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Internal Test2 –October 2018

Sub:	High Voltage Engineering							Code:	15EE73/ 10EE73
Date:	17/10 /2018	Duration:	90 mins	Max Marks:	50	Sem:	VII	Branch:	EEE

Note: Answer any FIVE full questions with neat diagram wherever necessary.

		Marks	OBE CO	OBE RBT
1.	Explain with a neat diagram sphere gap method for measuring high voltage. Explain the factors affecting the measurement.	[5+5]	CO4	L2
2.	Write a short notes on any **TWO** of the following: (a) Chubb-Fortesque Method (b) Trigatron Gap (c) Impulse Current Generator	[5+5]	CO4	L2
3.	With the help of neat sketch explain how cascaded transformer generates high voltage AC. Explain equivalent circuit.	[2+8]	CO3	L2
4.	Explain the working principle and construction of Generating Voltmeter with a neat diagram. Mention advantages and limitations.	[7+3]	CO4	L2
5a.	Define the wave front and wave tail time of impulse voltage wave. What are the percentage tolerances for a standard lightning impulse wave.	[3]	CO3	L2
5b.	With the help of a neat sketch explain how impulse voltage can be developed in the laboratory Marx's circuit.	[5+2]	CO3	L3
6.	Explain the working principle and construction of Electrostatic Voltmeter with a neat diagram. Mention advantages also.	[7+3]	CO4	L2
7a.	A generating voltmeter is required to measure voltage between 15kV to 250kV. If the indicating meter reads a minimum current of 2 μA and a maximum of 35 μA, determine the capacitance of generating voltmeter.	[5]	CO4	L3
7b	Calculate the front and tail resistance for 5 stages, 1000kV with the capacitance of each stage is 5μF and load capacitance of 10,000 pF for 1 μs of front and 50 μs of tail wave.	[5]	CO3	L3

1. **MEASUREMENT OF HVAC AND HVDC AND IMPULSE VOLTAGE USING SPHERE GAP**

- Sphere gap is by now considered as one of the standard methods for the measurement of peak value of d.c, a.c and impulse voltages and is used for checking the voltmeters and other voltage measuring devices used in high voltage test circuits.
- Two identical metallic spheres separated by certain distance form a sphere gap.
- The sphere gap can be used for measurement of impulse voltage of either polarity provided that the impulse is of a standard wave form and has wave front time at least 1 micro sec. and wave tail time of 5 micro sec.
- **the gap length between the sphere should not exceed a sphere radius**.
- If these conditions are satisfied and the specifications regarding the shape, mounting, clearances of the spheres are met, the results obtained by the use of sphere gaps are reliable to within ±3%.
- in standard specification that in places where the availability of ultraviolet radiation is low, irradiation of the gap by radioactive or other ionizing media should be used when voltages of magnitude less than 50 kV are being measured or where higher voltages with accurate results are to be obtained

Specifications on Spheres and Associated Accessories

- The spheres should be so made that their surfaces are smooth and their curvatures as uniform as possible.
- For smaller size, the spheres are placed in horizontal configuration whereas large sizes (diameters), the spheres are mounted with the axis of the sphere gaps vertical and the lower sphere is grounded.
- In either case, it is important that the spheres should be so placed that the space between spheres is free from external electric fields and from bodies which may affect the field between the spheres

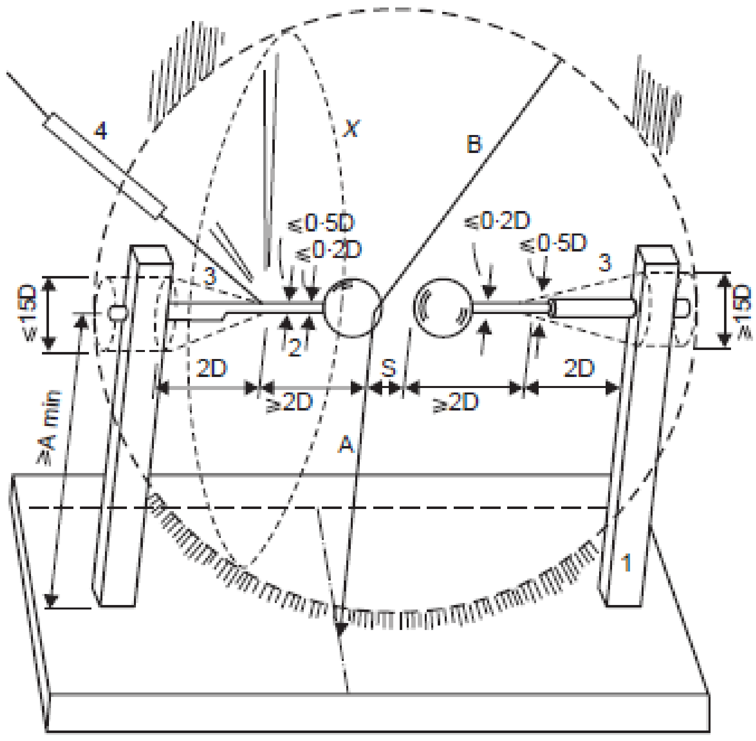


Fig. 4.1

- For the measurement of a.c. or d.c. voltage, a reduced voltage is applied to begin with so that the switching transient does not flash over the sphere gap and then the voltage is increased gradually till the gap breaks down.
- **Alternatively** the voltage is applied across a relatively large gap and the spacing is then gradually decreased till the gap breaks down. Corresponding to this gap the value of peak voltage can be read out from the calibration tables.
- The calibration tables values correspond to 760 mm Hg pressure and 20°C temperature.
- Any deviation from the value, a correction factor will have to be used to get the correct value of the voltage being measured.
- For the measurement of 50% impulse disruptive discharge voltages, the spacing of the sphere gap or the charging voltage of the impulse generator is adjusted in steps of 3% of the expected disruptive voltage.
- Six applications of the impulse should be made at each step and the interval between two applications is 5 seconds.
- The value giving 50% probability to disruptive discharge is preferably obtained

by interpolation between at least two gap or voltage settings, one resulting in two disruptive discharges or less out of six applications and the other in four disruptive discharges or more out of again six applications

Various factors that affect the sparkover voltage of a sphere gap are:
(i) nearby earthed objects,
(ii) atmospheric conditions and humidity,
(iii) irradiation, and
(i v) polarity and rise time of voltage waveforms.

Effect of nearby earthed objects

- **The effect of nearby earthed objects was investigated by Kuffel by enclosing the earthed sphere inside an earthed cylinder.**
- **It was observed that the sparkover voltage is reduced.**
- **The reduction was observed to be**

$$\Delta V = m \log (B/D) + C$$

where,
$\Delta V =$ percentage reduction,
$B =$ diameter of earthed enclosing cylinder,
$D =$ diameter of the spheres,
$S =$ spacing, and m and C are constants.

Effect of atmospheric conditions

- **The sparkover voltage of a spark gap depends on the air density which varies with the changes in both temperature and pressure.**
- **Let sparkover voltage = *V under test* conditions of temperature *T and pressure p torr***
- ***sparkover voltage =V0* under standard conditions of temperature *T = 2O°C and pressure p = 760 torr, then V=kV0***
- **where *k is a function of the air density factor d, given by***

$$d = \frac{p}{760}\left(\frac{293}{273+T}\right)$$

Influence of Humidity

Observation made by Kuffel.

- **It can be seen that**
- **(i) The a.c. breakdown voltage is slightly less than d.c. voltage.**
- **(ii) The breakdown voltage increases with the partial pressure of water vapour.**
- **It has also been observed that**
- **(i) The humidity effect increases with the size of spheres and is largest for uniform field electrodes.**
- **(ii) The voltage change for a given humidity change increase with gap length.**
- **The increase in breakdown voltage with increase in partial pressure of water vapour and this increase in voltage with increase in gap length is due to the relative values of ionisation and attachment coefficients in air.**
- **The water particles readily attach free electrons, forming negative ions.**
- **These ions therefore slow down and are unable to ionise neutral molecules under field conditions in which electrons will readily ionise.**

Influence of Dust Particles

- **When a dust particle is floating between the gap this results into erratic breakdown in homogeneous or slightly in homogenous 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 gaps.**

Effect of Irradiation

- **Illumination of sphere gaps with ultra-violet or x-rays aids easy ionization in gaps.**
- **The effect of irradiation is pronounced for small gap spacings.**
- **A reduction of about 20% in sparkover voltage was observed for spacings of 0.1 *D to 0.3 D for a 1.3 cm* sphere gap with d.c. voltages.**
- **The reduction in sparkover voltage is less than 5% for gap spacings more than 1 cm, and for gap spacings of 2 cm or more it is about 1.5%.**
- **Hence, irradiation is necessary for smaller sphere gaps of gap spacing less than 1 cm for obtaining consistent values.**

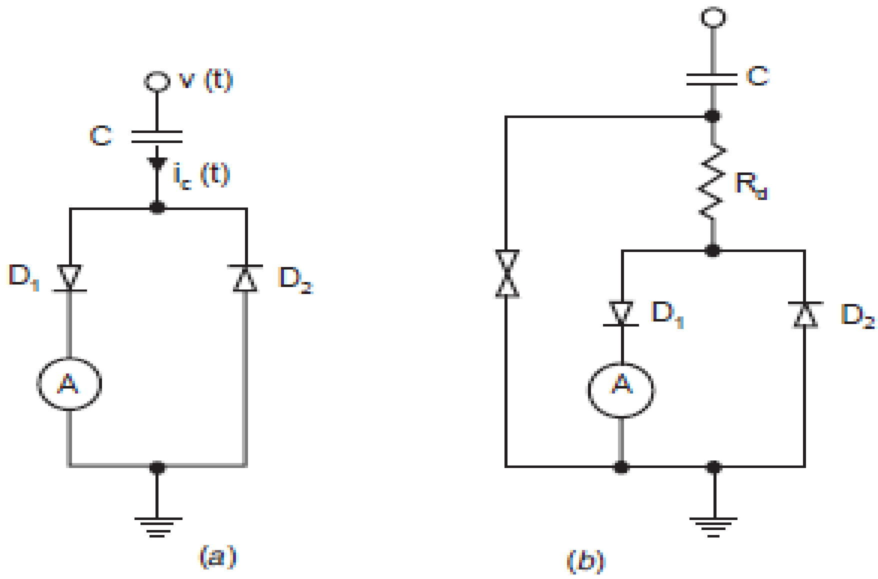
Effect of polarity and waveform

- **It has been observed that the sparkover voltages for positive and negative polarity impulses are different.**
- **Experimental investigation showed that for sphere gaps of 6.25 to 25 cm diameter, the difference between positive and negative d.c. voltages is not more than 1%.**
- **For smaller sphere gaps (2 cm diameter and less) the difference was about 8% between negative and positive impulses of 1/50 μs waveform.**

- **the wave front and wave tail durations also influence the breakdown voltage.**

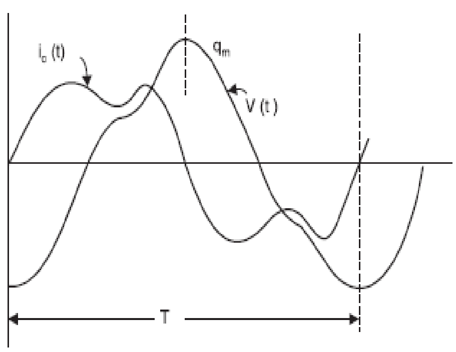
  For wave fronts of less than 0.5 μs and wave tails less than 5 μs the breakdown voltages are not consistent and hence the use of sphere gap is not recommended for voltage measurement in such cases.

2a) THE CHUBB-FORTESCUE METHOD



- **Chubb and Fortescue suggested a simple and accurate method of measuring peak value of a.c. voltages.**
- **The basic circuit consists of a standard capacitor, two diodes and a current integrating ammeter (MC ammeter) as shown in Fig.**
- **The displacement current ic(t), Fig. 4.12 is given by the rate of change of the charge and hence the voltage V(t) to be measured flows through the high voltage capacitor C and is subdivided into positive and negative components by the back to back connected diodes.**
- **The voltage drop across these diodes can be neglected (1 V for Si Diodes) as compared with the voltage to be measured.**
- **The measuring instrument (M.C. ammeter) is included in one of the branches.**
  The ammeter reads the mean value of the current
- **The relation is similar to the one obtained in case of generating voltmeters.**
- **An increased current would be obtained if the current reaches zero more than once during one half cycle.**
- **This means the wave shapes of the voltage would contain more than one maxima per half cycle.**
- **The standard a.c. voltages for testing should not contain any harmonics and, therefore, there could be very short and rapid voltages caused by the heavy predischarges, within the test circuit which could introduce errors in measurements.**
  To eliminate this problem filtering of a.c. voltage is carried out by introducing a damping resistor in between the capacitor and the diode circuit, Fig.

$$I = \frac{1}{T}\int_{t_1}^{t_2} C\frac{dv(t)}{dt}\,.\,dt = \frac{C}{T}\,.\,2V_m = 2V_m fC \text{ or } V_m = \frac{I}{2fC}$$

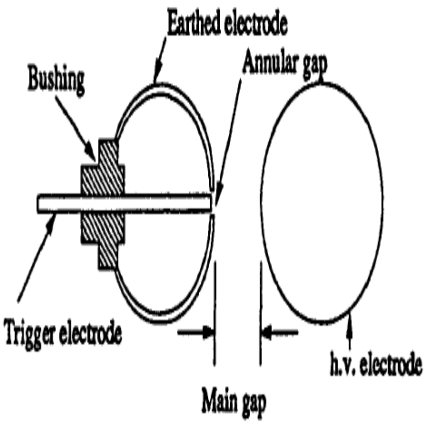


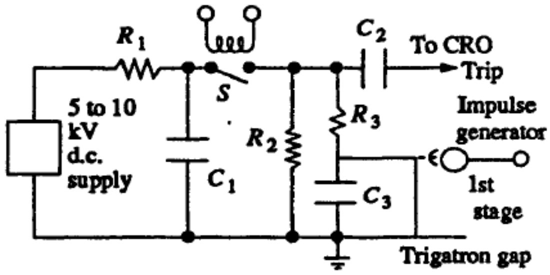
Also, if full wave rectifier is used instead of the half wave as shown in Fig. , the factor 2 in the denominator of the above equation should be replaced by 4.

Since the frequency f, the capacitance C and current I can be measured accurately, the measurement of symmetrical a.c. voltages using Chubb and Fortescue method is quite accurate and it can be used for calibration of other peak voltage measuring devices.

2b) Trigatron Gap

- Now-a-days a trigatron gap shown in Fig. is used, and this requires much smaller voltage for operation compared to the three electrode gap.
- A trigatron gap 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.
- The trigger electrode is a metal rod with an annular clearance of about 1 mm fitted into the main electrode through a bushing.
- The trigatron is connected to a pulse circuit as shown in Fig.
- Tripping of the impulse generator is affected by a trip pulse which produces a spark between the trigger electrode and the earthed sphere.
- Due to space charge effects and distortion of the field in the main gap, sparkover of the main gap occurs.
- The trigatron gap is polarity sensitive and a proper polarity pulse should be applied for correct operation.





(b) Tripping circuit using a trigatron

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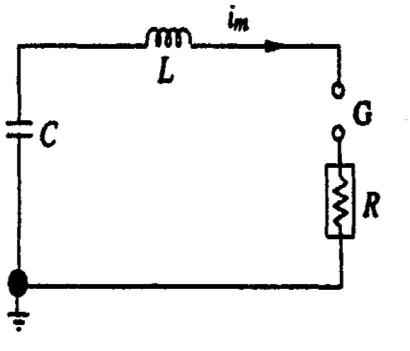
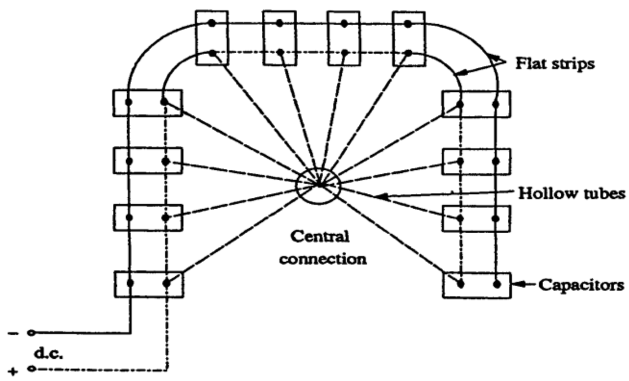
2c)



(a) Basic circuit of an impulse current generator



(c) Arrangement of capacitors for high impulse current generation

Fig. 6.20 Impulse current generator circuit and its waveform

- For producing impulse currents of large value, a bank of capacitors connected in parallel are charged to a specified value and are discharged through a series R-L circuit as shown in Fig.
- C represents a bank of capacitors connected in parallel which are charged from a d.c. source to a voltage up to 200 kV.
- R represents the dynamic resistance of the test object and the resistance of the circuit and the shunt.
- L is an air cored high current inductor, usually a spiral tube of a few turns

- **If the capacitor is charged to a voltage *V and discharged when the spark gap is* triggered, the current *im will be given by the equation***

$$V = R i_m + L \frac{di_m}{dt} + \frac{1}{C}\int_0^t i_m \, dt$$

The circuit is usually underdamped, so that

$$\frac{R}{2} < \sqrt{L/C}$$

Hence, im is given by

$$i_m = \frac{V}{\omega L}[\exp(-\alpha t)]\sin(\omega t)$$

where $\alpha = \frac{R}{2L}$ and $\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$

The time taken for the current i_m to rise from zero to the first peak value is

$$t_1 = t_f = \frac{1}{\omega}\sin^{-1}\frac{\omega}{\sqrt{LC}} = \frac{1}{\omega}\tan^{-1}\frac{\omega}{\alpha}$$

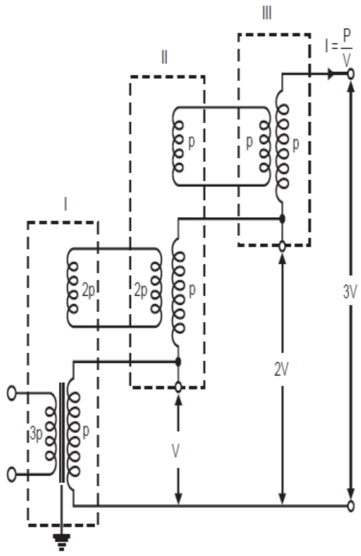
The duration for one half cycle of the damped oscillatory wave t_2 is,

$$t_2 = \frac{\pi}{\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}}$$

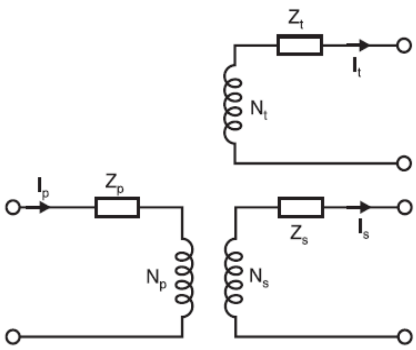
- **It can be shown that the maximum value of im is normally independent of the value of V and C for a given energy,** $W = \frac{1}{2}CV^2$, **and the effective inductance L.**
- **Eq. shows that a low inductance is needed in order to get high current magnitudes for a given charging voltage V.**
- **The present practice as per IEC 60.2 is to express the characteristic time t2 as the time for half value of the peak current, similar to the definition given for standard impulse voltage waves.**
- **With this definition, the values of α and ω for 8/20 μs impulse wave will be $\alpha = 0.0535 \times 10^6$ and $\omega = 0.113 \times 10^6$,**
- **R, L, C are expressed in ohms, henries and farads respectively.**
- **The product LC will be equal to 65 and the peak value of im is given by (VC/14). Here, the charging voltage is in kV and im is in kA.**

3. **Cascaded Transformer**
   - **When test voltage requirements are less than about 300 kV, a single transformer can be used for test purposes.**
   - **The impedance of the transformer should be generally less than 5% and must be capable of giving the short circuit current for one minute or more depending on the design.**
   - **Along with low and high voltage windings, a third winding known as meter winding is provided to measure the output voltage.**
   - **For higher voltage requirements, a single unit construction becomes difficult and costly due to insulation problems.**
   - **transportation and erection of large transformers become difficult.**
   - **Drawbacks are overcome by series connection or cascading of the several identical units of transformers, wherein the high voltage windings of all the units effectively come in series**
   - **the first transformer is at ground potential along with its tank.**
   - **The second transformer is kept on insulators and maintained at a potential of V2, the output voltage of the first unit above ground.**
   - **The high voltage winding of the first unit is connected to the tank of the second unit.**

- The low voltage winding of this unit is supplied from the excitation winding of the first transformer, which is in series with the high voltage winding of the first transformer at its high voltage end.
- The rating of the excitation winding is almost identical to that of the primary or the low voltage winding.
- The high voltage connection from the first transformer winding and the excitation winding terminal are taken through a bushing to the second transformer.
- the third transformer is kept on insulators above the ground at a potential of *2V2* and is supplied likewise from the second transformer.
- The number of stages in this type of arrangement are usually two to four
- three stages are adopted to facilitate a three-phase operation so that can be obtained between the lines $\sqrt{3V_2}$
- Supply to the units can be obtained from a motor-generator set or through an induction regulator for variation of the output voltage.
- The rating of the primary or low voltage winding is usually 230 or 400 V for small units up to 100 kVA.
- For larger outputs the rating of the low voltage winding may be 3.3kV, 6.6 kV or 11 kV
- Second Scheme: Isolating transformers *are 1:1 ratio transformers* insulated to their respective tank potentials and are meant for supplying the excitation for the second and the third stages at their tank potentials instead of using tertiary winding.



Basic 3 stage Transformer



Equivalent Circuit of 1-Stage

- *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 short circuit
  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

$$Z_{ps} = Z_p + Z_s,\ Z_{pt} = Z_p + Z_t \quad \text{and} \quad Z_{st} = Z_s + Z_t$$

Solving these equations, we have

$$Z_p = \frac{1}{2}(Z_{ps} + Z_{pt} - Z_{st}),\ Z_s = \frac{1}{2}(Z_{ps} + Z_{st} - Z_{pt})$$

and

$$Z_t = \frac{1}{2}(Z_{pt} + Z_{st} - Z_{ps}) \qquad (2.19)$$

Assuming negligible magnetising current, the sum of the ampere turns of all the windings must be zero.

$$N_p I_p - N_s I_s - N_t I_t = 0$$

Assuming lossless transformer, we have,

$$Z_p = jX_p, \quad Z_s = jX_s \quad \text{and} \quad Z_t = jX_t$$

Also let Np = Nt for all stages, the equivalent circuit for a 3-stage transformer would be given as in Fig.

Fig. can be further reduced to a very simplified circuit as shown in Fig. The resulting short circuit reactance Xres is obtained from the condition that the power rating of the two circuits be the same. Here currents have been shown corresponding to high voltage side.

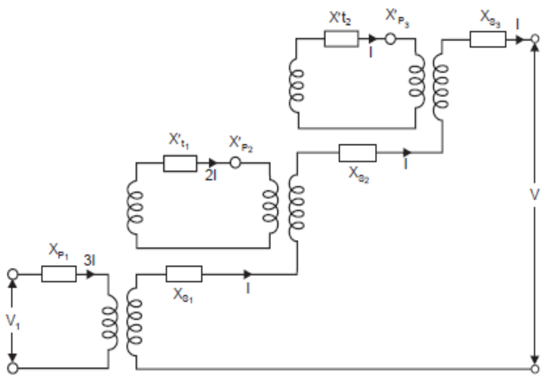


Fig. 2.11 Equivalent circuit of 3-stage transformer

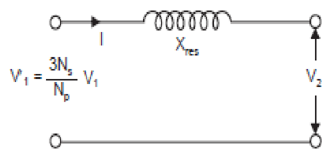


Fig. 2.12 A simplified equivalent circuit

$$I^2 X_{res} = (3I)^2 X_p + (2I)^2 X_p + I^2 X_p + I^2 X_s + I^2 X_s + I^2 X_s + (2I)^2 X_t + I^2 X_t$$

$$X_{res} = 14X_p + 3X_s + 5X_t \qquad (2.20)$$

Where Xpi, Xsi and Xti are the short-circuit reactance of the primary, secondary and tertiary windings of ith transformer

- **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***
- **For the three-stage transformer, the total output VA will be 3VI = 3P 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 2P.**
- **the first stage primary would be loaded with 3*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

4. **Generating Voltmeter**
   - **When the source loading is not permitted or when direct connection to the high voltage source is to be avoided, the generating principle is employed for the measurement of high voltages**
   - **Principle: A generating voltmeter is a variable capacitor electrostatic voltage generator which generates current proportional to the voltage to be measured.**
   - **Similar to electrostatic voltmeter the generating voltmeter provides loss free measurement of d.c. and a.c. voltages.**
   - **The device is driven by an external constant speed motor and does not absorb power or energy from the voltage measuring source.**
   - **The principle of operation explained with the help of Fig.**

     Construction:
   - **H is a high voltage electrode**
   - **the earthed electrode is subdivided into a sensing or pick up electrode P, a guard electrode G and a movable electrode M, all of which are at the same potential.**
   - **The high voltage electrode H develops an electric field between itself and the electrodes P, G and M.**
   - **The field lines are shown in Fig.**
   - **The electric field density σ is also shown.**
   - **If electrode M is fixed and the voltage V is changed, the field density σ would change and thus a current i (t) would flow between P and the ground.**

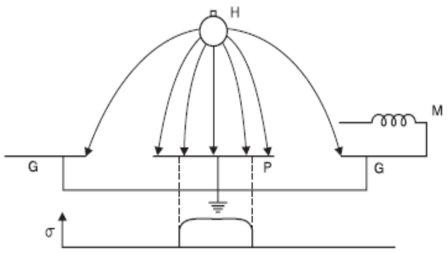


Fig. 4.8 Principle of generating voltmeter

$$i(t) = \frac{dq(t)}{dt} = \frac{d}{dt}\left[\int \sigma(a)da\right]$$

- **Where σ (a) is the electric field density or charge density along some path and is assumed constant over the differential area da of the pick up electrode.**
- **In this case σ (a) is a function of time also and ∫ da the area of the pick up electrode P exposed to the electric field.**
- **If the voltage V to be measured is constant (d.c voltage), a current i(t) will flow only if it is moved i.e. now σ (a) will not be function of time but the charge q is changing because the area of the pick up electrode exposed to the electric field is changing.**
- **The current i(t) is given by**

$$i(t) = \frac{d}{dt}\int_{A(t)} \sigma(a)da = \varepsilon \frac{d}{dt}\int_{A(t)} E(a)da$$

where σ (a) = εE(a) and ε is the permittivity of the medium between the high voltage electrode and the grounded electrode.

The integral boundary denotes the time varying exposed area.

The high voltage electrode and the grounded electrode in fact constitute a capacitance system.

The capacitance is, however, a function of time as the area A varies with time and, therefore, the charge q(t) is given as

For d.c. voltages $\frac{dV(t)}{dt} = 0$

Hence $i(t) = V\frac{dC(t)}{dt}$

If the capacitance varies linearly with time and reaches its peak value C_m is time $T_c/2$ and again reduces to zero linearly in time $T_c/2$, the capacitance is given as

$$C(t) = 2\frac{C_m}{T_c}t$$

For a constant speed of n rpm of synchronous motor which is varying the capacitance, time T_c is given by $T_c = 60/n$.

Therefore $I = 2C_m V\frac{n}{60} = \frac{n}{30}C_m V$

If the capacitance C varies sinusoidally between the limits C_0 and $(C_0 + C_m)$ then

$$C = C_0 + C_m \sin wt$$

and the current i is then given as

$$i(t) = i_m \cos wt \text{ where } i_m = VC_m\omega$$

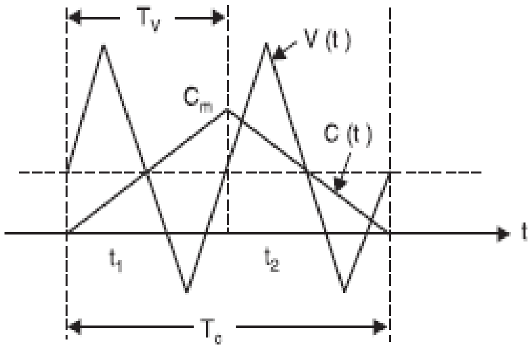


Fig. 4.9 Capacitance and voltage variation

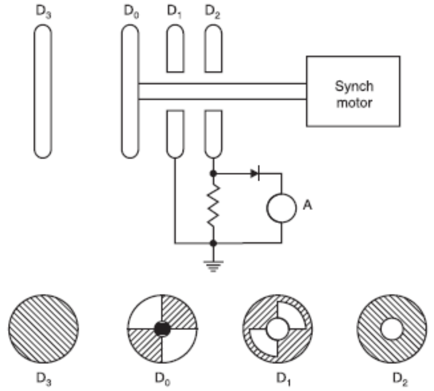
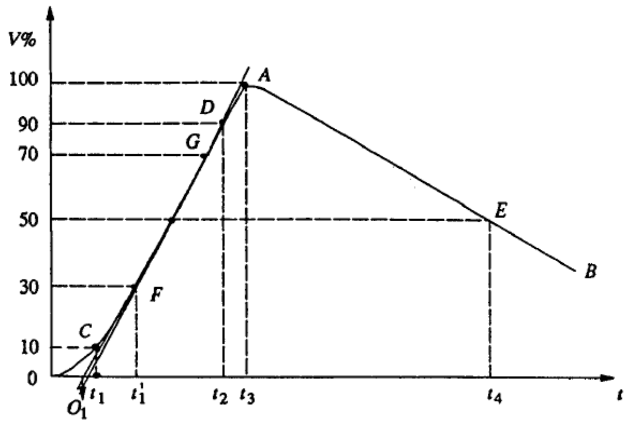
- **ω is the angular frequency of variation of the capacitance.**
- **If ω is constant the current measured is proportional to the voltage being measured.**
- **Generally the current is rectified and measured by a moving coil meter.**
- **Generating voltmeters can be used for a.c. voltage measurement also provided the angular frequency ω is the same or equal to half that of the voltage being measured.**
- **Fig shows the variations of *C as a function of time together with a.c. voltage,* the frequency of which is twice the frequency of *C (t).***
- **whatever be the phase relation between voltage and the capacitance, over one cycle variation of the voltage is same (e.g. V(t1) – V(t2))**
- **the rate of change of capacitance over the period Tv is equal to Cm/Tv. Therefore, the instantaneous value of current i(t) = Cm fvV(t)**
- **where fv = 1/Tv the frequency of voltage.**
- **Since fv = 2fc and fc = 60/n we obtain**
- **I(t) = n/30 CmV(t)**
- 

Fig. 4.10 Schematic diagram of generating voltmeter

- Fig. shows a schematic diagram of a generating voltmeter which employs rotating vanes for variation of capacitance.
- The high voltage electrode is connected to a disc electrode D3 which is kept at a fixed distance on the axis of the other low voltage electrodes D2, D1, and D0.
- The rotor D0 is driven at a constant speed by a synchronous motor at a suitable speed.
- The rotor vanes of D0 cause periodic change in capacitance between the insulated disc D2 and the high voltage electrode D3.
- The number and shape of vanes are so designed that a suitable variation of capacitance (sinusoidal or linear) is achieved.
- The a.c. current is rectified and is measured using moving coil meters.
- If the current is small an amplifier may be used before the current is measured.
- Generating voltmeters are linear scale instruments and applicable over a wide range of voltages.
- The sensitivity can be increased by increasing the area of the pick up electrode and by using amplifier circuits.
- Advantages
- (i) scale is linear and can be extrapolated
- (ii) source loading is practically zero
- (iii) no direct connection to the high voltage electrode.
- Limitations of Generating Voltmeters
- (i) They require calibration,
- (ii) careful construction is needed and is a cumbersome instrument requiring an auxiliary drive, and
- (iii) disturbance in position and mounting of the electrodes make the calibration invalid

5a



Wave front time is defined as time taken to reach the peak value. In case, when finding out origin is difficult then the points corresponding to 10% and 90% of the peak values are located in the front portion (points C and D).
The line joining these points is extended to cut the time axis at o1.
o1 is taken as the virtual origin. 1.25 times the interval between times t1 and t2 corresponding to points C and D (projections on the time axis)
is defined as the front time, i.e. 1.25 (o1t2 – o1t1).
Wave tail time is defined as time required to reach to 50% of its peak value.

The tolerance allowed in the peak value is ± 3%.

5b Multistage Impulse Generators—Marx Circuit

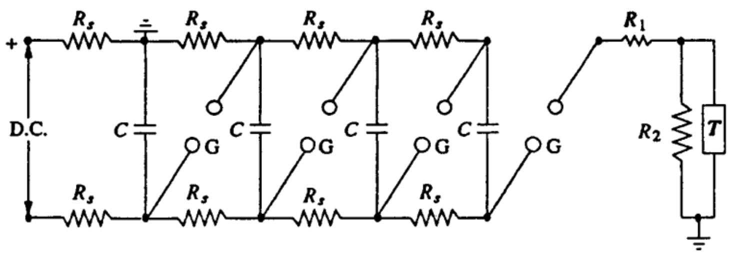


Fig. 6.17a Schematic diagram of Marx circuit arrangement for multistage impulse generator

C — Capacitance of the generator
R_s — Charging resistors
G — Spark gap
R_1, R_2 — Wave shaping resistors
T — Test object

- **the generator capacitance C1 is to be first charged and then discharged into the wave shaping circuits.**
- **A single capacitor C1 may be used for voltages up to 200 kV.**
- **Beyond this voltage, a single capacitor and its charging unit may be too costly, size becomes very large.**
- **The cost and size of the impulse generator increases at a rate of the square or cube of the voltage rating.**
- **Producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series.**
- **The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by Marx.**
- **Modified Marx circuits are used for the multistage impulse generators.**
- **The schematic diagram of Marx circuit in Figs.**

- **Usually the charging resistance is chosen to limit the charging current to about 50 to 100 mA, and the generator capacitance *C* is chosen such that the product CRs is about 10 s to 1 min.**
- **The gap spacing is chosen such that the breakdown voltage of the gap G is greater than the charging voltage V.**
- **all the capacitances are charged to the voltage V in about 1 minute.**
- **When the impulse generator is to be discharged, the gaps G are made to spark over simultaneously by some external means.**
- **all the capacitors C get connected in series and discharge into the load capacitance or the test object**
- **The discharge time constant CR1/n (for n stages) will be very very small (microseconds), compared to the charging time constant CRs which will be few seconds.**
- **Hence, no discharge takes place through the charging resistors Rs.**
- **In the Marx circuit is of Fig. 6.17a the impulse wave shaping circuit is connected externally to the capacitor unit In Fig. b,**
- **the modified Marx circuit is shown, wherein the resistances R1 and R2 are incorporated inside the unit.**
- **R1 is divided into n parts equal t oR1/n and put in series with the gap G.**
- **R2 is also divided into n parts and arranged across each capacitor unit after the gap G.**
- **This arrangement saves space, and also the cost is reduced.**
- **But, in case the waveshape is to be varied widely, the variation becomes difficult.**
- **The additional advantages gained by distributing R1 and R2 inside the unit are that the control resistors are smaller in size and the efficiency (Vo/nV) is high**
- **Impulse generators are nominally rated by the total voltage (nominal), the number of stages, and the gross energy stored.**

- The nominal output voltage is the number of stages multiplied by the charging voltage.
- The nominal energy stored is given by $\frac{1}{2}C_1V^2$
- - where C1 = *C/n (the discharge capacitance) and V is the nominal maximum* voltage (n times charging voltage).
- The waveform of either polarity can be obtained by suitably changing the charging unit polarity

6. ELECTROSTATIC VOLTMETER

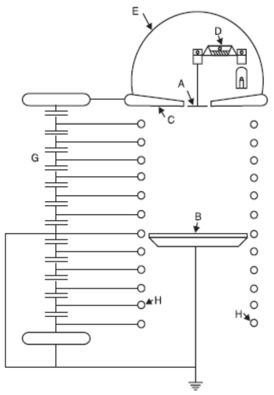


Fig. 4.7 Schematic diagram of electrostatic voltmeter

- **D/E –Metal Dome**
- **M/A-mounting Plate**
- **G/C –guard plate**
- **P/B –Fixed Plate**
- **H- Guard loop or ring**
- **B/D-Balance**
- **C/G-Capacitance Divider**
- **W Balancing Weight**
- **Fig. shows a schematic diagram of an absolute electrostatic voltmeter.**
- **The hemispherical metal dome *D encloses a sensitive balance B which measures the force of attraction between the movable* disc which hangs from one of its arms and the lower plate *P.***
- ***The movable electrode M hangs with a* clearance of above 0.01 cm, in a central opening in the upper plate which serves as a guard ring.**
- **The diameter of each of the plates is 1 metre.**
- **Light reflected from a mirror carried by the balance beam serves to magnify its motion and to indicate to the operator at a safe distance when a condition of equilibrium is reached.**
- **As the spacing between the two electrodes is large (about 100 cms for a voltage of about 300 kV), the uniformity of the electric field is maintained by the guard rings G which surround the space between the discs M and P.**
- **The guard rings G are maintained at a constant potential in space by a capacitance divider ensuring a uniform spatial potential distribution.**
- **When voltages in the range 10 to 100 kV are measured, the accuracy is of the order of 0.01 per cent.**
- **Principle: The electric field according to Coulomb is the field of forces. The electric field is produced by voltage and, therefore, if the field force could be measured, the voltage can also be measured.**

- The voltmeters are used for the measurement of high a.c. and d.c. voltages. The measurement of voltages lower than about 50 volt is, however, not possible, as the forces become too small.
- When a voltage is applied to a parallel plate electrode arrangement, an electric field is set up between the plates.
- It is possible to have uniform electric field between the plates with suitable arrangement of the plates.
- The field is uniform, normal to the two plates and directed towards the negative plate.
- If A is the area of the plate and E is the electric field intensity between the plates ε the permittivity of the medium between the plates, we know that the energy density of the electric field between the plates is given as,
- Consider a differential volume between the plates and parallel to the plates with area *A and* thickness *dx, the energy content in this differential volume Adx is*

$$dW = W_d\, Adx = \frac{1}{2}\varepsilon E^2\; Adx$$

Now force *F between the plates is defined as the derivative of stored electric energy along the* field direction *i.e.,*

$$F = \frac{dW}{dx} = \frac{1}{2}\varepsilon E^2 A$$

Now *E = V/d where V is the voltage to be measured and d the distance of separation between the* plates. Therefore, the expression for force

$$F = \frac{1}{2}\varepsilon\frac{V^2 A}{d^2}$$

Since the two plates are oppositely charged, there is always force of attraction between the plates.

If the voltage is time dependant, the force developed is also time dependant. In such a case the mean value of force is used to measure the voltage. Thus

$$F = \frac{1}{T}\int_0^T F(t)dt = \frac{1}{T}\int\frac{1}{2}\varepsilon\frac{V^2(t)}{d^2}A\,dt = \frac{1}{2}\frac{\varepsilon A}{d^2}\cdot\frac{1}{T}\int V^2(t)dt = \frac{1}{2}\varepsilon A\frac{V_{rms}^2}{d^2}$$

- Electrostatic voltmeters measure the force based on the above equations and are arranged such that one of the plates is rigidly fixed whereas the other is allowed to move.
- With this the electric field gets disturbed.
- For this reason, the movable electrode is allowed to move by not more than a fraction of a millimetre to a few millimetres even for high voltages so that the change in electric field is negligibly small.
- As the force is proportional to square of *Vrms, the meter can be used both for a.c. and d.c. voltage* measurement
- The force developed between the plates is sufficient to be used to measure the voltage.
- Various designs of the voltmeter have been developed which differ in the construction of electrode arrangement and in the use of different methods of restoring forces required to balance the electrostatic force of attraction.
- Some of the methods are
- (*i) Suspension of moving electrode on one arm of a balance.*

- *(ii) Suspension of the moving electrode on a spring.*
- *(iii) Pendulous suspension of the moving electrode.*
- *(iv) Torsional suspension of moving electrode.*
- **The small movement is generally transmitted and amplified by electrical or optical methods.**
- **If the electrode movement is minimised and the field distribution can exactly be calculated, the meter can be used for absolute voltage measurement as the calibration can be made in terms of the fundamental quantities of length and force**
- **advantage of the electrostatic voltmeter is its extremely low loading effect as only electric fields are required to be set up.**
- **Because of high resistance of the medium between the plates, the active power loss is negligibly small.**
- **The voltage source loading is, therefore, limited only to the reactive power required to charge the instrument capacitance which can be as low as a few picofarads for low voltage voltmeters.**
- **The measuring system as such does not put any upper limit on the frequency of supply to be measured.**
- **However, as the load inductance and the measuring system capacitance form a series resonance circuit, a limit is imposed on the frequency range.**
- **For low range voltmeters, the upper frequency is generally limited to a few MHz**

7a

$$I_{rms} = \frac{VC_m w}{\sqrt{2}}$$

$$2 \times 10^{-6} = \frac{15 \times 1000 \times C_m}{\sqrt{2}} \times \frac{2\,\pi \times 1500}{60}$$

$$C_m = 12 \times 10^{-7} \times 10^{-6} = 1.5 \text{ pF} \quad \text{Ans.}$$

At 250 kV, the current indicated will be

$$2 \times \frac{250}{15} = 33.3\ \mu\text{A} \quad \text{Ans.}$$

7b

Each stage capacitance → 5 μF.

load cap → 10,000 pF.

time to front t_1 = 1.2 μs. $= 3.0\, R_1 \dfrac{C_1 C_2}{C_1 + C_2}$.

$$R_1 = \frac{1.2 \times 10^{-6}}{3.0} \times \frac{(5 + 0.01) \times 10^{-6}}{5 \times 0.01 \times 10^{-12}}$$

$R_1 = \sout{40.08\,\Omega}\ 33.33\,\Omega.$

time to fail, $t_2 = 0.7(R_1 + R_2)(C_1 + C_2)$.

$\frac{50 \times 10^{-6}}{0.7 \times 5.01 \times 10^{-6}} = (\sout{40.08}\ 33.33 + R_2).$

So $R_2 = |14 - 33| = 19\,\Omega.$