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Internal Test2 –December 2022

Sub:	High Voltage Engineering							Code:	18EE56
Date:	01/12/2022	Duration:	90 mins	Max Marks:	50	Sem:	**VA &B**	Branch:	EEE

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

		Marks	OBE CO	OBE RBT
1.	Define impulse wave. Discuss how impulse wave is generated in laboratory with a neat diagram of Marx generator.	[2+3+5]	CO3	L2

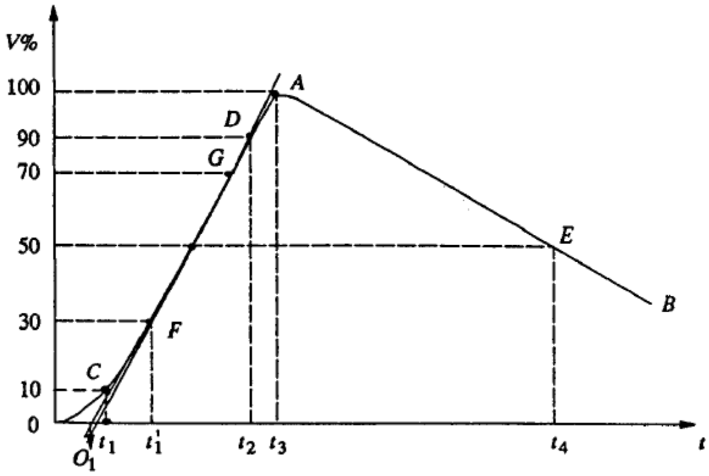


Fig. 6.14 Impulse waveform and its definitions

Impulse waves are specified by defining their rise or front time, fall or tail time to 50% peak value, and the value of the peak voltage.

Thus 1.2/50 µs, 1000 kV wave represents an impulse voltage wave with a front time of 1.2 (is, fall time to 50% peak value of 50 µs and a peak value of 1000 kV.
Theoretical Representation of impulse Waves

The impulse waves are generally represented by the Eq.

V0 in the equation represents a factor that depends on the peak value. when time t is expressed in microseconds, α and β control the front and tail times of the wave respectively.

Multistage Impulse Generators—Marx Circuit

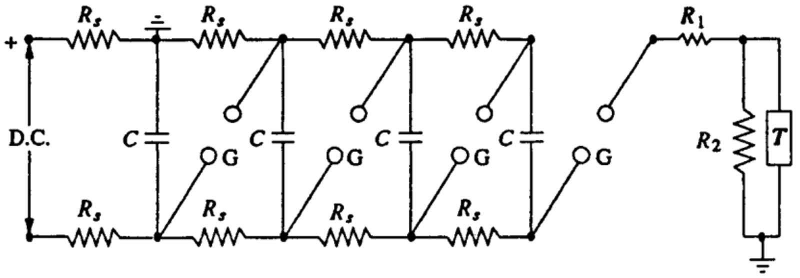


Fig. 6.17a Schematic diagram of Marx circuit arrangement for multistage impulse generator

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.

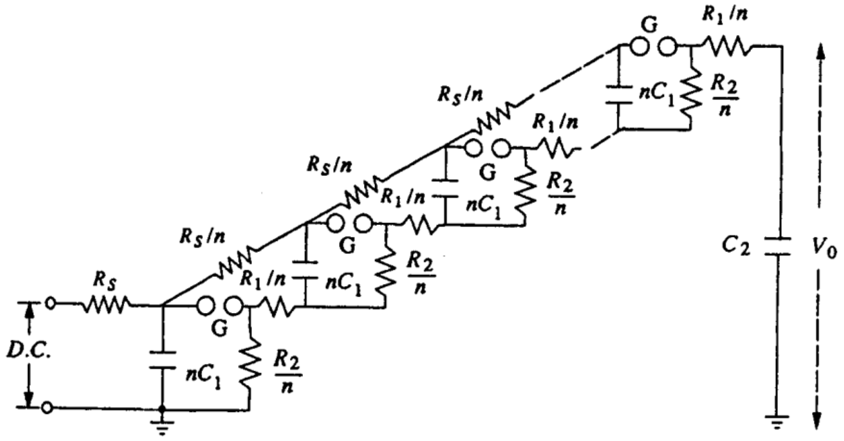


Fig. 6.17b Multistage impulse generator incorporating the series and wave tail resistances within the generator

he schematic diagram of Marx circuit and its modification are shown in Figs. 6.17a and 6.17b, respectively.

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 to R1/n and put in series with the gap G.

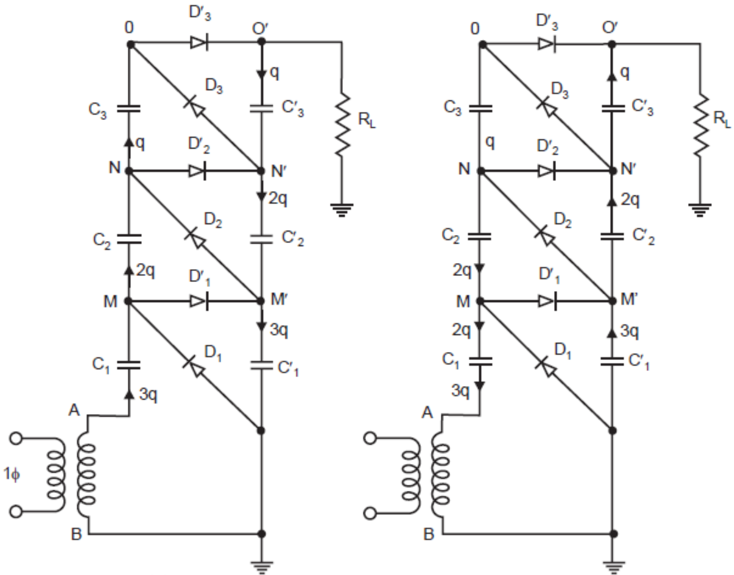
R2 is also divided into n parts and arranged across each capacitor unit after the gap G.
This arrangement saves space, and also the cost is reduced.
But, in case the waveshape is to be varied widely, the variation becomes difficult.
The additional advantages gained by distributing R1 and R2 inside the 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
- 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.

2.	Explain with neat sketches Cockroft-Walton voltage multiplier circuit. Derive the expression for a) voltage regulation, b) ripple, c) optimum no of stages when the circuit is loaded.	[4+6]	CO3	L2



(a) (b)

Fig. 2.4 (*a*) Charging of smoothening Column (*b*) Charging of oscillating column

During the transfer cycle shown in Fig. 2.4 (*b*), the diodes D_1, D_2, D_3, conduct when B is positive with reference to A. Here C'_2 transfers q charge to C_3, C_1 transfers charge $2q$ to C_2 and the transformer provides change $3q$.

For n-stage circuit, the total ripple will be

$$2\delta V = \frac{I}{f}\left(\frac{1}{C'_n} + \frac{2}{C'_{n-1}} + \frac{3}{C'_{n-2}} + \ldots + \frac{n}{C'_1}\right)$$

or

$$\delta V = \frac{I}{2f}\left(\frac{1}{C'_n} + \frac{2}{C'_{n-1}} + \frac{3}{C'_{n-2}} + \ldots + \frac{n}{C'_1}\right) \qquad (2.7)$$

From equation (2.7), 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.*, $C'_n = C'_{n-1} = \ldots C'_1 = C$ and the ripple is given as

$$\delta V = \frac{I}{2fC}\,\frac{n(n+1)}{2} = \frac{In(n+1)}{4fC} \qquad (2.8)$$

The second quantity to be evaluated is the voltage drop ΔV which is the difference between the theoretical no load voltage $2nV_{max}$ and the onload voltage. In order to obtain the voltage drop ΔV refer to Fig. 2.4 (*a*).

Here C'_1 is not charged upto full voltage $2V_{max}$ but only to $2V_{max} - 3q/C$ because of the charge given up through C_1 in one cycle which gives a voltage drop of $3q/C = 3I/fC$

The voltage drop in the transformer is assumed to be negligible. Thus, C_2 is charged to the voltage

$$\left(2V_{max} - \frac{3I}{fC}\right) - \frac{3I}{fC}$$

since the reduction in voltage across C'_3 again is $3I/fC$. Therefore, C'_2 attains the voltage

$$2V_{max} - \left(\frac{3I + 3I + 2I}{fC}\right)$$

In a three stage generator

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

$$\Delta V_2 = \{2 \times 3 + (3 - 1)\}\,\frac{I}{fC}$$

$$\Delta V_3 = (2 \times 3 + 2 \times 2 + 1)\,\frac{I}{fC}$$

In general for a *n*-stage generator

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

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

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

$$\vdots$$

$$\Delta V_1 = \frac{I}{fC}\ \{2n + 2\,(n-1) + 2\,(n-2) + \ldots\ 2 \times 3 + 2 \times 2 + 1\}$$

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

After omitting I/fC, the series can be rewritten as:

$$\begin{aligned}
T_n &= n \\
T_{n-1} &= 2n + (n-1) \\
T_{n-2} &= 2n + 2\,(n-1) + (n-2) \\
T_{n-3} &= 2n + 2\,(n-1) + 2\,(n-2) + (n-3) \\
&\vdots \\
T_1 &= 2n + 2\,(n-1) + 2\,(n-2) + \ldots + 2 \times 3 + 2 \times 2 + 1 \\
T &= T_n + T_{n-1} + T_{n-2} + \ldots + T_1
\end{aligned}$$

To sum up we add the last term of all the terms (T_n through T_1) and again add the last term of the remaining term and so on, *i.e.,*

$$\begin{aligned}
&[n + (n-1) + (n-2) + \ldots + 2 + 1] \\
&+ [2n + 2\,(n-1) + 2\,(n-2) + \ldots + 2 \times 2] \\
&+ [2n + 2\,(n-1) + \ldots + 2 \times 4 + 2 \times 3] \\
&+ [2n + 2\,(n-1) + \ldots + 2 \times 4] \\
&+ [2n + 2\,(n-1) + 2\,(n-2) + \ldots + 2 \times 5] + \ldots\ [2n]
\end{aligned}$$

Rearranging the above terms we have

$$\begin{aligned}
&n + (n-1) + (n-2) + \ldots + 2 + 1 \\
&+ [2n + 2\,(n-1) + 2\,(n-2) + \ldots + 2 \times 2 + 2 \times 1] - 2 \times 1 \\
&+ [2n + 2\,(n-1) + 2\,(n-2) + \ldots + 2 \times 3 + 2 \times 2 + 2 \times 1] - 2 \times 2 - 2 \times 1 \\
&+ [2n + 2\,(n-1) + 2\,(n-2) + \ldots + 2 \times 4 + 2 \times 3 + 2 \times 2 + 2 \times 1] \\
&- 2 \times 3 - 2 \times 2 - 2 \times 1 \\
&\vdots \\
&[2 \times n + 2\,(n-1) + \ldots + 2 \times 2 + 2 \times 1] - [2\,(n-1)] \\
&+ 2\,(n-2) + \ldots + 2 \times 2 + 2 \times 1]
\end{aligned}$$

or $\quad n + (n-1) + (n-2) + \ldots + 2 + 1$

Plus $(n - 1)$ number of terms of $2\,[n + (n-1) + \ldots + 2 + 1]$

minus $2\,[1 + (1 + 2) + (1 + 2 + 3) + \ldots + \ldots\ \{1 + 2 + 3 + \ldots\ (n-1)\}]$

The last term (minus term) is rewritten as

$$2\,[1 + (1 + 2) + \ldots + \{1 + 2 + 3 + \ldots\ (n-1)\} + \{1 + 2 + \ldots + n\}]$$
$$-\,2\,[1 + 2 + 3 + \ldots + n]$$

The *n*th term of the first part of the above series is given as

$$t_n = \frac{2n\,(n+1)}{2} = (n^2 + n)$$

Therefore, the above terms are equal to

$$\begin{aligned}
&= \sum (n^2 + n) - 2 \sum n \\
&= \sum (n^2 - n)
\end{aligned}$$

Taking once again all the term we have

$$T = \sum n + 2\,(n-1)\sum n - \sum (n^2 - n)$$

$$= 2n \sum n - \sum n^2$$

$$= 2n \,.\, \frac{n\,(n+1)}{2} - \frac{n\,(n+1)\,(2n+1)}{6}$$

$$= \frac{6\,(n^3 + n^2) - n\,(2n^2 + 3n + 1)}{6}$$

$$= \frac{6n^3 + 6n^2 - 2n^3 - 3n^2 - n}{6}$$

$$= \frac{4n^3 + 3n^2 - n}{6} = \frac{2}{3}n^3 + \frac{n^2}{2} - \frac{n}{6}$$

Here again the lowest capacitors contribute most to the voltage drop ΔV and so it is advantageous to increase their capacitance in suitable steps. However, only a doubling of C_1 is convenient as this capacitors has to withstand only half of the voltage of other capacitors. Therefore, ΔV_1 decreases by an amount nI/fC which rreduces ΔV of every stage by the same amount *i.e.*, by

$$n \,.\, \frac{nI}{2fC}$$

Hence $$\Delta V = \frac{I}{fC}\left(\frac{2}{3}n^3 - \frac{n}{6}\right) \tag{2.10}$$

If $n \geq 4$ we find that the linear term can be neglected and, therefore, the voltage drop can be approximated to

$$\Delta V \approx \frac{I}{fC} \cdot \frac{2}{3}n^3 \tag{2.11}$$

Substituting n_{opt} in equation (2.12) we have

$$(V_{0\,max})_{max} = \sqrt{\frac{V_{max}\,fC}{I}}\left(2V_{max} - \frac{2I}{3fC}\,\frac{V_{max}\,fC}{I}\right)$$

$$= \sqrt{\frac{V_{max}\,fC}{I}}\left(2V_{max} - \frac{2}{3}\,V_{max}\right)$$

$$= \sqrt{\frac{V_{max}\,fC}{I}} \cdot \frac{4}{3}\,V_{max} \tag{2.14}$$

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.

The maximum output voltage is given by

$$V_{0\,max} = 2nV_{max} - \frac{I}{fC} \cdot \frac{2}{3}n^3 \tag{2.12}$$

From (2.12) it is clear that for a given number of stages, a given frequency and capacitance of each stage, the output voltage decrease linearly with load current I. For a given load, however, $V_0 = (V_{0max} - V)$ may rise initially with the number of stages n, and reaches a maximum value but decays beyond on optimum number of stage. The optimum number of stages assuming a constant V_{max}, I, f and C can be obtained for maximum value of $V_{0\,max}$ by differentiating equation (2.12) with respect to n and equating it to zero.

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

$$= V_{max} - \frac{I}{fC}n^2 = 0$$

or $$n_{opt} = \sqrt{\frac{V_{max}\,fC}{I}} \tag{2.13}$$

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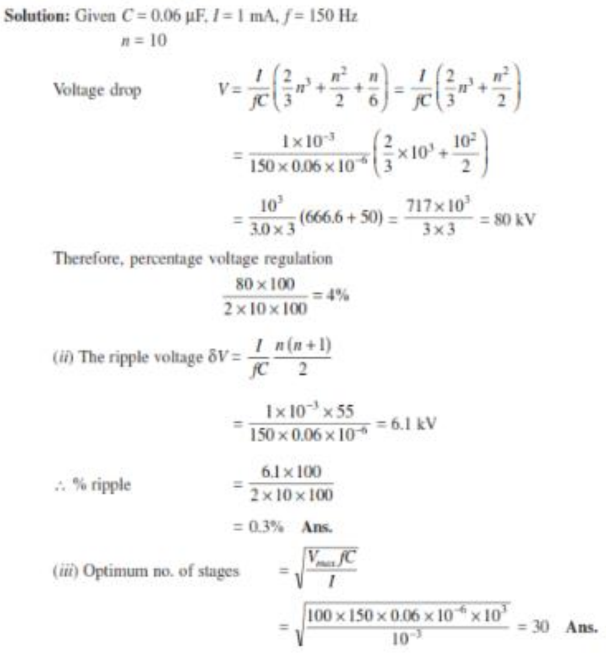
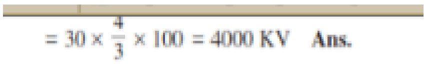
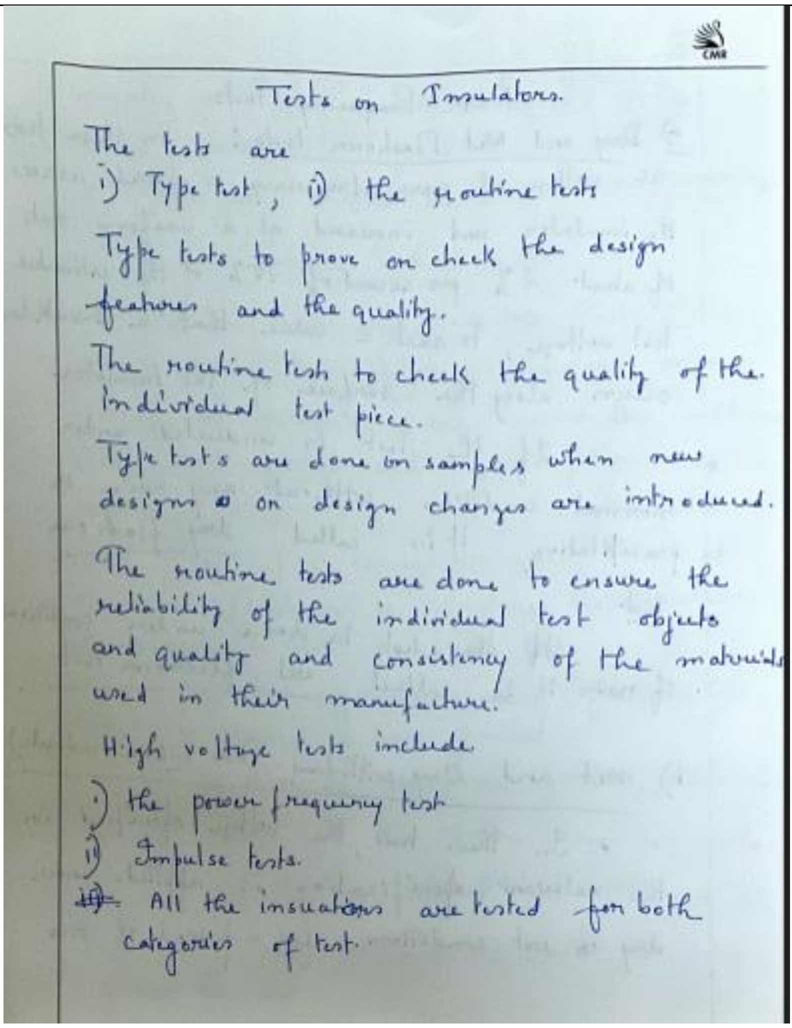
3.	A ten stage Cockraft-Walton circuit has all capacitors of 0.06 **μ**F. The secondary voltage of the supply transformer is 100 kV at a frequency of 150 Hz. If the load current is 1 mA, determine (i) voltage regulation (ii) the ripple (iii) the optimum number of stages for maximum output voltage (iv) the maximum output voltage.  **Solution:** Given $C = 0.06\ \mu F, I = 1\ mA, f = 150\ Hz$ $n = 10$ Voltage drop $V = \frac{I}{fC}\left(\frac{2}{3}n^3 + \frac{n^2}{2} + \frac{n}{6}\right) = \frac{I}{fC}\left(\frac{2}{3}n^3 + \frac{n^2}{2}\right)$ $= \frac{1 \times 10^{-3}}{150 \times 0.06 \times 10^{-6}}\left(\frac{2}{3} \times 10^3 + \frac{10^2}{2}\right)$ $= \frac{10^3}{3.0 \times 3}(666.6 + 50) = \frac{717 \times 10^3}{3 \times 3} = 80\ kV$ Therefore, percentage voltage regulation $\frac{80 \times 100}{2 \times 10 \times 100} = 4\%$ (*ii*) The ripple voltage $\delta V = \frac{I}{fC}\frac{n(n+1)}{2}$ $= \frac{1 \times 10^{-3} \times 55}{150 \times 0.06 \times 10^{-6}} = 6.1\ kV$ $\therefore$ % ripple $= \frac{6.1 \times 100}{2 \times 10 \times 100}$ $= 0.3\%$ **Ans.** (*iii*) Optimum no. of stages $= \sqrt{\frac{V_{max} fC}{I}}$ $= \sqrt{\frac{100 \times 150 \times 0.06 \times 10^{-6} \times 10^3}{10^{-3}}} = 30$ **Ans.** -  $= 30 \times \frac{4}{3} \times 100 = 4000\ KV$ **Ans.** - Vmax=	[10]	CO3	L3
4.	Discuss various electrical tests done on insulator.	[10]	CO6	L2



Tests on Insulators.

The tests are

i) Type test, ii) the routine tests

Type tests to prove on check the design features and the quality.

The routine test to check the quality of the individual test piece.

Type tests are done on samples when new designs on design changes are introduced.

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.

High voltage tests include

i) the power frequency test

ii) Impulse tests.

~~iii)~~ All the insuators are tested for both categories of test.

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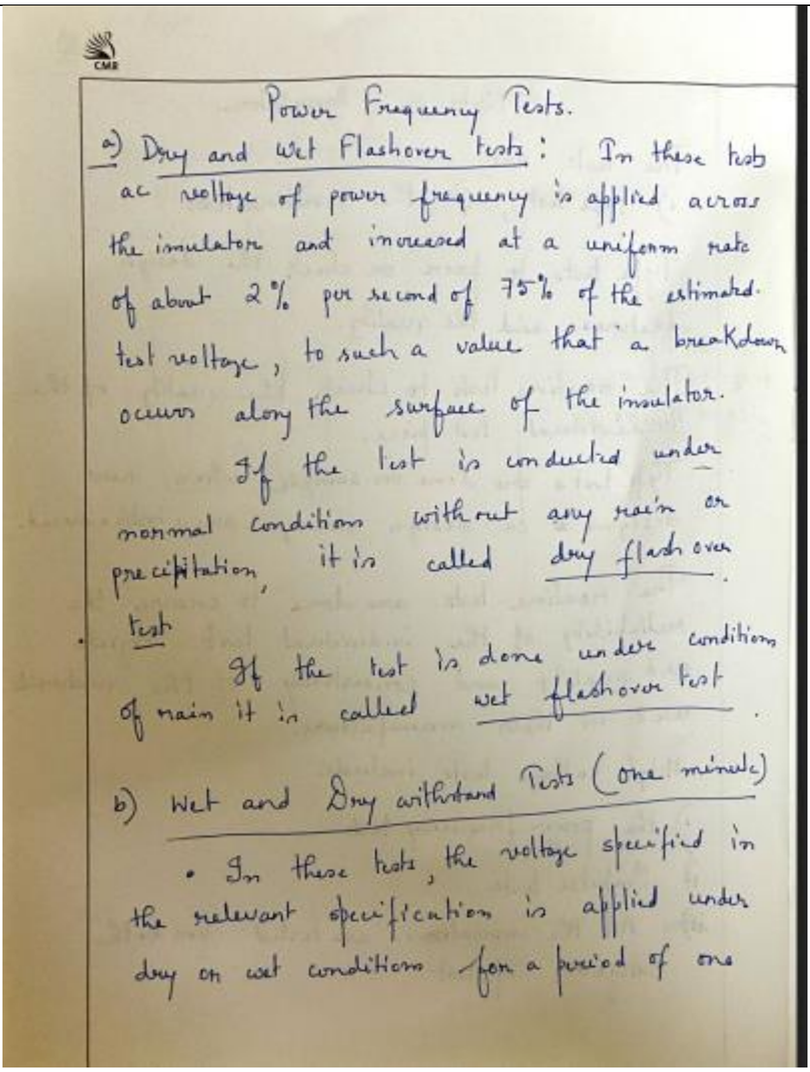


Power Frequency Tests.

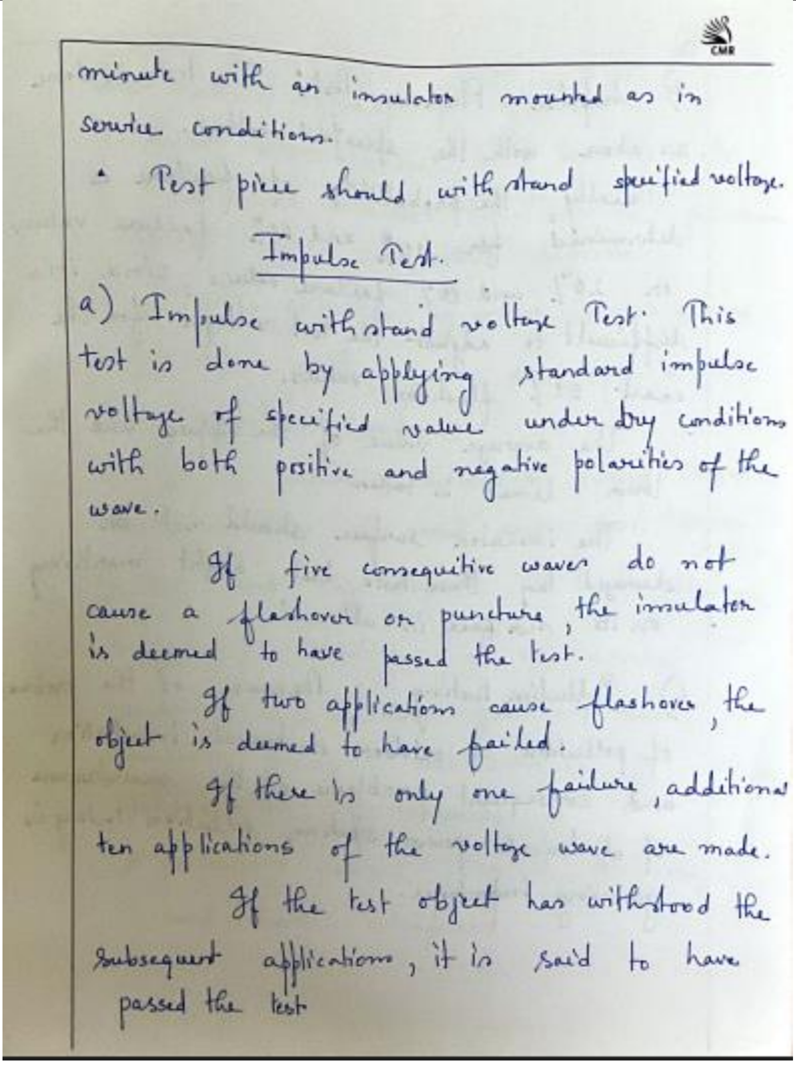
a) Dry and Wet Flashover tests: In these tests ac voltage of power frequency is applied across the insulator and increased at a uniform rate of about 2% per second of 75% of the estimated test voltage, to such a value that a breakdown occurs along the surface of the insulator.

If the test is conducted under normal condition without any rain or precipitation, it is called dry flash over test.

If the test is done under conditions of rain it is called wet flashover test.

b) Wet and Dry withstand Tests (one minute)

- In these tests, 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.

- Test piece should withstand specified voltage.

Impulse Test.

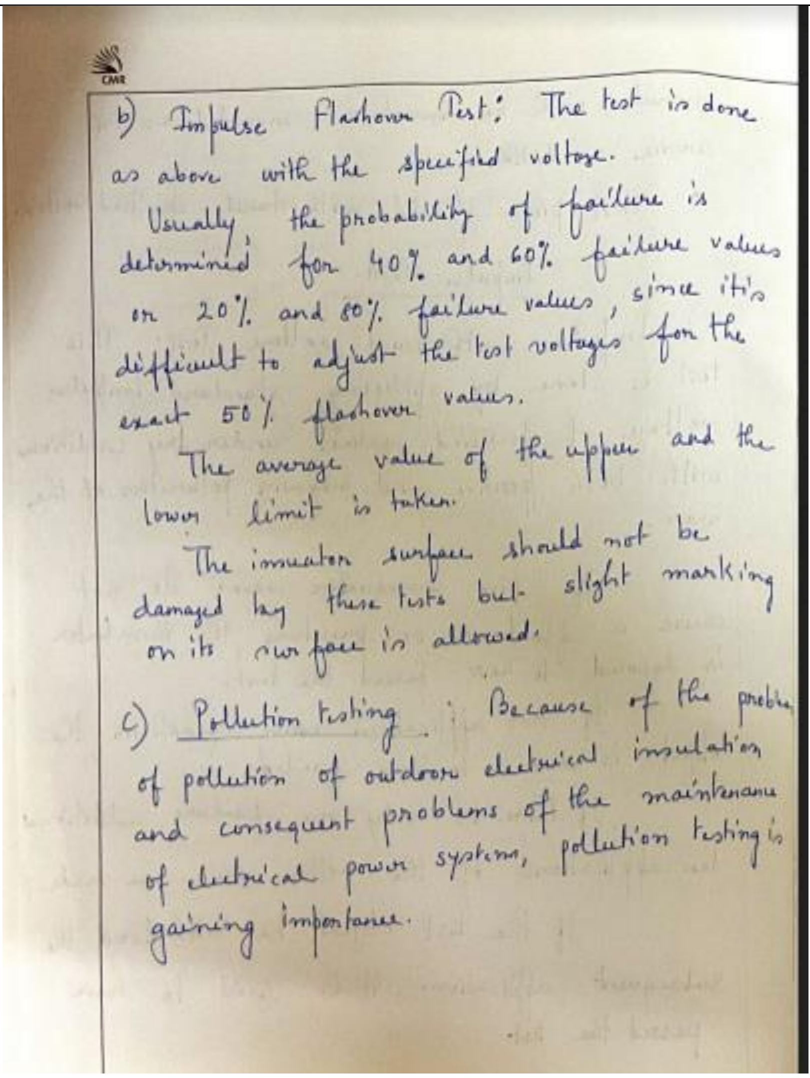
a) Impulse withstand voltage Test. This test is done by applying standard impulse voltage of specified value under dry conditions with both positive and negative polarities of the wave.

If five consequitive waves do not cause a flashover or puncture, the insulator is deemed to have passed the test.

If two applications cause flashover, the object is deemed to have failed.

If there is only one failure, additional ten applications of the voltage wave are made.

If the test object has withstood the subsequent applications, it is said to have passed the test



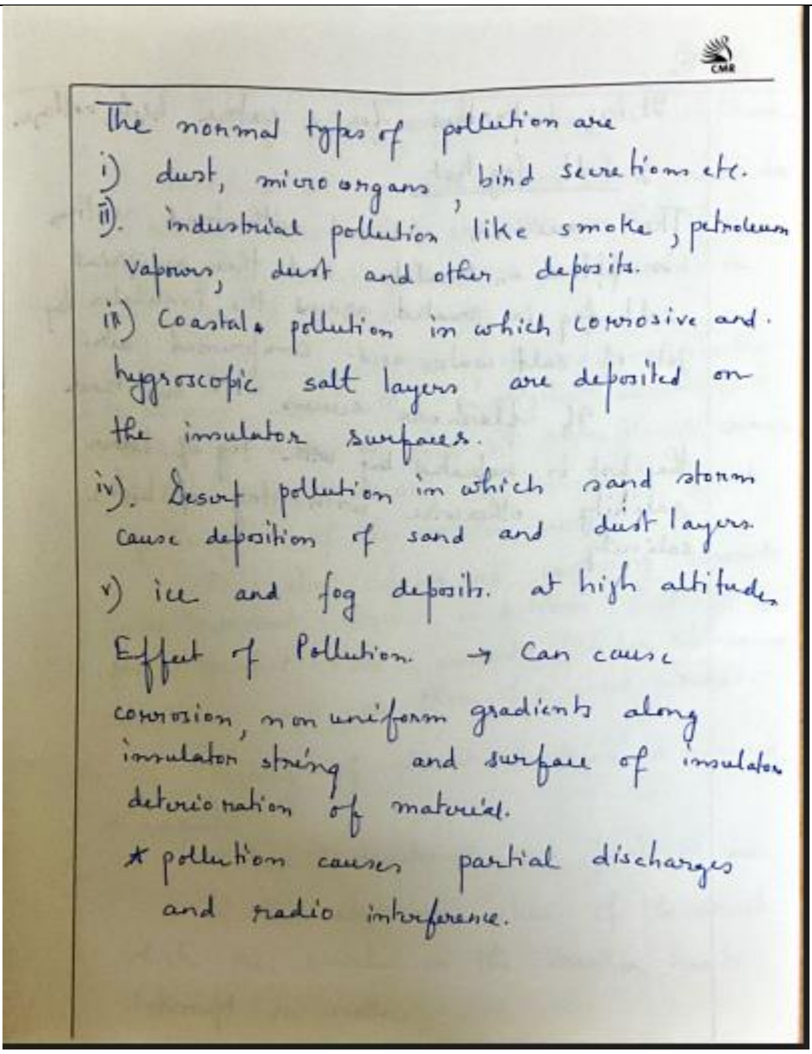
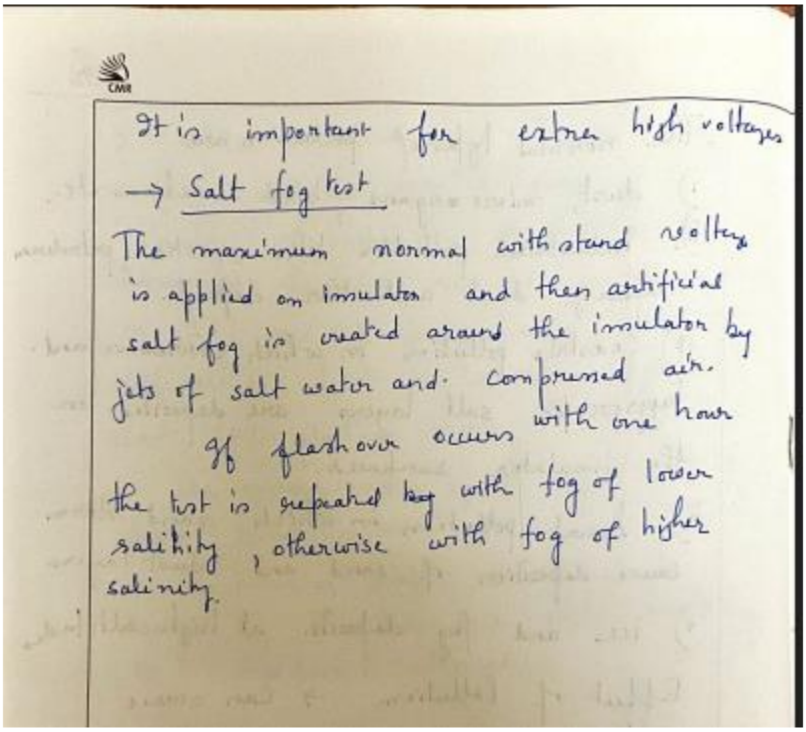
b) Impulse Flashover Test: The test is done as above with the specified voltage.

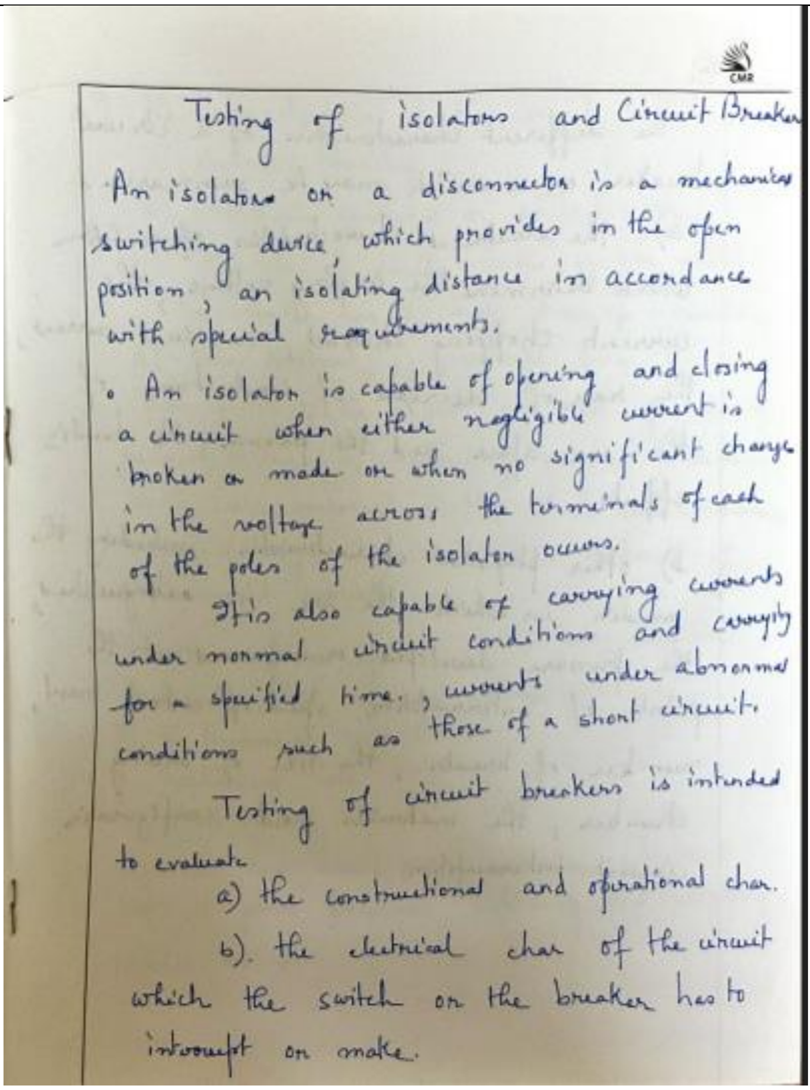
Usually, the probability of failure is determined for 40% and 60% failure values or 20% and 80% failure values, since it's difficult to adjust the test voltages for the exact 50% flashover values.

The average value of the upper and the lower limit is taken.

The insulator surface should not be damaged by these tests but slight marking on its surface is allowed.

c) <u>Pollution testing</u> : Because of the proble of pollution of outdoor electrical insulation and consequent problems of the maintenance of electrical power systems, pollution testing is gaining importance.

	 The normal types of pollution are i) dust, micro organs, bird secretions etc. ii). industrial pollution like smoke, petroleum vapours, dust and other deposits. iii) Coastal pollution in which corrosive and hygroscopic salt layers are deposited on the insulator surfaces. iv). Desert pollution in which sand storm cause deposition of sand and dust layers. v) ice and fog deposits. at high altitudes Effect of Pollution → Can cause corrosion, non uniform gradients along insulator string and surface of insulator deterioration of material. * pollution causes partial discharges and radio interference.  It is important for extra high voltages → Salt fog test The maximum normal withstand voltage is applied on insulator and then artificial salt fog is created around the insulator by jets of salt water and compressed air. If flashover occurs with one hour the test is repeated ~~by~~ with fog of lower salinity, otherwise with fog of higher salinity.			
5.	Discuss various electrical tests done on circuit breakers and cable.	[10]	CO6	L2



Testing of isolators and Circuit Breaker

An isolator or a disconnector is a mechanical switching device, which provides in the open position, an isolating distance in accordance with special requirements.

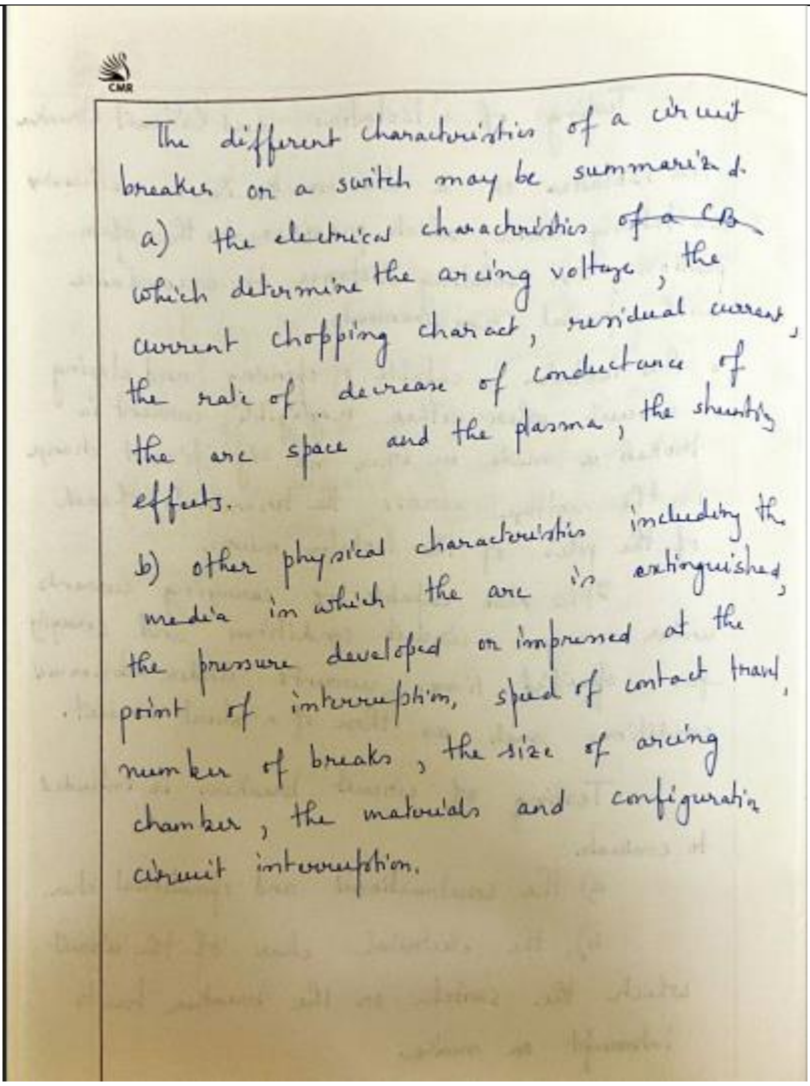
- An isolator is capable of opening and closing a circuit when either negligible current is broken or made or when no significant change in the voltage across the terminals of each of the poles of the isolator occurs.

It is also capable of carrying currents under normal circuit conditions and carrying for a specified time., currents under abnormal conditions such as those of a short circuit.

Testing of circuit breakers is intended to evaluate

a) the constructional and operational char.

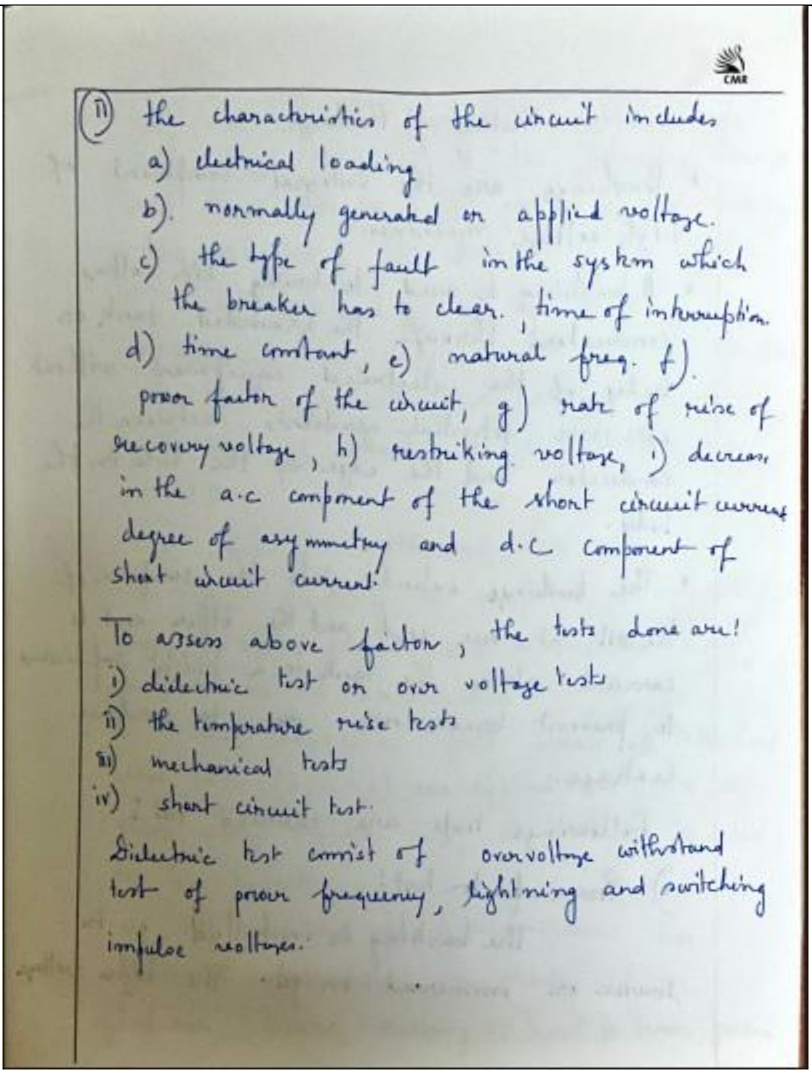
b). the electrical char of the circuit which the switch or the breaker has to interrupt or make.



The different characteristics of a circuit breaker or a switch may be summarized.

a) the electrical characteristics ~~of a CB~~ which determine the arcing voltage, the current chopping charact, residual current, the rate of decrease of conductance of the arc space and the plasma, the shunting effects.

b) other physical characteristics including the media in which the arc is extinguished, the pressure developed or impressed at the point of interruption, speed of contact travel, number of breaks, the size of arcing chamber, the materials and configuration circuit interruption.

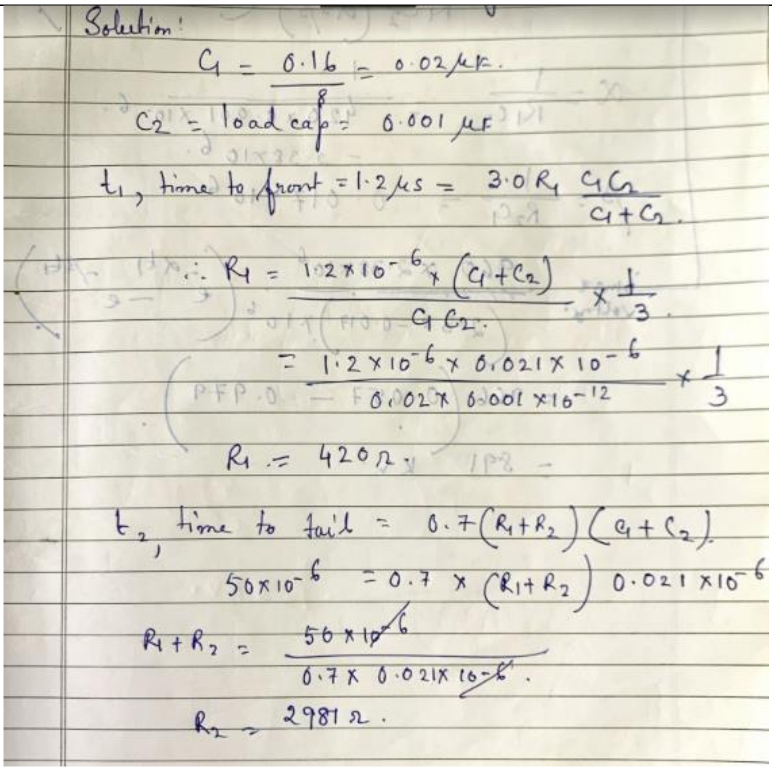
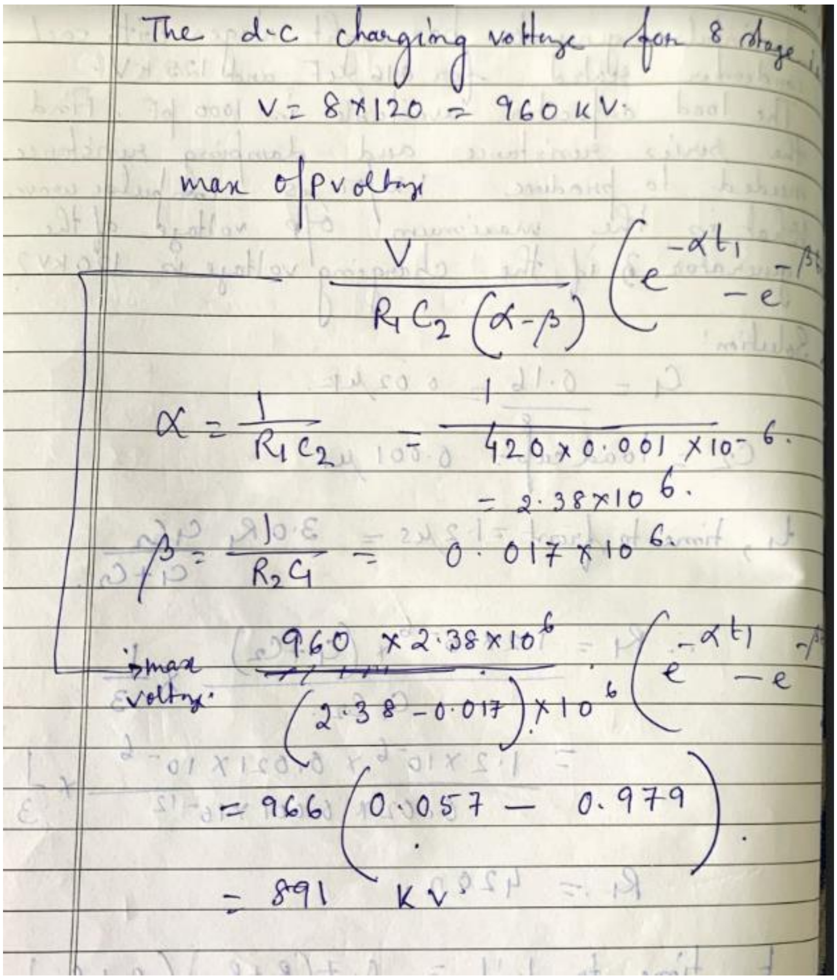
- 

(ii) the characteristics of the circuit includes
a) electrical loading
b). normally generated or applied voltage.
c) the type of fault in the system which the breaker has to clear., time of interruption
d) time constant, e) natural freq. f). power factor of the circuit, g) rate of rise of recovery voltage, h) restriking voltage, i) decrease in the a.c component of the short circuit current degree of asymmetry and d.c component of short circuit current.

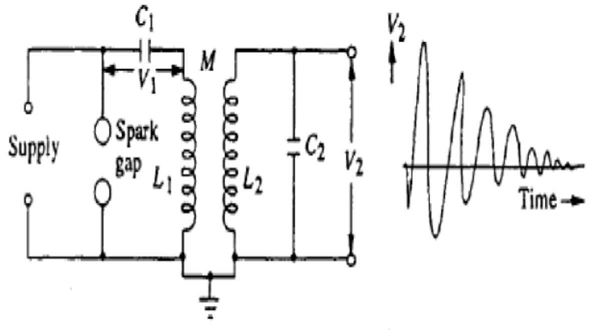
To assess above factor, the tests done are!
i) dielectric test on over voltage tests
ii) the temperature rise tests
iii) mechanical tests
iv) short circuit test.

Dielectric test consist of overvoltage withstand test of power frequency, lightning and switching impulse voltages.

6. a	An impulse generator has eight stages with each condenser rated for 0.16 µf and 125 kV. The load capacitor available is 1000 pF. Find the series resistance and the damping resistance needed to produce 1.2/50 µS is impulse wave. What is the maximum output voltage of the generator, if the charging voltage is 120 kV?	[6]	CO3	L3

	 Solution: $C_1 = \frac{0.16}{8} = 0.02 \mu F.$ $C_2 = \text{load cap} = 0.001 \mu F$ t_1, time to front $= 1.2 \mu s = 3.0 R_1 \frac{C_1 C_2}{C_1 + C_2}.$ $\therefore R_1 = \frac{1.2 \times 10^{-6} \times (C_1 + C_2)}{C_1 C_2} \times \frac{1}{3}.$ $= \frac{1.2 \times 10^{-6} \times 0.021 \times 10^{-6}}{0.02 \times 0.001 \times 10^{-12}} \times \frac{1}{3}$ $R_1 = 420 \Omega.$ t_2, time to tail $= 0.7 (R_1 + R_2)(C_1 + C_2).$ $50 \times 10^{-6} = 0.7 \times (R_1 + R_2)\ 0.021 \times 10^{-6}$ $R_1 + R_2 = \frac{50 \times \cancel{10^{-6}}}{0.7 \times 0.021 \times \cancel{10^{-6}}}.$ $R_2 = 2981 \Omega.$ -  The d-c charging voltage for 8 stage $V = 8 \times 120 = 960 kV.$ max o/p voltage $\frac{V}{R_1 C_2 (\alpha - \beta)} \left(e^{-\alpha t_1} - e^{-\beta}\right.$ $\alpha = \frac{1}{R_1 C_2} = \frac{1}{420 \times 0.001 \times 10^{-6}}.$ $= 2.38 \times 10^{6}.$ $\beta = \frac{1}{R_2 C_1} = 0.017 \times 10^{6}.$ max voltage. $\frac{960 \times 2.38 \times 10^{6}}{(2.38 - 0.017) \times 10^{6}} \left(e^{-\alpha t_1} - e^{-\beta}\right.$ $= 966 (0.057 - 0.979).$ $= 891$ kV. -			
6. b	What is Tesla coil? How are damped high frequency oscillation obtained from the Tesla coil? • High frequency high voltages are required for • rectifier d.c. power supplies • testing electrical apparatus for switching surges, high frequency high voltage damped oscillations are needed which need high voltage high frequency transformers. • The advantages of these high frequency transformers are:	[4]	CO3	L3

- the absence of iron core in transformers and hence saving in cost and size,
- pure sine wave output,
- slow build-up of voltage over a few cycles and hence no damage due to switching surges, and
- uniform distribution of voltage across the winding coils due to subdivision of coil stack into a number of units.
- The commonly used high frequency resonant transformer is the Tesla coil
- Doubly tuned resonant circuit
- The primary voltage rating is 10 kV
- 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 C1.
- A spark gap G connected across the primary is triggered at the desired voltage V1 which induces a high self-excitation in the secondary.
- The primary and the secondary windings (L1)and (L2) 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 C1 and C2



(a) Equivalent circuit (b) Output waveform

utput voltage V2 is a function of L1, L2, C1, C2, M.

winding resistances will be small , contribute only for damping of the oscillations.

neglecting the winding resistances.

Let the condenser C1 be charged to a voltage V1 when the spark gap is triggered.

Let a current i1 flow through the primary winding L1 and produce a current i2 through L2 and C2

$$V_1 = \frac{1}{C_1}\int_0^t i_1\,dt + L_1\frac{di_1}{dt} + M\frac{di_2}{dt}$$

$$\frac{V_1}{s} = \left[L_1 s + \frac{1}{C_1 s}\right]I_1 + MsI_2$$

$$0 = \frac{1}{C_2}\int_0^t i_2\,dt + L_2\frac{di_2}{dt} + M\frac{di_1}{dt}$$

$$0 = [Ms]I_1 + \left[L_2 s + \frac{1}{[C_2 s]}\right]I_2$$

$V_2 = \frac{1}{C_2}\int_0^t i_2 dt;$ or its transformed equation is

$$V_2(s) = \frac{I_2}{C_2 s}$$

$$V_2 = \frac{MV_1}{\sigma L_1 L_2 C_1}\,\frac{1}{\gamma_2^2 - \gamma_1^2}\,[\cos\gamma_1 t - \cos\gamma_2 t]$$

where,

$$\sigma^2 = 1 - \frac{M^2}{L_1 L_2} = 1 - K^2$$

K = coefficient of coupling between the windings L_1 and L_2

$$\gamma_{1,2} = \frac{\omega_1^2 + \omega_2^2}{2} \pm \sqrt{\left(\frac{\omega_1^2 + \omega_2^2}{2}\right)^2 - \omega_1^2\omega_2^2(1 - K^2)}$$

$$\omega_1 = \frac{1}{\sqrt{L_1 C_1}} \text{ and } \omega_2 = \frac{1}{\sqrt{L_2 C_2}}$$

7. With the help of a neat sketch, explain how cascade transformer generates High Voltage AC. Explain the problem associated with increase in number of stages. [10] CO3 L2

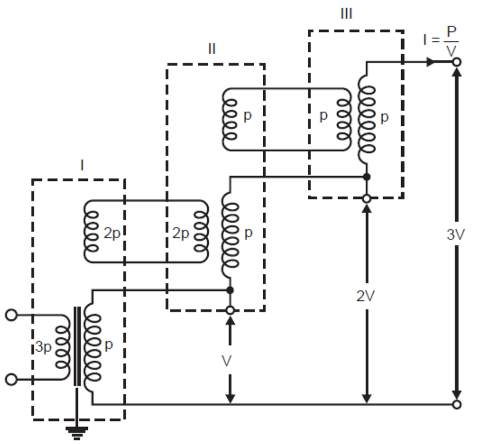


Fig. 2.9 Basic 3 stage cascaded transformer

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
he 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.

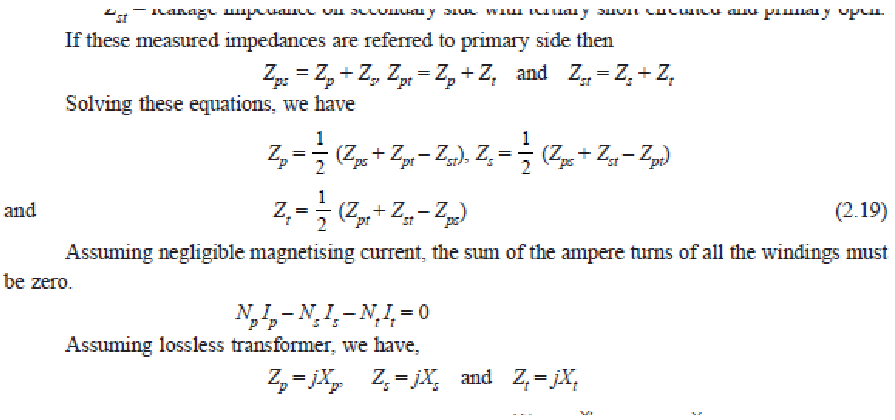
the third transformer is kept on insulators above the ground at a potential of 2V2 and is supplied likewise from the second transformer.
The number of stages in this type of arrangement are usually two to four
three stages are adopted to facilitate a three-phase operation so that can be obtained between the lines. $\sqrt{3V_2}$
p, 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



Z_{st} = 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

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

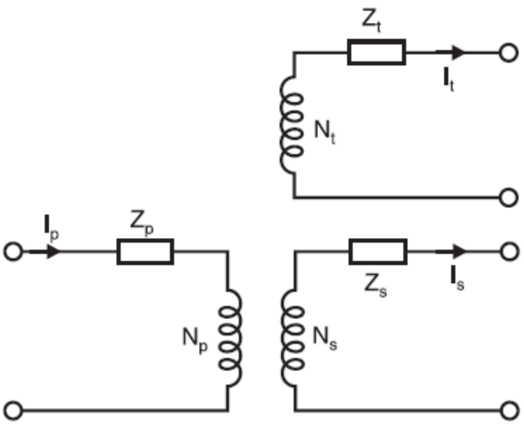
Assuming negligible magnetising current, the sum of the ampere turns of all the windings must be zero.

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

Assuming lossless transformer, we have,

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

Equivalent Circuit of 1-Stage



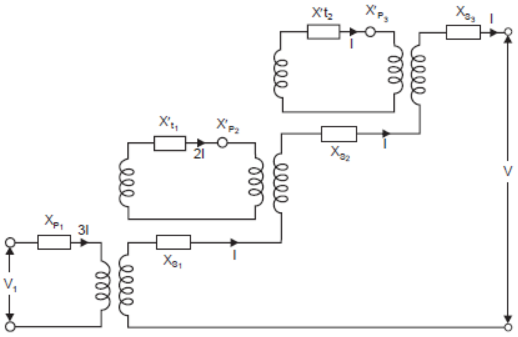


Fig. 2.11 Equivalent circuit of 3-stage transformer

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.

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

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

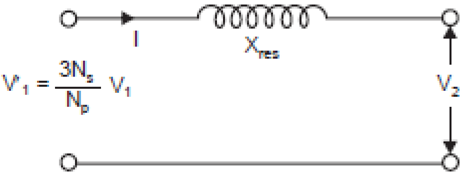


Fig. 2.12 A simplified equivalent circuit

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 3P.

Therefore, while designing the primaries and tertiaries of these transformers, this factor must be taken into consideration.

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6. a	Calculate the front and tail resistance for 5 stages, 1000kV with the capacitance of each stage is 5µF and a load capacitance of 10,000pF for 1 µs front and 50 µs tail wave.	[6]	CO3	L3
6. b	Briefly discuss impulse current generator.	[4]	CO3	L3
7.	With the help of a neat sketch, explain how cascade transformer generates High Voltage AC. Explain the problem associated with increase in number of stages.	[10]	CO3	L2

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