Hall Ticket Number:

IV/IV B.Tech (Regular/Supplementary) DEGREE EXAMINATION

November, 2022 | **Electrical & Electronics Engineering**

Seventh Semester | **High Voltage Engineering**

Time: Three Hours | **Maximum:** 50 Marks

Answer Question No. 1 Compulsorily. (1X10 = 10 Marks)
Answer ANY ONE question from each Unit. (4X10=40 Marks)

1.	a)	Define ionization process in breakdown mechanism	CO1,L1	
	b)	State Paschen's law.	CO1,L2	
	c)	State difference between pure and commercial liquids	CO1,L2	
	d)	What is the working principle of Tesla coil?	CO2,L2	
	e)	List the various techniques for generation of high DC voltages	CO2,L4	
	f)	What is the function of series resistance micro ammeter?	CO2,L1	
	g)	What are the various methods available for measurement of high DC voltages	CO3,L1	
	h)	What is the necessity of over voltage protection?	CO3,L2	
	i)	How are the testing of insulators classified	CO4,L1	
	j)	Define the flashover voltage	CO4,L1	
		Unit - I		
2.	a)	Explain Townsend's breakdown mechanism in gases	CO1,L2	5M
	b)	Explain the various mechanisms of breakdown phenomenon in commercial liquids	CO1,L2	5M
		(OR)		
3.	a)	Explain electromechanical breakdown in solid dielectrics	CO1,L2	5M
	b)	Explain how treeing and tracking leads to breakdown in solid insulating materials	CO1,L2	5M
		Unit – II		
4.	a)	Explain with neat sketch of voltage multiplier circuit for generation of high DC voltages	CO2,L3	5M
	b)	Explain the generation high AC Voltages using cascade connection of transformer	CO2,L2	5M
		(OR)		
5.	a)	Explain the Marx circuit arrangement for generation of Impulse voltages	CO2,L3	5M
	b)	Explain about tripping and control of impulse generators.	CO2,L2	5M
		Unit – III		
6.	a)	Describe the generating voltmeter used for measuring high dc voltages.	CO3,L2	5M
	b)	Explain the principle and construction of an electrostatic voltmeter for very high voltages	CO3,L2	5M
		(OR)		
7.	a)	What are the different types of resistive shunts used for impulse current measurements?	CO3,L1	5M
	b)	Explain the high voltage Schering bridge for the tan δ and capacitance measurement of insulators or bushings.	CO3,L2	5M
		Unit – IV		
8.	a)	What are the different power frequency tests done on insulators? Mention the procedure for testing.	CO4,L1	5M
	b)	Explain the significances of power factor tests and partial discharge tests on bushings	CO4,L2	5M
		(OR)		
9.	a)	Explain the method of impulse testing of high voltage transformers	CO4,L2	5M
	b)	List the common test facilities available in high-voltage laboratories	CO4,L4	5M

Scheme

IV/IV B.Tech (Regular) Degree Exam

18EE701 : High voltage Engineering

Seventh Semester, NOV, 2022, AR18

1a At higher fields, charged particles may gain sufficient energy between collision to cause ionization on impact with neutral molecules. It is known that during an ~~elastic~~ elastic collision, an electro loses little energy and rapidly builds up its kinetic energy which is supplied by an external field. During elastic collision a large part of kinetic energy is transformed into potential energy by ionizing the molecule struck by the electron. 1M

1b 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 1M

$$V_b = f(P.d)$$

1C. Liquids which are chemically pure, structurally simple and donot contain any impurity even in traces of 1 in 10^9 1M are known as pure liquids. In contrast, Commercial liquids used as insulating liquids are chemically impure and contains mixtures of complex organic molecules. In fact their behaviour is quite erratic

1d. For producing damped oscillations the source of high voltage is a tesla coil, which consists of an air-cored transformer. Its LV side is connected to the DC or AC supply circuit through a capacitor C_1 and a series element. C_2 is the equivalent capacitance of the high-voltage windg and the test object 1M

1e. Generation of high dc voltage using different methods like halfwave and fullwave rectifier, voltage doubler circuits, voltage multiplier circuit, cockcroft-walton circuits and vande graff generators 1M

1f High ohmic series resistance with micrometer. High dc voltages are usually measured by connecting a very high resistance in series with a micro ammeter. 1M

1g. sphere gaps, Generating voltmeters, high ohmic series resistance with micrometer, Resistance Potential Dividers. 1M

1h. Over voltage protection is an essential part of any electrical and electronic system. It ensures that the system runs as designed and undamaged despite changes in external conditions specifically those that cause over voltage and power surges. 1M

1i High voltage test on insulators that are normally conducted are usually subdivided as

1M

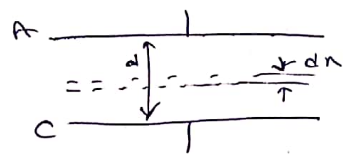
i) Type tests and (ii) the routine tests.

High voltage test on Insulators

A) power frequency tests and B) Impulse tests.

1j The voltage at which an electric discharge occurs between two electrodes that are separated by an Insulator. 1M

2a Townsend's first Ionization coefficient



The variation of current as a function of voltage was studied of townsend

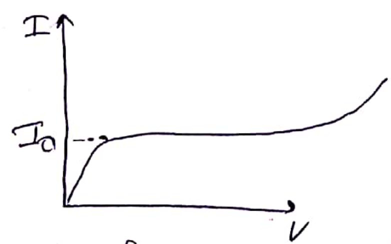


Fig: Variation of current as a function of voltage

Let no be the number of electrons leaving the cathode.

x be the distance moved from the cathode

n electrons

dx distance

dn additional electrons due to collision

$$dn = \alpha n\, dx$$

$$\frac{dn}{n} = \alpha dx$$

$$\ln n = \alpha x + A$$

$$x = 0 \quad n = n_0$$

$$\ln n_0 = A$$

$$\ln n = \alpha x + \ln n_0$$

$$\ln n - \ln n_0 = \alpha x$$

$$\ln \frac{n}{n_0} = \alpha x$$

2M

At $x = d$ $n = n_0 e^{\alpha d}$

$$I = I_0 e^{\alpha d}$$ $e^{\alpha d}$ is called electrons avelonce

Current Growth in the presence of secondary processes

n_0' = number of secondary electrons produced due to secondary (γ) processes

n_0'' = total number of electrons leaving the cathod

$$n_0'' = n_0 + n_0'$$

$$n_0 = n_0'' \exp(\alpha d)$$

$$n_0' = \gamma(n - (n + n_0'))$$

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

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

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

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

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

$$\gamma e^{\alpha d} \simeq 1$$ 3M

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

2b Suspended solid particle mechanism.

commercial liquids will always contain solid impurities either as fibers or as dispersed solid particles. The permittivity of these solids (ε_1) will always be different from that of the liquid (ε_2). Let us assume these particles to be sphere of radius r.

$$F = r^3 \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + 2\varepsilon_2} E . \frac{dE}{dx}$$

$$F = r^3 \frac{1 - \varepsilon_2/\varepsilon_1}{1 + 2\varepsilon_2/\varepsilon_1} E \frac{dE}{dx}$$ 2M

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

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

$$E_b = \frac{3E_0}{\varepsilon_2 + 2}$$

$$E_b = \frac{1}{\epsilon_2 - \epsilon_1} \left\{ \frac{2\pi\sigma(2\epsilon_2 + \varepsilon_1)}{r} \right\} \left[\frac{\pi}{4} \sqrt{\frac{V_b}{2rE_0}} - 1 \right] \Big\}^{1/2}$$

$$E_c = 600 \frac{\sqrt{\pi\sigma}}{\epsilon_2\ r} \left\{ \frac{\epsilon_2}{\epsilon_2 - \epsilon_1} - G \right] H$$

H^2

Electroconvection Breakdown:

$$V_e = \sqrt{\epsilon_2 / \rho}$$

$$V_d = KE$$ 3M

$$M\ \frac{V_e}{V_d} = \sqrt{\frac{\epsilon_2}{\rho}} / KE$$

3a.

Where solid dielectrics are subjected to high electric fields, failure occurs due to electrostatic compressive forces which can exceed the mechanical compressive strength. 2M

$$\epsilon_0 \epsilon_r \frac{V^2}{2d^2} = Y \ln\left[\frac{d_0}{d}\right]$$ Y = Young's Modulus

$$V^2 = d^2 \left[\frac{2Y}{\varepsilon_0 \epsilon_r}\right] \ln\left[\frac{d_0}{d}\right]$$

$d/d_0 = 0.6$ (or) $d_0/d = 1.67$ 3M

$$E_{max} = \frac{V}{d_0} = 0.6 \left[\frac{Y}{\epsilon_0 \epsilon_r}\right]^{1/2}$$

The above equation is only approximate as Y depends on the mechanical stress. Also when the material is subjected to high stresses the theory of elasticity does not hold good

3b. Break down due to treeing and tracking

1. we know that the strength of a chain is given by the strength of the weakest link in the chain

2. Solid material has some impurities

3. for example some gas pockets trapped in a solid material. the gas has a relative permittivity of unity and solid material Er, the electric field in the gas will be Er times the field in the solid materials

2M

4. As a result the gas breakdown at a relatively low voltage

5. The charge concentration is higher in void and give fields of the order 10mu/cm

6. Dielectric breakdown step by step and leads to complete rupture of the dielectric.

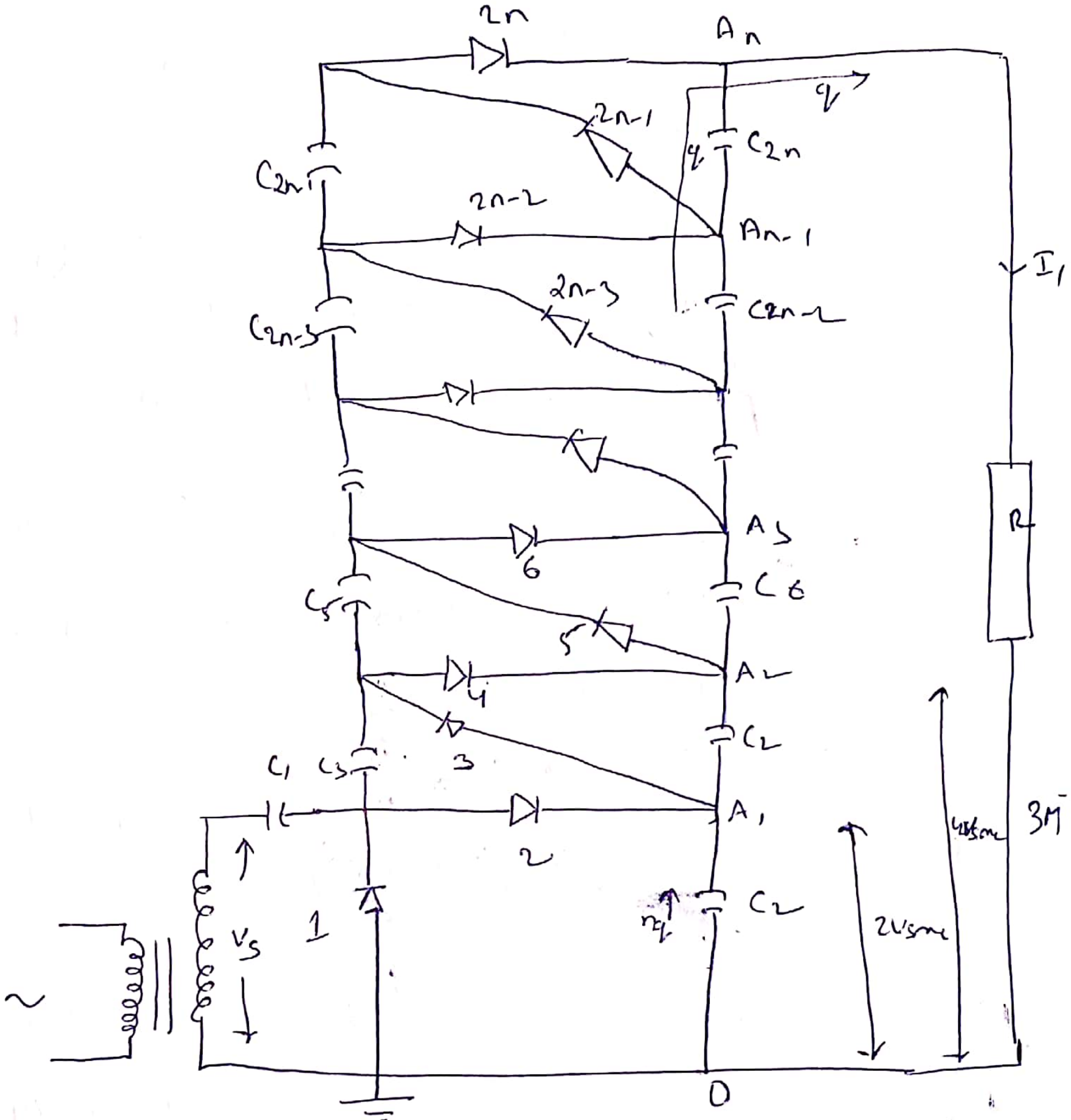
7. The treeing phenomenon can be demonstrated in a laboratory by applying impulse voltage b/w electrodes embedded in transparent solid dielectric

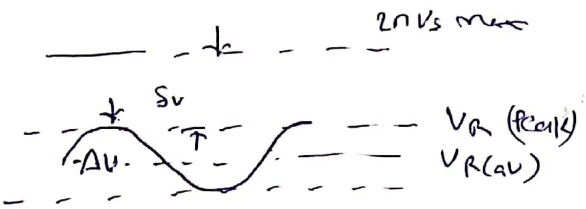
8. Suppose two electrode are separated by dielectric material and assembly placed outside of environment absorbed moisture or dust accumulated on the surface of materials 3M

9. Which leads to leakage current starts. → sparks → cause carbonization and volatilization → permanent carbon tracks on surface of Insulation

10 so tracking is the formation on the permanent on the surface. This tracking can be reduce by adding filters to the polymers

4a.





Fig(b) Tracing of load voltage drop δv and ripple Δv

$$RF = \frac{(V_{av})_{no\,load} - V_{av}}{V_{av}\ no\,load}$$

For n stage circuit the total ripple will be

$$2\delta V = \frac{I}{F}\left[\frac{1}{C'_n} + \frac{2}{C'_{n-1}} + \frac{3}{C'_{n-2}} + \cdots + \frac{n}{C'_1}\right]$$

$$\delta V = \frac{I}{2F}\left[\frac{1}{C'_n} + \frac{2}{C'_{n-1}} + \frac{3}{C'_{n-2}} + \cdots + \frac{n}{C'_1}\right]$$

$$C'_n = C'_{n-1} = \cdots C'_1 = C$$

$$\delta V = \frac{I}{2fC}\,\frac{n(n+1)}{2}$$

$$\delta V = \frac{In(n+1)}{4FC}$$

$$\Delta V_1 = \frac{3I}{FC}$$

$$\Delta V_2 = \{2\times3 + (3-1)\}\frac{I}{FC}$$

$$\Delta V_3 = (2\times3 + 2\times2 + 1)\frac{I}{FC}$$

For n-stage generator 2M

$$\Delta V_n = \frac{nI}{FC}$$

$$\Delta V_{n-1} = \frac{I}{FC}\{2n + (n-1)\}$$

$\vdots$

$$\Delta V = \Delta V_n + \Delta V_{n-1} + \cdots + \Delta V_1$$

omitting I/FC the series

$$T_n = n$$

$$T_{n-1} = 2n + (n-1)$$

$$T_{n-2} = 2n + 2(n-1) + (n-2)$$

$\vdots$

$$T_1 = 2n + 2(n-1) + 2(n-2) + \cdots + 2\times3 + 2\times2 + 1$$

$$T_1 = T_n + T_{n-1} + T_{n-2} + \cdots + T_1$$

$$\Delta V \simeq \frac{I}{FC}\,\frac{2}{3}n^3$$

$V_0 \quad \ldots \quad -I/C \quad \frac{2}{3}n^3$

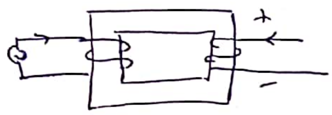
$$\frac{dV_{max}}{dn} = 2V_{max} - \frac{2}{3}\frac{I}{F_c}3n^2 = 0$$

$$(V_{0max})_{max} = \sqrt{\frac{V_{max}F_c}{I}}\left[2V_{max} - \frac{2F}{3F_c}\frac{V_{max}F_c}{I}\right]$$

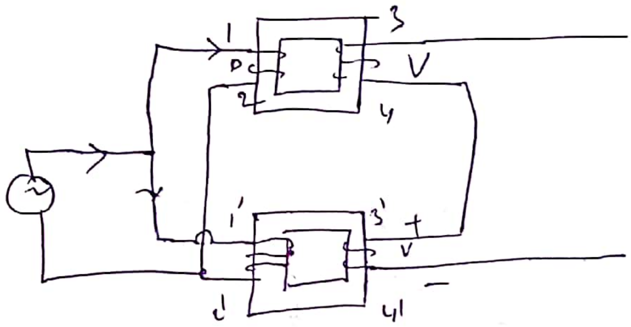
$$= \sqrt{\frac{V_{max}F_c}{I}}\ \frac{4}{3}V_{max}$$

4b. Cascaded transformer:

Let us look #



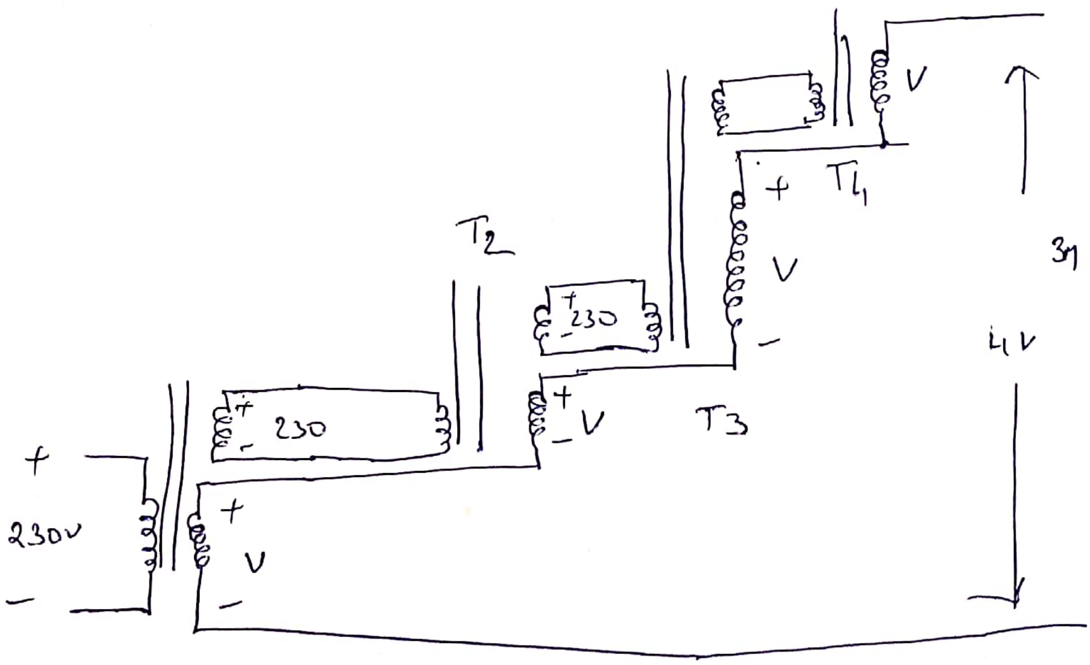
The cascaded transformer



1M

So consider we are to generate voltage in terms of Kilovolts we required large t/f & large space

To avoid this we can used no of transformer like



3M

Limitation: However there a limitations with regard to the number of stages as the lower transformer have to supply the energy for the upper one.

1. The very small ripple factor 2) High stability 3 fast response 4) Small stored energies are the main Advantages of this circuit. 1M

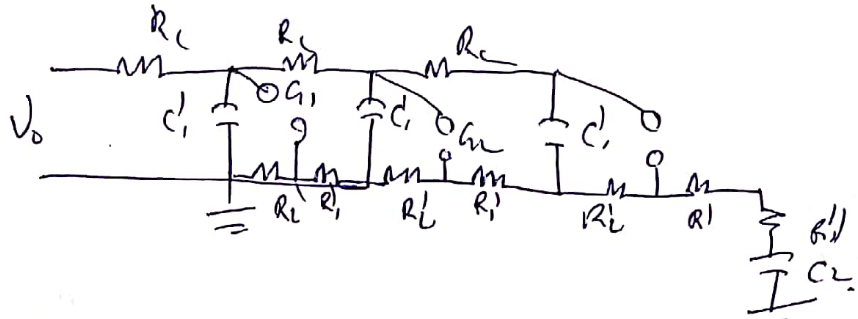
5a. A single capacitor C_1 may be used for voltages upto 200kV. Beyond this voltage a single capacitor and its charging unit may be too costly, and the size becomes very large. The cost and size of the impulse generator increase at a rate of the square or cube of the voltage rating. 1M

(i) The physical size of the circuit elements becomes very large

(ii) High DC charging voltage is required 1M

(iii) Suppression of corona discharge from the structure and leads during the charging period is difficult

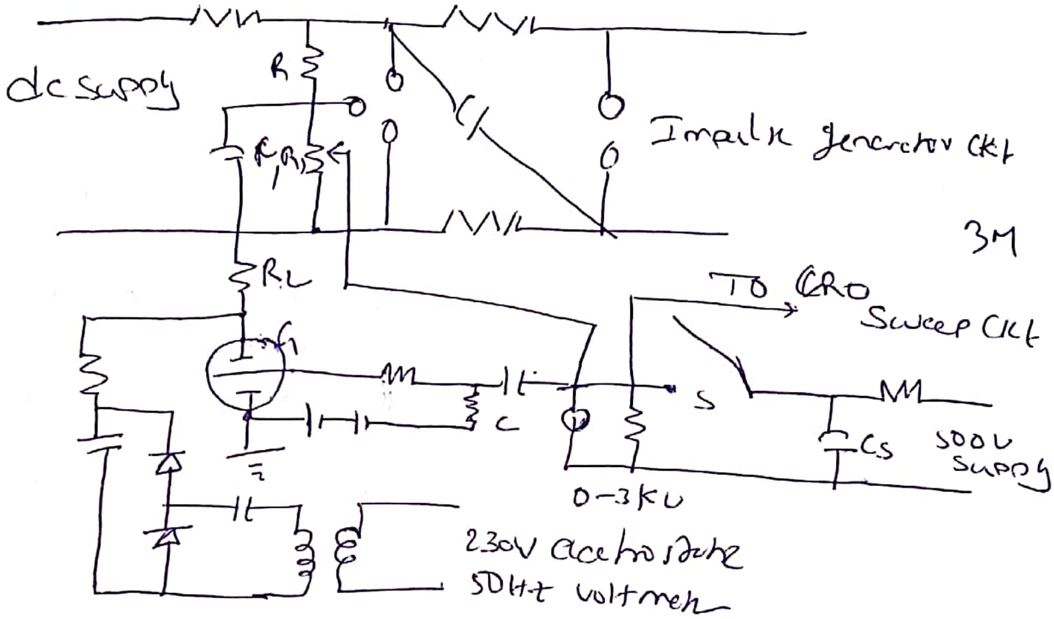
(v) Switching of very high voltages with spark gaps is difficult



3M

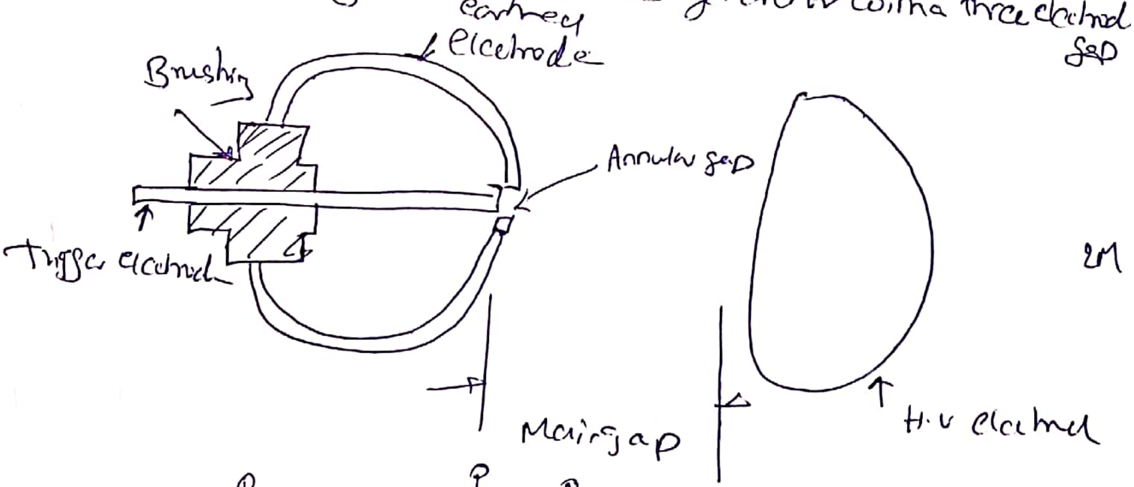
Fig. A 3 stage marx impulse generator in ckt & connection

5b In large impulse generators the spark gaps are generally sphere gaps or gaps formed by hemispherical electrodes. The gaps are arranged such that sparking of one gap results in automatic sparking of other other gap as overvoltage is also impressed on the other.



3M

Fig: Tripping of an impulse generator with a three electrode gap



2M

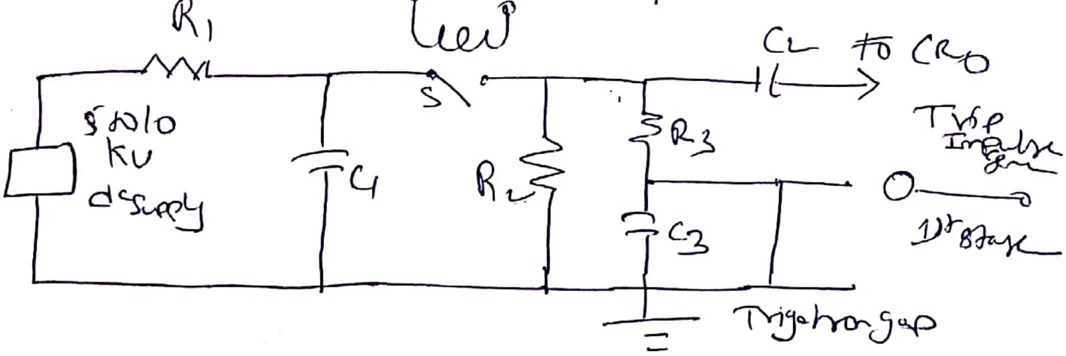
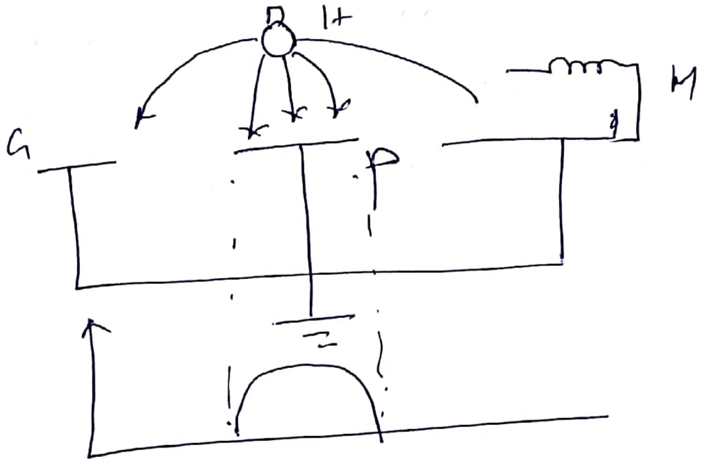


Fig: Trigatron gap and tripping circuit

6a. Similar to electrostatic voltmeter the generating voltmeter provides loss free measurement of dc and ac voltages



2M

Principle of generating voltmeter

$$q(t) = C(t)\,v(t)$$

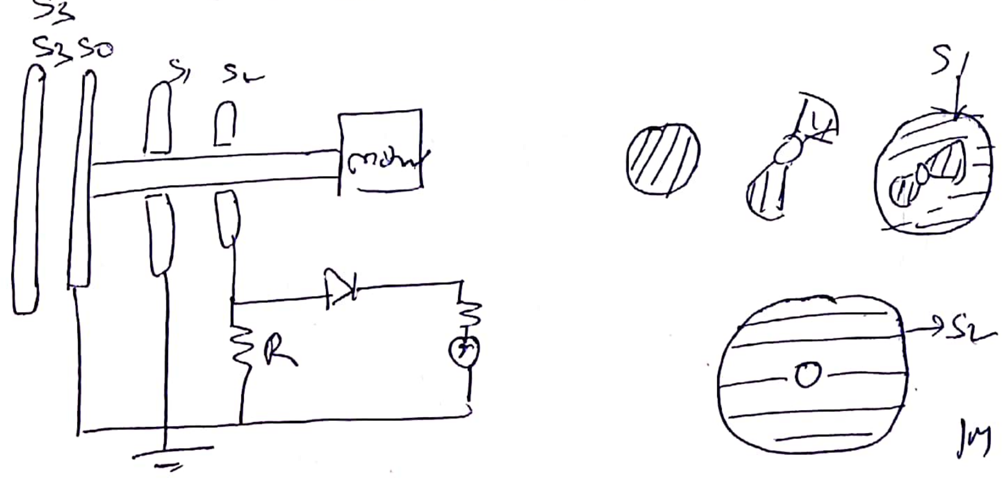
$$\frac{dq(t)}{dt} = \frac{d}{dt}\left(c(t)\,v(t)\right)$$

$$i(t) = C(t)\frac{dv(t)}{dt} + v(t)\frac{dc(t)}{dt}$$

$$i(t) = v\frac{dc(t)}{dt} \quad -①$$ 2M

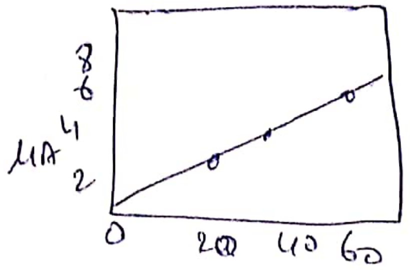
$$c(t) = 2\frac{C_m}{T_c}t \quad -②$$

$$C = C_0 + C_m \sin\omega t$$



1M

Fig. Schematic diagram of a generating voltmeter



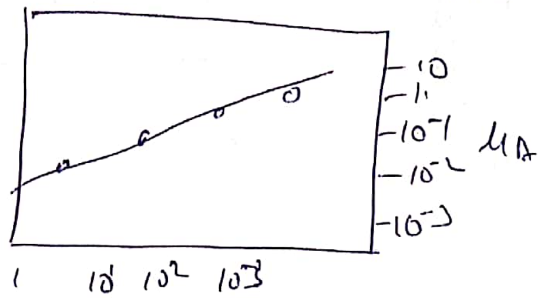
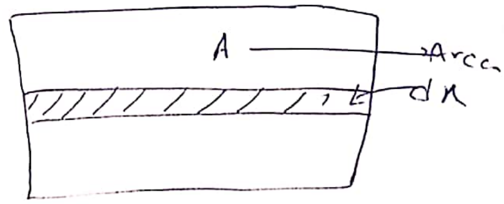


Fig. Rotating cylinder type b) Rotating vane type

6b. Electrostatic voltmeter

$W_d = \frac{1}{2} \epsilon E^2$

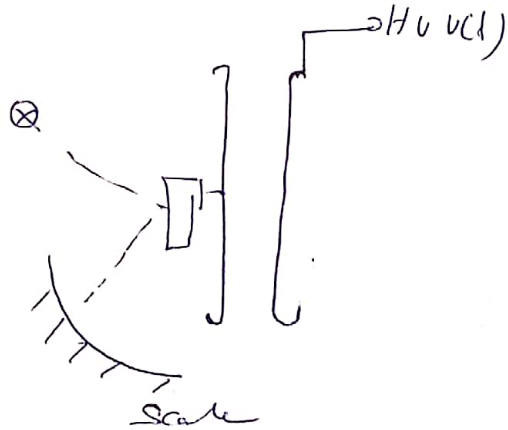


$W_d = \frac{dw}{dv}$

$dw = W_d \, dv$

$dw = \frac{1}{2} \epsilon E^2 dv$

$dw = \frac{1}{2} \epsilon E^2 A \, dx$



$dw = F dx$ 3M

$F = \frac{dw}{dx}$

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

$F = \frac{1}{2} \epsilon E^2 A$

$F = \frac{1}{T} \int_0^T F(t) \, dt$

$= \frac{1}{T} \int_0^T \frac{1}{2} \epsilon E^2 A \, dt$

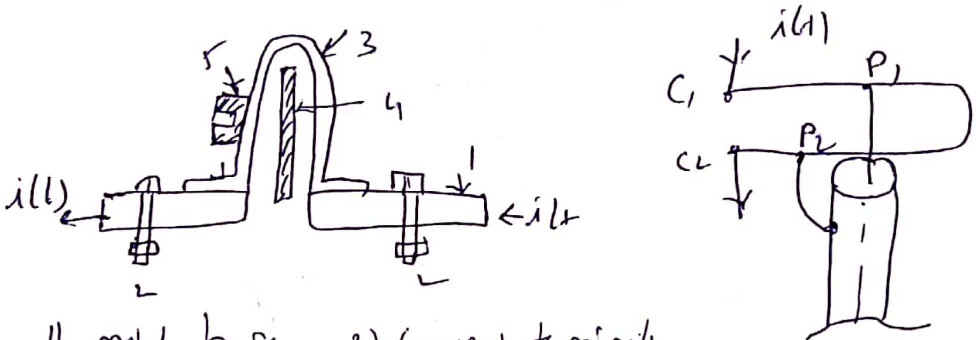
$= \frac{1}{T} \int_0^T \frac{1}{2} \epsilon \frac{V^2}{d^2} A \, dt$ 2M

$= \frac{1}{2} \frac{\epsilon A}{d^2} V_{rms}^2$

$F \propto V_{rms}^2$

7a. The resistance shunt is usually designed in the following manner to reduce the stray effects P-15

(a) Bifilar flat strip design

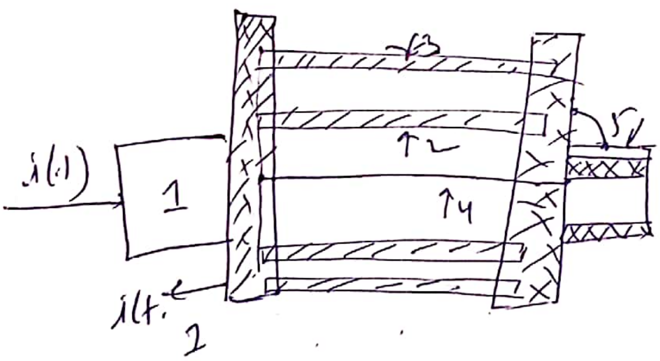


1) metal base 2) current terminals
3) bifilar resistance strip 4) Insulating spacer
5) coaxial UHF connector

2M

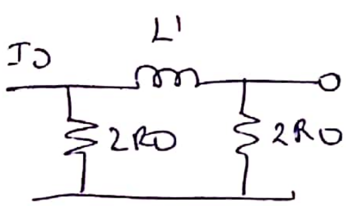
(b) Coaxial tubular (or) Park's shunt

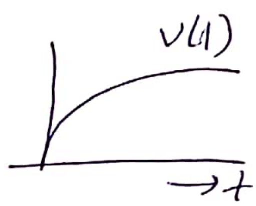
$$L_0 = \frac{\mu d l}{2\pi r}$$



1) Current terminals
2) coaxial cylindrical resistive element
3) Coaxial cylindrical return conductor
4) potential pick up lead
5) UHF coaxial connector

2M

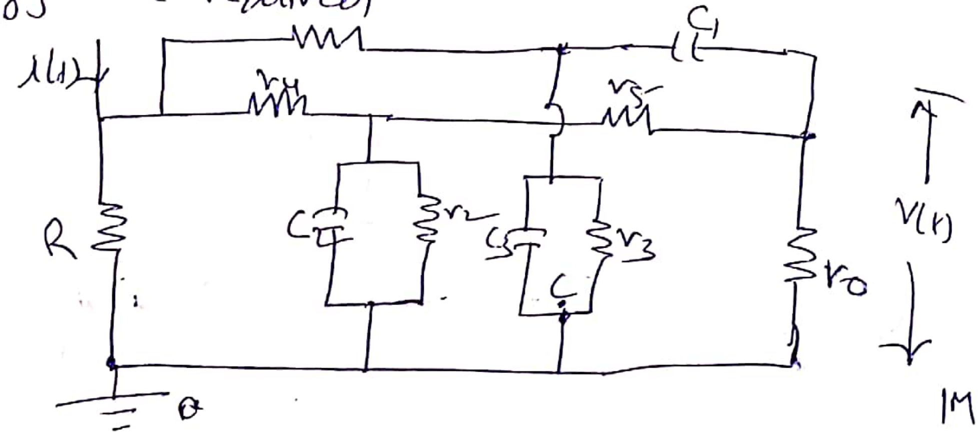




R0: dc resistance

c) Squirrel cage Shunts

In certain applications such as post arc current measurement high ohmic value shunts which can dissipate larger energy are required



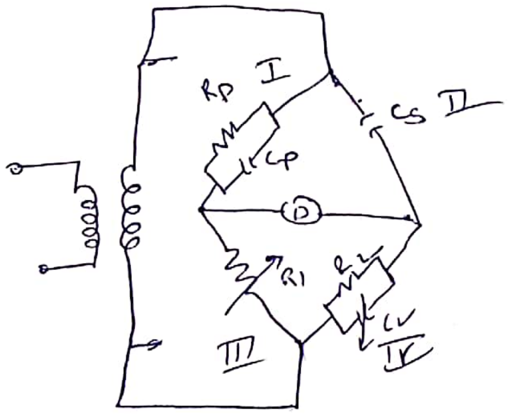
1M

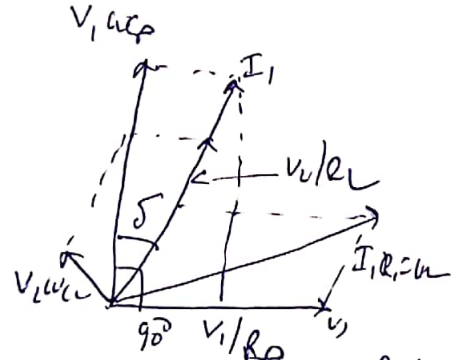
R - shunt resistance

$r_1 - r_6$ - Resistance and capacitors in compensating double T network and $C_1 - C_3$

Fig: compensating network for squirrel cage shunts

7b.





3M

Fig: a) Schering Bridge

b) Phasor diagram

Case I Parallel.

$$\frac{Z_I}{Z_{II}} = \frac{Z_{III}}{Z_{IV}}$$

$$Z_I = \frac{R_p}{1+j\omega C_p R_p}$$

$$Z_{II} = \frac{1}{j\omega C_s}$$

$$Z_{III} = R_1$$

$$Z_{IV} = \frac{R_L}{1+j\omega C_2 R_L}$$

from balance equation

$$\frac{R_p}{R_1(1+j\omega C_p R_p)} = \frac{1/j\omega C_s (1+j\omega C_2 R_L)}{R_L}$$

Equating real part

$$\frac{R_p}{R_1(1+\omega^2 C_p^2 R_p^2)} = \frac{C_2}{C_s}$$ 2M

equating imaginary part

$$\frac{\omega C_p R_p^2}{R_1(1+\omega^2 C_p^2 R_p^2)} = \frac{1}{\omega C_s R_L}$$

From phasor diagram

$$\tan\delta = \frac{V_1/R_p}{V_1 \omega C_p} = \omega C_2 R_L$$

$$\cos^2\delta = \frac{\omega^2 C_p^2 R_p^2}{1+\omega^2 C_p^2 R_p^2}$$

$$C_p \simeq C_s \frac{R_L}{R_1}$$

$$R_p = \frac{R_1}{\omega^2 C_L C_S R_L^2}$$

Case II

$$Z_1 = R_s - \frac{j}{\omega C_S}$$

$$\frac{Z_1}{Z_{II}} = \frac{Z_{III}}{Z_{IV}}$$

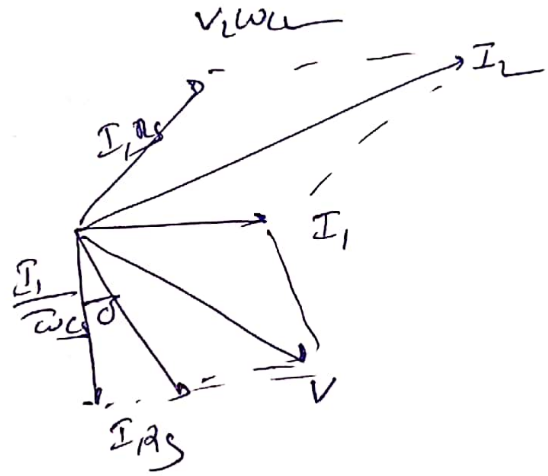
$$R_S = R_1 \frac{C_2}{C_3'}$$

$$C_S = C_S' \frac{R_L}{R_1}$$

$$\tan\delta_S = \frac{I_1 R_S}{I_1 / \omega C_S}$$

$$= \omega C_S R_S$$

$$\boxed{\tan\delta_S = \omega C_S R_S}$$



8a. High voltage tests include (i) the power frequency tests and (ii) impulse tests. All the insulators are tested for both categories of test. 1M

Power frequency tests:

(i) Dry and wet flashover tests: In these tests the ac voltage of power frequency is applied across the insulators and increased at a uniform rate of about 2% per second of 75% of the estimated test voltage, to such a value that a breakdown occurs along the surface of the insulator. If the test is conducted under normal conditions without any rain or precipitation 2M

it is ...

If the test is done under conditions of rain it is called wet flashover test. In general wet tests are not intended to reproduce the actual operating conditions but only to provide a criterion based on experience that a satisfactory service operation will be obtained.

The characteristics of the spray are

a) precipitation rate : 3 ± 100% (mm/min)
b) direction = 45° to the vertical
c) conductivity of water = 100 micro Siemens ± 10%
d) water temperature = ambient ± 15°C.

Average precipitation rate

vertical component = 1 to 1.5 mm/min
horizontal component = 1 to 1.5 mm/min

Limits for individual measurement = 0.5 to 2.0 mm/min
temperature of collected water = ambient temperature ± 15°C
and the conductivity of water corrected to 20°C = 100 ± 15 μS

(ii) Wet and Dry withstand tests (one minute): In these sets the voltage specified in the relevant specification is applied under dry or wet conditions for a period of one minute with an insulator mounted as in service conditions. The test piece should withstand the specified voltage

8b

Testing of Bushings:

Power frequency tests:

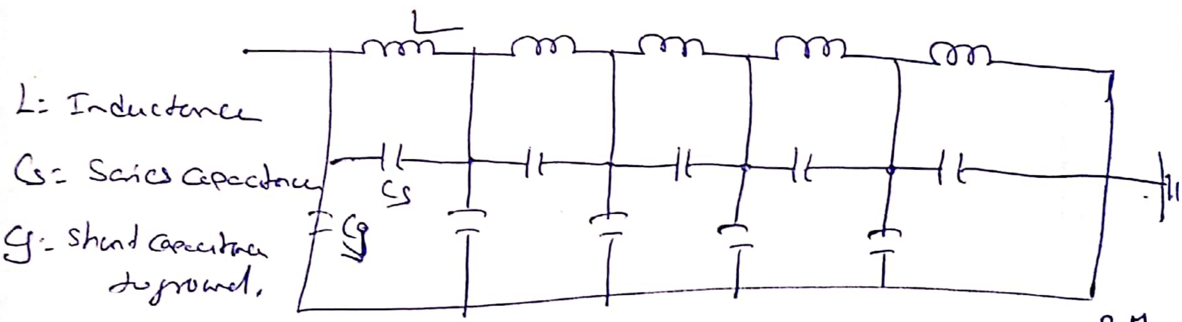
1M

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 protion goes to the detector side of the high voltage Schering bridge. voltage is applied up to the line value in increasing steps and then reduced The capacitance and power factor are recorded at each step The characteristics of power factor or tanδ versus applied voltage is drawn. This is a normal routine test but sometimes may be conducted on parcentage basis 2M

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 2M in service. This is now a routine test for high voltage bushings.

9a. Impulse testing of transformers

The purpose of the impulse tests is to determine the ability of the insulation of the transformers to withstand the transient voltage due to lighting etc. Since the transients are impulses of short rise time, the voltage distribution along the transformer winding will not be uniform. The equivalent circuit of a transformer winding for impulses is shown in figure below. If an impulse wave is applied to such a network. the voltage distribution along the element will be uneven and oscillations will be set in producing voltages much higher than the applied voltage 1M



2M

Fig: Equivalent circuit of transformer winding for impulses

Impulse testing of transformers is done using both the Full wave and the chopped wave of the standard impulse, produced by a rod gap with a chopping times of 3 to 6μs.

To prevent large overvoltages being induced in the windings not under test they are short circuited and connected to ground. But the short circuiting reduces the impedance of the transformer and hence poses problems in adjusting the standard waveshape of the impulse generators. It also reduces the sensitivity of detection,

a) Procedure for Impulse testing

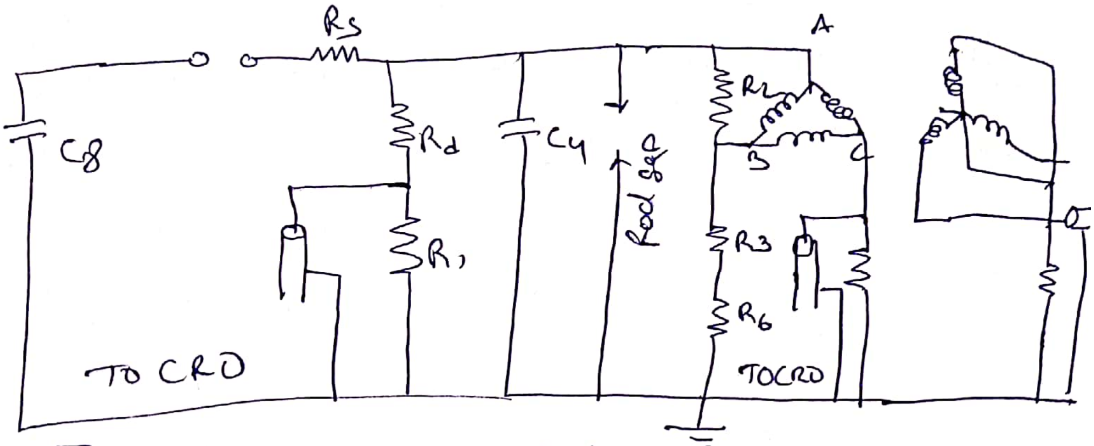


Figure : Arrangement of transformer for impulse testing

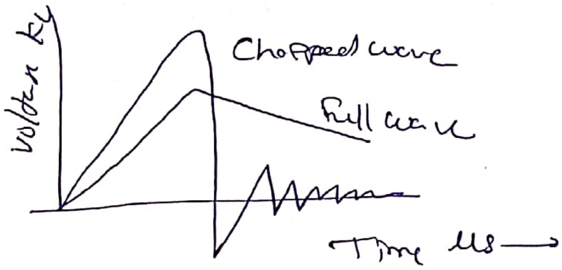


Fig. Full wave and chopped wave.

2M

b) Detection and location of fault during impulse testing

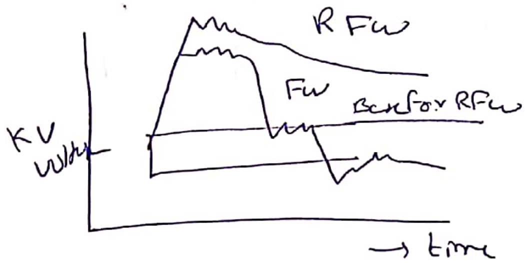


Fig: Failure from the line lead to ground through oil

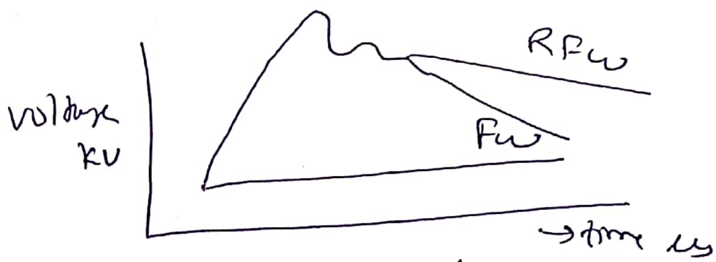


Fig. 8.5% windg failed.

9b. Test facilities provided in high voltage laboratories.

A high voltage laboratory is expected to carry out withstand and /or flashover tests at high voltages on the following transmission system equipment 1M

(i) transformers
(ii) Lightning arresters
(iii) Isolators and circuit breakers
(iv) Different types of insulators.
(v) Cables 2M
(vi) Capacitors
(vii) Line hardware and accessories
(viii) other equipment like reactors etc.

Different tests conducted on the above equipment

(i) power frequency withstand tests - wet and dry
(ii) Impulse tests
(iii) dc withstand tests
(iv) switching surge tests ·2M.
(v) Testing under polluted atmospheric conditions
(vi) partial discharge and RIV measurements
(vii) High current tests.

Scheme prepared by

M. Satyadinesh

1) Dr M. S. Dinesh
Asst professor.

Signature of HoD

K. Kamaladevi.

2. Dr K. Kamala Devi
Asst., Professor.