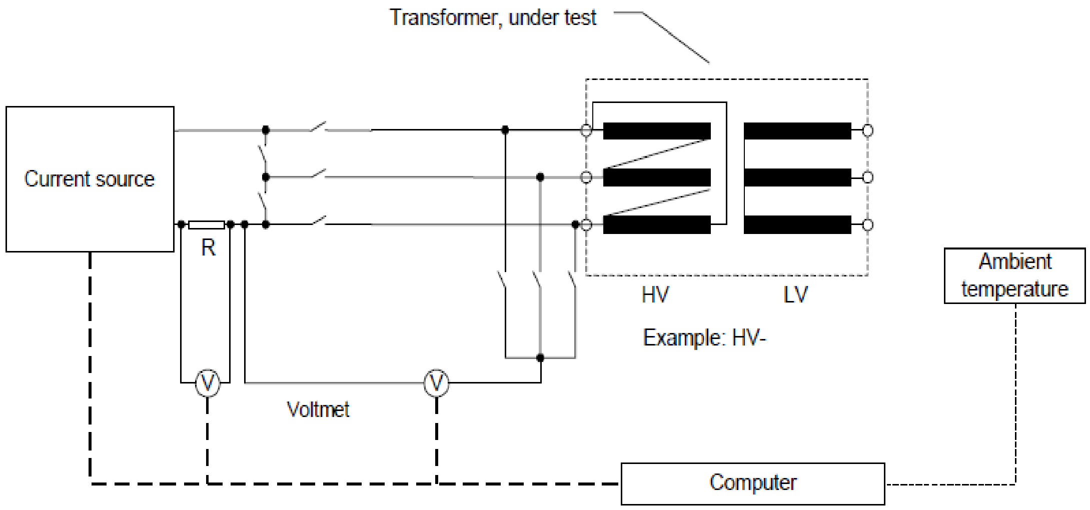
Unless otherwise agreed, the HV winding shall be connected on principal tapping.

LV winding resistance measurement

LV winding resistance measurement shall be performed by measuring simultaneously voltage and current. The voltmeter and ammeter shall be connected as follows :

• voltmeter terminals shall be connected beyond current cables;
• the current shall not exceed 5% of winding rated current;
• the measurement shall be carried out after voltage and current are stable.

CONNECTION SCHEME:

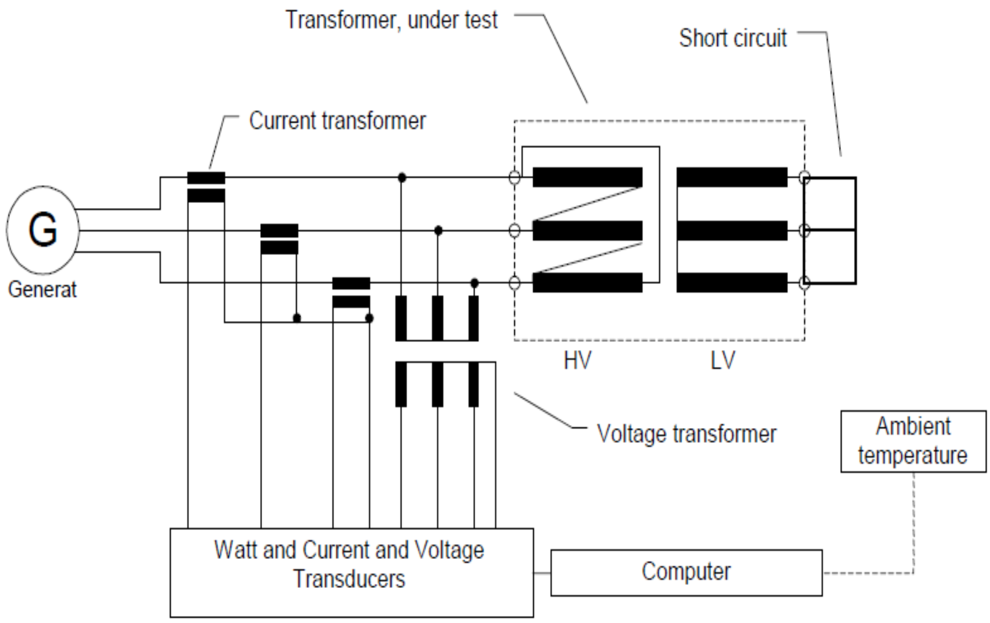


6) SHORT-CIRCUIT IMPEDANCE AND LOAD LOSS MEASUREMENT

Short-circuit impedance and load loss measurement shall be performed at rated frequency, by applying on the transformer primary windings (connected on principal tapping) a three –phase sine-wave voltage system. The secondary windings shall be short-circuited. Applied voltage, current and load loss shall be measured.

The frequency of the test shall not differ from the rated frequency more than ± 1%. In case the rated power is higher than 1000 kVA, load loss shall be measured by using three wattmeters, in order to reduce measurement uncertainties. When necessary, instrument transformers and transducers shall be used. The measured values shall be referred to rated current and then calculated at reference temperature. This temperature is the annual average ambient temperature (20°C) increased by the permissible temperature rise in accordance with the temperature class of the windings. IEC 60726 specify the permissible temperature rises on table no. 4. Beside, IEC 60076-1 give a complete explanation of how to perform the carries at rated current and at reference temperature.

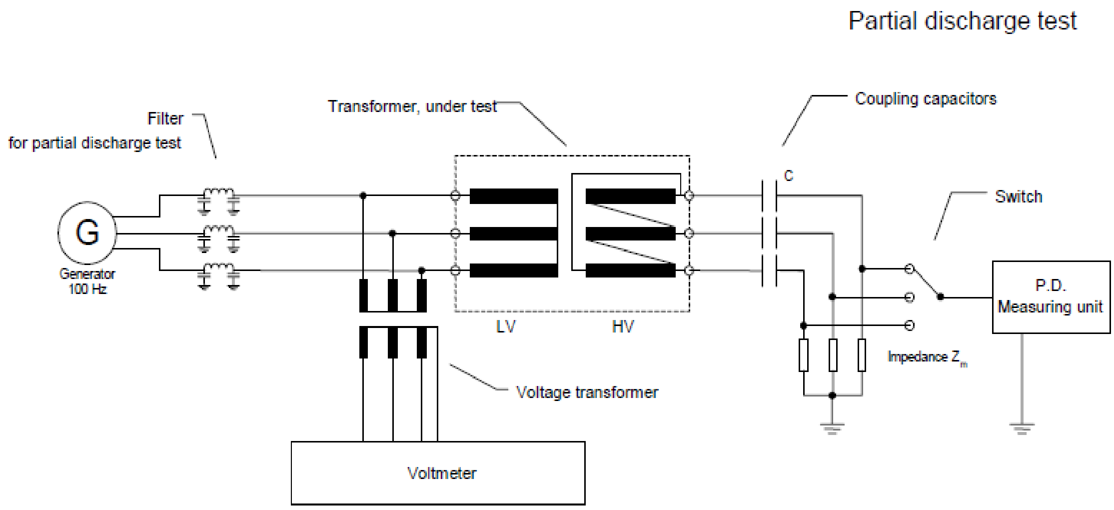
CONNECTION SCHEME:



7) *PARTIAL DISCHARGE MEASUREMENT*

A basic measuring circuit for partial discharge test is shown in figure 2 , IEC Standards 60726. The low-voltage windings shall be supplied from an alternate 100 Hz voltage source. The voltage shape shall be as nearly as possible of the sine-wave. Unless otherwise specified, a pre-stress voltage of 1,5 Um shall be induced for 30 s, followed without interruption by a voltage of 1,1 Um for three minutes, during which the partial discharge level shall be measured. The calibration of the measuring circuit is carried out by injecting simulated discharge pulses of 100pC at transformer terminals. Partial discharge measurement shall be carried out by use of an oscilloscope, in order to analise the developing of the ongoing phenomena. Test procedures must be in accordance with IEC Standards 60726. The test is successful if the partial discharge level is lower than 20 pC unless otherwise agreed between manufacturer and purchaser.

CONNECTION SCHEME:



UNIVERSITY QUESTIONS

PART-A

1. Distinguish between flashover and puncture**.(May-2014,NOV/DEC-2015)**
2. Define creepage distance.**(Dec-14)**
3. What are the tests conducted on insulators?(NOV-DEC 2009,MAY-2013,DEC-2013)
4. Differntiate type test and routine test.**(MAY/JUNE 2012,MAY-2013,DEC-2013)**
5. How is impulse withstand voltage test carries?(April-2005,May-14)
6. . What is insulation coordination**?(Dec-2008,May-2008,Dec-14)**

7.Why is insulation coordination needed**?(MAY/JUNE 2012)**

8.What are called Type Tests? APRIL/MAY-2015

9.What is BIL? APRIL/MAY-2015

10.What are called Type Tests? APRIL/MAY-2015

11.What is BIL? APRIL/MAY-2015

12.Define safety margin as applied to insulation coordination.(NOV 2015)

13.Define 50% flashover voltage.Dec-16

14.What are the tests conducted on transformers?(MAY/JUNE 2009,Dec-16)

PART-B

1.What are the different tests conducted on insulator? Explain any one of them**. (MAY/JUNE-2009,DEC-2013)**

2. What are the different tests conducted on cable? Explain any one of them. **(May/June-2012,DEC-2013)**

3. What are the test conducted on circuit breaker and isolator? Explain any one method for each**.(may/june-2012,DEC-16)**

4. Explain the method of impulse testing of high voltage transformer. What is the procedure adopted for locating the failure**?(apr/may-2011,NOV/DEC-15)**

5. Explain the power frequency voltage test withstand test on a 66kv insulator**.(nov/dec-2007apr,may-2008)**

6. Explain different aspects of insulation design and insulation co-ordination adopted for EHV systems**.(APR/MAY-2011,NOV/DEC-2015)**

7. What are the test conducted on circuit breaker and isolator? Explain any one method for each**.(may/june-2012,Dec-14)**

8. Explain the method of impulse testing of high voltage transformer. What is the procedure adopted for locating the failure?**(may-2011,Dec-14)**

9. What are volt-time curves? Explain the procedure for constructing volt-time curves with neat sketch. Give its significance in power system studies. **(May-2014)**

10. Discuss the various tests carried out in a surge arrester at high voltage laboratories**.(May-2014)**

11.With neat diagram explain the various hv testing's carried out on bushings. April/may-2015

12.Explain in sequence the various high voltage teste being carried out in a power transformer.april/may-2015,DEC-16

13.what are the different tests conducted on insulator? Explain any one of them. (may/june-2009, may/june -2013,2015,dec-2013)

14.detection and location of fault during impulse testing(nov-2015)

Reg. No. :

Question Paper Code : 51445

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2014.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 – HIGH VOLTAGE ENGINEERING

(Regulation 2008/2010)

(Common to PTEE 2353- High Voltage Engineering for B.E. (Part-Time) Fifth Semester-Electrical and Electronics Engineering-Regulation 2009)

Time : Three hours — Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Draw the mathematical model for lightning discharges.
2. Classify the lightning strokes.
3. What are the factors which affect breakdown of gaseous dielectrics?
4. What is meant by Penning Effect?
5. What are the advantages of series resonant circuit?
6. Mention the necessity of generating high dc voltage.
7. Give the procedure for dc and ac peak voltage measurement using sphere gap.
8. What are different types of resistive shunts used for impulse current measurements?
9. How is impulse voltage withstand test conducted?
10. Distinguish between flash over and puncture.

PART B — (5 × 16 = 80 marks)

11. (a) (i) Discuss the step by step procedure for constructing Bewley's Lattice Diagram with an example. (8)

(ii) Explain how are switching and power frequency over voltages controlled in power system. (8)

Or

(b) (i) Draw the cross-sectional view of a valve type lightning arrester and explain its operation with V-I characteristics . (8)

(ii) What are the requirements of a ground wire for protecting power conductors against direct lightning stroke? Explain how they are achieved in practice. (8)

12. (a) (i) Discuss the streamer theory of breakdown in gases. (8)

(ii) Explain the various mechanism of vacuum breakdown. (8)

Or

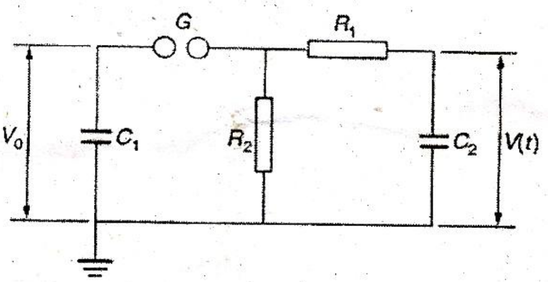
(b) Explain thermal breakdown mechanism in solid dielectrics. Derive an expression for critical thermal breakdown voltage (V_c) and critical electric field (E_c) for the same . State clearly the assumptions made. (16)

13. (a) (i) Explain the working of Cockroft-Walton voltage multiplier circuit under unloaded and loaded conditions. (8)

(ii) Derive an expression for total voltage drop and total ripple voltage of n-stage voltage multiplier circuit and hence deduce the condition for optimum number of stages. (8)

Or

(b) Give complete analysis of the given impulse circuit and derive the condition for physical realization of wavefront and wave tail resistances. (16)



14. (a) Describe the construction, principle of operation of a generating voltmeter and give its application and limitations. (16)

Or

(b) Discuss and compare the performance of resistance capacitance and mixed R- C potential dividers for measurement of impulse voltages. (16)

15. (a) (i) What are volt-time curves? Explain the procedure for constructing volt-time curves with neat sketch. Give its significance in power system studies. (10)

(ii) Explain the modern trends in the insulation design of EHV and UHV substations. (6)

Or

(b) Discuss the various tests carried out in a surge arrester at high voltage laboratories. (16)

Reg. No. :

Question Paper Code : 31405

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2013.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 — HIGH VOLTAGE ENGINEERING

(Regulation 2008/2010)

(Common to PTEE 2353 – High Voltage Engineering for B.E. (Part-Time) Fifth Semester – Electrical and Electronics Engineering – Regulation 2009)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. State the sources which determine the wave shape of switching surges.

2. Write down the causes of power frequency and its harmonic over voltages.

3. What are the properties required for a gaseous dielectric for HV applications?

4. What are commercial liquid dielectrics and how are they different from pure liquid dielectrics?

5. Define the front and tail times of an impulse wave.

6. What are the disadvantages of half wave rectifier circuit?

7. What is the effect of dust particles on the measurement using sphere gaps?

8. List out the limitations of generating voltmeters.

9. Define disruptive discharge voltage.

10. Mention the characteristics of the spray used in wet flashover test.

PART B — (5 × 16 = 80 marks)

11. (a) (i) What are the mechanisms by which lightning strokes develop and induce over voltages on over head power lines? (8)

(ii) Write short notes on ground rods as protective devices. (8)

Or

(b) What are the causes for switching and power frequency over voltages? How are they controlled in power systems?

12. (a) (i) Describe the various mechanisms of vacuum break down. (8)

(ii) What are treeing and trenching? Explain clearly the two processes in solid dielectrics. (8)

Or

(b) (i) Explain the various theories that explain break down in commercial liquid dielectrics. (8)

(ii) What is corona discharge? Explain clearly anode and cathode coronas. (8)

13. (a) Explain with neat sketches cockroft-walton voltage multiplier circuit. Explain clearly its operation when the circuit is

(i) unloaded and

(ii) loaded.

Or

(b) (i) Explain one method of controlled tripping of impulse generators. Why is controlled tripping necessary? (8)

(ii) What is a cascaded transformer? Explain why cascading is done? Describe with neat diagram, a 3 stage cascaded transformer. (8)

14. (a) (i) Discuss various methods of measuring high impulse currents. (8)

(ii) Describe the construction of uniform field spark gap and discuss its advantages and disadvantages for high voltage measurements. (8)

Or

(b) (i) What are the requirements of a sphere gap for measurement of high voltages? Discuss the disadvantages of sphere gap for measurements. (8)

(ii) Draw a simplified equivalent circuit of resistance potential divider and discuss its step response. (8)

15. (a) Describe the various tests to he carried out on a circuit breaker.

Or

(b) (i) Discuss the different aspects of insulation design and insulation co-ordination adopted for EHV systems. (8)

(ii) Explain the function of discharge device used in power capacitor and explain the test for efficacy of this device. (8)

Question Paper Code : 21405

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2013.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 – HIGH VOLTAGE ENGINEERING

(Regulation 2008/2010)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Mention the different kinds of over voltages.
2. What is stepped leader stroke?
3. What is meant by corona discharges?
4. What are electronegative gases?
5. Mention the specifications of the standard impulse voltage.
6. Give any two methods of switching surge generation in laboratory.
7. Define CVT.
8. Give the advantages of electrostatic voltmeter.
9. What are the different tests conducted on insulators?
10. What are type and routine tests?

PART B — (5 × 16 = 80 marks)

11. (a) (i) Explain the mechanism of lighting strokes. (10)

(ii) Give the mathematical models for lightning discharges and explain them. (6)

Or

(b) (i) Explain causes of power frequency over voltages in power system.(8)

(ii) Give a brief note on protection of transmission lines using protection devices. (8)

12. (a) State the criteria for sparking potential and hence obtain the relation between sparking potential and (pd) values (Paschen's Law). Discuss on the nature of variations of sparking potential with (pd) values. (16)

Or

(b) Explain the breakdown mechanism involved in commercial liquid dielectrics. (16)

13. (a) (i) Explain the operation of basic impulse generator. (8)

(ii) Explain the cascaded transformer method of HVAC generation. (8)

Or

(b) Explain the operation of vande graff generator from the electrostatic principle. (16)

14. (a) (i) Explain the operation of the hall effect generator for measuring high DC currents. (8)

(ii) Discuss the factors influencing the spark over voltage on Sphere gaps. (8)

Or

(b) Tabulate the various methods of High AC and DC voltage and current measurements. (16)

15. (a) Explain the various tests conducted in high voltage insulators. (16)

Or

(b) Explain the tests conducted on high voltage cables. (16)

Reg. No. :

Question Paper Code : 71511

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2015.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 — HIGH VOLTAGE ENGINEERING

(Regulation 2008/2010)

(Common to PTEE 2353/10133 EE 603 – High Voltage Engineering for B.E. (Part-Time) Fifth Semester – Electrical and Electronics Engineering – Regulation 2009/2010)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What are various abnormalities in a High Voltage system?

2. What are the characteristics of a lightning voltage?

3. What is Town-sends condition for Breakdown?

4. Define statistical time lag and formative time lag.

5. What are differences between a high voltage testing transformer and a power transformer?

6. What do you mean by tracking index?

7. What is the principle behind the operation of generating voltmeter?

8. Calculate the correction factors for atmospheric conditions, if the laboratory temperature is 37°C, the atmospheric pressure is 750 mmHg and the wet bulb temperature is 27°C.

9. What are called type tests?

10. What is BIL?

PART B — (5 × 16 = 80 marks)

11. (a) (i) Briefly describe a method of recording the occurrence of lightning in an overhead transmission line. (8)

(ii) Explain why a steep fronted surge waveform are more vulnerable to insulation. (8)

Or

(b) Briefly explain, with the aid of suitable diagrams, the statistical method of insulation co ordination.

12. (a) A certain dielectric can be considered to be represented by the equivalent circuit shown in figure 1. What is the maximum voltage that can be applied across the dielectric, if partial discharges in air to be avoided? State any assumptions made.

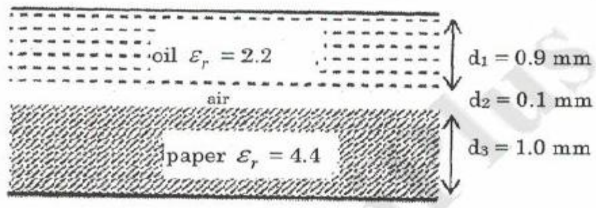


Figure. 1

Or

(b) From the fundamental principles, derive Townsend's criteria for the breakdown of gaseous dielectric medium.

13. (a) A Cockcroft – Walton type voltage multiplier has eight stages with capacitances equal to 0.05 μF. The supply transformer secondary voltage is 125 kV at a frequency of 150 Hz. If the load current to be supplied is 5 mA, find (i) the percentage ripple (ii) the regulation and (iii) the optimum number of stages for minimum regulation of voltage drop.

Or

(b) A six-stage impulse generator designed to generate the standard waveform (1.2/50 μs) has a per stage capacitance of 0.06 μF to be used to test transformers with an equivalent winding to earth capacitance of 1 nF. A peak output voltage of 550 kV is required for testing the transformer. The wavefront time is to be defined based on 30% and 90% values. With the aid of appropriate calculations select the values of the resistive elements in the circuit to produce the required waveform. State any assumptions made.

14. (a) Explain in detail the various techniques for the measurement of High DC voltages.

Or

(b) With neat sketch explain in detail the various methods used to measure the RMS and peak values of High AC voltages.

15. (a) With neat diagram explain the various HV testing's carried out on Insulators and Bushings.

Or

(b) Explain in sequence the various high voltage tests being carried out in a Power Transformer.

Reg. No. :

Question Paper Code : 21511

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2015.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 — HIGH VOLTAGE ENGINEERING

(Regulations 2008/2010)

(Common to PTEE 2353/10133 EE 603 – High Voltage Engineering for B.E. (Part–Time) Fifth Semester – Electrical and Electronics Engineering – Regulations 2009/2010)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. What are the factors that influence the lightning induced voltage on transmission line?

2. Why a simple spark gap cannot offer full protection against over voltages?

3. Name the various secondary ionization processes involved in gaseous dielectric breakdown.

4. What are electronegative gases? Give its significance.

5. How is the circuit inductance controlled and minimized in impulse current generator?

6. Mention the specification of impulse current as per Indian Standards.

7. What are the drawbacks of series resistance micro-ammeter technique in HVAC measurements?

8. How the stray effect of capacitance potential divider is minimized for impulse measurements?

9. Distinguish between flash over and puncture.

10. Define safety margin as applied to insulation co-ordination.

PART B — ($5 \times 16 = 80$ marks)

11. (a) (i) What are the sources of switching surges? Explain the characteristics of switching surges with typical wave shapes. (10)

(ii) Discuss the various controlling methods of over voltages due to switching and power frequency. (6)

Or

(b) (i) A long transmission line is energized by a unit step voltage of 1.0 V at the sending end and is open circuited at the receiving end. Construct the Bewley Lattice diagram and obtain the value of the voltage at the receiving end after a long time. Take the attenuation factor $\alpha = 0.8$. (10)

(ii) Write a short note on ground rods as protective devices. (6)

12. (a) (i) Discuss the important properties of composite dielectrics. (6)

(ii) Discuss the various mechanism of breakdown in composite dielectrics. (10)

Or

(b) State why the very high intrinsic strength of a solid dielectrics is not fully realized in practice? Explain the different mechanisms by which breakdown occurs in solid dielectrics in practice. (16)

13. (a) (i) Explain the Marx circuit arrangement for multistage generator. How is the basic arrangements modified to accommodate the wave time control resistances? (10)

(ii) How are the wave front and wave tail time controlled in impulse generator circuit? (6)

Or

(b) (i) With a neat sketch, describe the construction and working of a Van de Graaff generator. (10)

(ii) Explain the functions and operation of a trigatron gap. (6)

14. (a) (i) Discuss the construction and vertical arrangement of sphere-gap. Explain the procedures for peak value measurement of high voltage DC, AC and impulse voltages using standard sphere gap. (10)

(ii) Explain the parameters and factors that influence the sphere-gap measurements. (6)

Or

2 21511

(b) (i) Give the schematic arrangement of an impulse potential divider with an oscilloscope connected for measuring impulse voltages. Explain the arrangement used to minimize errors. (10)

(ii) What are the requirements of a digital storage oscilloscope for impulse and high frequency measurements in HV test circuits? (6)

15. (a) (i) Discuss with a circuit arrangements, the detailed procedure for conducting impulse voltage testing of HV power transformer. (8)

(ii) Explain the procedure adopted for detection and location of fault during impulse voltage testing. (8)

Or

(b) Explain the different aspects of insulation design and insulation coordination adopted for EHV systems. (16)

Reg. No. :

Question Paper Code : 51445

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2014.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 – HIGH VOLTAGE ENGINEERING

(Regulation 2008/2010)

(Common to PTEE 2353- High Voltage Engineering for B.E. (Part-Time) Fifth Semester-Electrical and Electronics Engineering-Regulation 2009)

Time : Three hours | Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Draw the mathematical model for lightning discharges.
2. Classify the lightning strokes.
3. What are the factors which affect breakdown of gaseous dielectrics?
4. What is meant by Penning Effect?
5. What are the advantages of series resonant circuit?
6. Mention the necessity of generating high dc voltage.
7. Give the procedure for dc and ac peak voltage measurement using sphere gap.
8. What are different types of resistive shunts used for impulse current measurements?
9. How is impulse voltage withstand test conducted?
10. Distinguish between flash over and puncture.

PART B — (5 × 16 = 80 marks)

11. (a) (i) Discuss the step by step procedure for constructing Bewley's Lattice Diagram with an example. (8)

(ii) Explain how are switching and power frequency over voltages controlled in power system. (8)

Or

(b) (i) Draw the cross-sectional view of a valve type lightning arrester and explain its operation with V-I characteristics . (8)

(ii) What are the requirements of a ground wire for protecting power conductors against direct lightning stroke? Explain how they are achieved in practice. (8)

12. (a) (i) Discuss the streamer theory of breakdown in gases. (8)

(ii) Explain the various mechanism of vacuum breakdown. (8)

Or

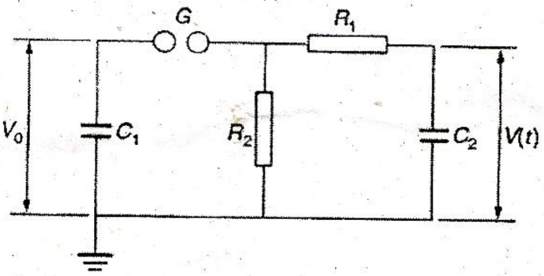
(b) Explain thermal breakdown mechanism in solid dielectrics. Derive an expression for critical thermal breakdown voltage (V_c) and critical electric field (E_c) for the same . State clearly the assumptions made. (16)

13. (a) (i) Explain the working of Cockroft-Walton voltage multiplier circuit under unloaded and loaded conditions. (8)

(ii) Derive an expression for total voltage drop and total ripple voltage of n-stage voltage multiplier circuit and hence deduce the condition for optimum number of stages. (8)

Or

(b) Give complete analysis of the given impulse circuit and derive the condition for physical realization of wavefront and wave tail resistances. (16)



14. (a) Describe the construction, principle of operation of a generating voltmeter and give its application and limitations. (16)

Or

(b) Discuss and compare the performance of resistance capacitance and mixed R- C potential dividers for measurement of impulse voltages. (16)

15. (a) (i) What are volt-time curves? Explain the procedure for constructing volt-time curves with neat sketch. Give its significance in power system studies. (10)

(ii) Explain the modern trends in the insulation design of EHV and UHV substations. (6)

Or

(b) Discuss the various tests carried out in a surge arrester at high voltage laboratories. (16)

Reg. No. :

Question Paper Code : 31405

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2013.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 — HIGH VOLTAGE ENGINEERING

(Regulation 2008/2010)

(Common to PTEE 2353 – High Voltage Engineering for B.E. (Part-Time) Fifth Semester – Electrical and Electronics Engineering – Regulation 2009)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. State the sources which determine the wave shape of switching surges.

2. Write down the causes of power frequency and its harmonic over voltages.

3. What are the properties required for a gaseous dielectric for HV applications?

4. What are commercial liquid dielectrics and how are they different from pure liquid dielectrics?

5. Define the front and tail times of an impulse wave.

6. What are the disadvantages of half wave rectifier circuit?

7. What is the effect of dust particles on the measurement using sphere gaps?

8. List out the limitations of generating voltmeters.

9. Define disruptive discharge voltage.

10. Mention the characteristics of the spray used in wet flashover test.

PART B — (5 × 16 = 80 marks)

11. (a) (i) What are the mechanisms by which lightning strokes develop and induce over voltages on over head power lines? (8)

(ii) Write short notes on ground rods as protective devices. (8)

Or

(b) What are the causes for switching and power frequency over voltages? How are they controlled in power systems?

12. (a) (i) Describe the various mechanisms of vacuum break down. (8)

(ii) What are treeing and trenching? Explain clearly the two processes in solid dielectrics. (8)

Or

(b) (i) Explain the various theories that explain break down in commercial liquid dielectrics. (8)

(ii) What is corona discharge? Explain clearly anode and cathode coronas. (8)

13. (a) Explain with neat sketches cockroft-walton voltage multiplier circuit. Explain clearly its operation when the circuit is

(i) unloaded and

(ii) loaded.

Or

(b) (i) Explain one method of controlled tripping of impulse generators. Why is controlled tripping necessary? (8)

(ii) What is a cascaded transformer? Explain why cascading is done? Describe with neat diagram, a 3 stage cascaded transformer. (8)

14. (a) (i) Discuss various methods of measuring high impulse currents. (8)

(ii) Describe the construction of uniform field spark gap and discuss its advantages and disadvantages for high voltage measurements. (8)

Or

(b) (i) What are the requirements of a sphere gap for measurement of high voltages? Discuss the disadvantages of sphere gap for measurements. (8)

(ii) Draw a simplified equivalent circuit of resistance potential divider and discuss its step response. (8)

15. (a) Describe the various tests to he carried out on a circuit breaker.

Or

(b) (i) Discuss the different aspects of insulation design and insulation co-ordination adopted for EHV systems. (8)

(ii) Explain the function of discharge device used in power capacitor and explain the test for efficacy of this device. (8)

Question Paper Code : 21405

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2013.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 – HIGH VOLTAGE ENGINEERING

(Regulation 2008/2010)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. Mention the different kinds of over voltages.
2. What is stepped leader stroke?
3. What is meant by corona discharges?
4. What are electronegative gases?
5. Mention the specifications of the standard impulse voltage.
6. Give any two methods of switching surge generation in laboratory.
7. Define CVT.
8. Give the advantages of electrostatic voltmeter.
9. What are the different tests conducted on insulators?
10. What are type and routine tests?

PART B — ($5 \times 16 = 80$ marks)

11. (a) (i) Explain the mechanism of lighting strokes. (10)

(ii) Give the mathematical models for lightning discharges and explain them. (6)

Or

(b) (i) Explain causes of power frequency over voltages in power system.(8)

(ii) Give a brief note on protection of transmission lines using protection devices. (8)

12. (a) State the criteria for sparking potential and hence obtain the relation between sparking potential and (pd) values (Paschen's Law). Discuss on the nature of variations of sparking potential with (pd) values. (16)

Or

(b) Explain the breakdown mechanism involved in commercial liquid dielectrics. (16)

13. (a) (i) Explain the operation of basic impulse generator. (8)

(ii) Explain the cascaded transformer method of HVAC generation. (8)

Or

(b) Explain the operation of vande graff generator from the electrostatic principle. (16)

14. (a) (i) Explain the operation of the hall effect generator for measuring high DC currents. (8)

(ii) Discuss the factors influencing the spark over voltage on Sphere gaps. (8)

Or

(b) Tabulate the various methods of High AC and DC voltage and current measurements. (16)

15. (a) Explain the various tests conducted in high voltage insulators. (16)

Or

(b) Explain the tests conducted on high voltage cables. (16)

Reg. No. :

Question Paper Code : 21511

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2015.

Sixth Semester

Electrical and Electronics Engineering

EE 2353/EE 63/10133 EE 603 — HIGH VOLTAGE ENGINEERING

(Regulations 2008/2010)

(Common to PTEE 2353/10133 EE 603 – High Voltage Engineering for B.E. (Part–Time) Fifth Semester – Electrical and Electronics Engineering – Regulations 2009/2010)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. What are the factors that influence the lightning induced voltage on transmission line?

2. Why a simple spark gap cannot offer full protection against over voltages?

3. Name the various secondary ionization processes involved in gaseous dielectric breakdown.

4. What are electronegative gases? Give its significance.

5. How is the circuit inductance controlled and minimized in impulse current generator?

6. Mention the specification of impulse current as per Indian Standards.

7. What are the drawbacks of series resistance micro-ammeter technique in HVAC measurements?

8. How the stray effect of capacitance potential divider is minimized for impulse measurements?

9. Distinguish between flash over and puncture.

10. Define safety margin as applied to insulation co-ordination.

PART B — ($5 \times 16 = 80$ marks)

11. (a) (i) What are the sources of switching surges? Explain the characteristics of switching surges with typical wave shapes. (10)

(ii) Discuss the various controlling methods of over voltages due to switching and power frequency. (6)

Or

(b) (i) A long transmission line is energized by a unit step voltage of 1.0 V at the sending end and is open circuited at the receiving end. Construct the Bewley Lattice diagram and obtain the value of the voltage at the receiving end after a long time. Take the attenuation factor $\alpha = 0.8$. (10)

(ii) Write a short note on ground rods as protective devices. (6)

12. (a) (i) Discuss the important properties of composite dielectrics. (6)

(ii) Discuss the various mechanism of breakdown in composite dielectrics. (10)

Or

(b) State why the very high intrinsic strength of a solid dielectrics is not fully realized in practice? Explain the different mechanisms by which breakdown occurs in solid dielectrics in practice. (16)

13. (a) (i) Explain the Marx circuit arrangement for multistage generator. How is the basic arrangements modified to accommodate the wave time control resistances? (10)

(ii) How are the wave front and wave tail time controlled in impulse generator circuit? (6)

Or

(b) (i) With a neat sketch, describe the construction and working of a Van de Graaff generator. (10)

(ii) Explain the functions and operation of a trigatron gap. (6)

14. (a) (i) Discuss the construction and vertical arrangement of sphere-gap. Explain the procedures for peak value measurement of high voltage DC, AC and impulse voltages using standard sphere gap. (10)

(ii) Explain the parameters and factors that influence the sphere-gap measurements. (6)

Or

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(b) (i) Give the schematic arrangement of an impulse potential divider with an oscilloscope connected for measuring impulse voltages. Explain the arrangement used to minimize errors. (10)

(ii) What are the requirements of a digital storage oscilloscope for impulse and high frequency measurements in HV test circuits? (6)

15. (a) (i) Discuss with a circuit arrangements, the detailed procedure for conducting impulse voltage testing of HV power transformer. (8)

(ii) Explain the procedure adopted for detection and location of fault during impulse voltage testing. (8)

Or

(b) Explain the different aspects of insulation design and insulation coordination adopted for EHV systems. (16)

Reg. No. :

Question Paper Code : 80385

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2016.

Seventh Semester

Electrical and Electronics Engineering

EE 6701 — HIGH VOLTAGE ENGINEERING

(Regulations 2013)

Time : Three hours

Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What is back flashover?
2. Define Isokeraunic level or thunderstorm days.
3. What is ionization by collision?
4. Define Gas law.
5. What is a tesla coil?
6. What is Deltatron circuit?
7. What are the advantages of generating voltmeters?
8. List some advantages of Faraday generator.
9. Define 50% flash over voltage.
10. What are the tests need to be conducted on power transformer?

PART B — (5 × 16 = 80 marks)

11. (a) (i) Explain the mechanism of lightning stroke. (10)

(ii) Give the mathematical model for lightning discharges and explain them. (6)

Or

(b) Explain the different methods employed for lightning protection of overhead lines. (16)

12. (a) From the fundamental principles, derive Townsend's criteria for the breakdown of gaseous dielectric medium. (16)

Or

(b) Explain the various breakdown theories involved in commercial liquid dielectrics. (16)

13. (a) (i) Mention the necessity of generating high DC voltages. (4)

(ii) Explain with a neat diagram the generation of high DC voltages using Van-de-graff generator. State the factors which limit the voltage developed. (12)

Or

(b) Explain the working principle of Cockroft-Walton voltage multiplier circuit. Derive an expression for total voltage drop and total ripple voltage of n-stage voltage multiplier circuit and hence deduce the condition for optimum number of stages. (16)

14. (a) (i) Enumerate digital peak voltmeter. (8)

(ii) What is CVT? Explain how CVT can be used for high voltage AC measurement. (8)

Or

(b) Explain how a sphere gap can be used to measure the peak value of voltages? Also discuss the parameters and factors that influence such voltage measurement? (16)

15. (a) Discuss the various tests carried out in a circuit breaker at HV labs. (16)

Or

(b) Explain in sequence the various high voltage test being carried out in a power transformer. (16)

Reg. No. : 4 2 1 6 1 3 1 0 5 3 1 3

Question Paper Code : 71784

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2017.

Seventh Semester

Electrical and Electronics Engineering

EE 6701 — HIGH VOLTAGE ENGINEERING

(Regulations 2013)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. Define: Corona Critical Disruptive Voltage. Q:31, P(7)

2. What are the different methods employed for protection of over head lines against lightning? Q 32, P(7)

3. State Paschen's Law. Q:17, P(52)

4. Define Townsends first ionization coefficient Q:6, P(50)

5. A 12 stage impulse generator has $0.12\,\mu F$ capacitors. The Wave front and wave tail resistances connected are $400\,\Omega$ and $600\,\Omega$ respectively. If the load capacitor is 800pF, find the front and tail time of the impulse wave produced.

6. What is trigatron gap? Q:14, P(94)

7. What are the different types of resistive shunts used for impulse and high frequency measurements? Q:26, P(136)

8. What are the problems associated with measurement of very high impulse voltages? Q:47 P(141)

9. List out the various electrical tests to be carried out for bushings. Q:28, P(90)

10. Define: Air density correction factor. Q:44, P(139)

PART B — (5 × 16 = 80 marks)

11. (a) (i) Explain the construction and working principle of expulsion gaps and protector tubes. (10)

(ii) Describe the causes for switching and power frequency over voltages. (6)

Or

(b) Explain the different theories of charge formation in clouds. (16)

12. (a) Discuss about the Various mechanisms of Vacuum breakdown. (16)

Correction

Or

(b) (i) Explain the various theories that explain breakdown in commercial liquid dielectrics. (10)

(ii) Discuss about the various properties of composite dielectrics. (6)

13. (a) (i) A Cockroft Walton type voltage multiplier has eight stages with capacitances, all equal to $0.05\,\mu F$. The supply transformer secondary voltage is 125 kV at a frequency of 125Hz. If the load current to be supplied is 4.5mA. Find (1) the % ripple, (2) the regulation. (8)

(ii) Describe the construction and working principle of a Van de Graff generator with a neat sketch. (8)

Or

(b) Describe the construction and principle of operation of a multistage Marx Generator. (16)

14. (a) (i) Explain how a sphere gap can be used to measure the peak value of voltages. (8)

(ii) A co axial shunt is to be designed to measure an impulse current of 40kA. If the bandwidth of the shunt is to be at east 10 MHz and if the voltage drop across the shunt should not exceed 50V.Find the ohmic value of the shunt and its dimensions. (8)

Or

(b) Explain the principle and construction of a generating voltmeter for the measurement of high dc voltages. List out its advantages and disadvantages. (16)

15. (a) Explain the method of impulse testing of high voltage transformers. What is the procedure adopted for locating the failure? (16)

Or

(b) (i) Write short notes on statistical methods for insulation coordination. (6)

(ii) Draw the layout for synthetic testing and explain the procedure. (10)

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Reg. No. :

Question Paper Code : 50493

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2017
Seventh Semester
Electrical and Electronics Engineering
EE 6701 : HIGH VOLTAGE ENGINEERING
(Regulations 2013)

Time : Three Hours | Maximum : 100 Marks

Answer ALL questions

PART – A **(10×2=20 Marks)**

1. What are the causes for power frequency over voltage in power system ?
2. What is isokeraunic level ?
3. What are electronegative gases ? Give example.
4. What are pure liquid dielectrics ?
5. What are the advantages of Vande-Graff generator ?
6. Draw the standard impulse waveform.
7. What are the advantages of CVT measurement in HVAC ?
8. What type of measuring devices preferred for measurement of high frequency impulse current ?
9. Define disruptive discharge voltage.

10. What is meant by insulation coordination ?

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PART – B **(5×16=80 Marks)**

11. a) Explain in detail about the protection of transmission lines against over voltage. **(16)**

(OR)

b) i) Explain the theories of charge formation in clouds. **(10)**

ii) Derive the mathematical model for lightning discharges. **(6)**

12. a) Explain in detail about the various mechanisms of breakdown in vacuum. **(16)**

(OR)

b) Explain the various theories of breakdown mechanism of the commercial liquid dielectrics. **(16)**

13. a) What is Tesla coil ? How is damped high frequency oscillations obtained from a Tesla coil ? **(16)**

(OR)

b) Describe with a neat sketch the working of a Vande Graff generator. What are the factors that limit the maximum voltage obtained ? **(16)**

14. a) Explain the construction features and operation of generating type voltmeter. **(16)**

(OR)

b) Explain the operation of Electrostatic voltmeter with neat sketch and give its advantages and limitations. **(16)**

15. a) Explain the direct and synthetic testing of isolators and circuit breakers in detail. **(16)**

(OR)

b) Explain in detail about the insulation coordination. **(16)**

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Question Paper Code : 41011

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2018

Seventh Semester

Electrical and Electronics Engineering

EE 6701 – HIGH VOLTAGE ENGINEERING

(Regulations 2013)

Time : Three Hours

Maximum : 100 Marks

Answer ALL questions

PART – A

(10×2=20 Marks)

1. Write the mathematical model for lightning.
2. What is the use of protective devices ?
3. Define Paschen's law.
4. Define uniform and non-uniform fields.
5. What is a tesla coil ?
6. What is cascaded transformer ?
7. How the stray effect is reduced in resistive shunt type of measurements ?
8. Explain the basic principle of hall generator.
9. What is the significance of power factor tests ?
10. What is meant by insulation co-ordination ?

PART – B

(5×16=80 Marks)

11. a) Explain the different methods employed for lightning protection of over head lines. (16)

(OR)

b) i) Explain the different theories of charge formation in clouds. (8)

ii) Cloud discharge 15 coulombs with in 1.5 ms on to a transmission line during lightning. Estimate the voltage produced at the point of the stroke on the transmission line. (Assume surge impedance of the line as 350 Ω). (8)

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12. a) Explain the breakdown mechanism involving in solid dielectrics breakdown. (16)

(OR)

b) i) Explain the Townsends criterion for a spark. (8)

ii) List out the problems caused by corona discharges. (8)

13. a) Explain with neat diagram the generation of high DC voltage using Vande-Graff generator. State the factors which limit the ultimate voltage developed. (16)

(OR)

b) Explain the Marx circuit arrangement for multistage impulse generators. How is the basic arrangement modified to accommodate the wave time control resistances ? (16)

14. a) Explain any two methods to measure high impulse current. (16)

(OR)

b) A Rogowski coil is required to measure impulse current of 8 KA having rate of change of current of 10^{10} A/sec. The voltmeter is connected across the integrating circuit which reads 8V for full scale deflection. The input to integrating circuit is from Rogowski coil. Determine the mutual inductance of coil, R and C for the integrating circuit. (16)

15. a) Explain the impulse testing procedure for insulators. (16)

(OR)

b) Explain the different high voltage tests conducted on bushings. (16)
