CMR
INSTITUTE OF
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Internal Assesment Test - II

Sub:	HIGH VOLTAGE ENGINEERING							Code:	10EE73
Date:	03 / 11 / 2016	Duration:	90 mins	Max Marks:	50	Sem:	VII	Branch:	EEE
Answer Any FIVE FULL Questions									

		Marks	OBE	
			CO	RBT
1 (a)	Discuss Thermal Breakdown in solid dielectrics with supporting equations and curves	[08]	CO3	L2
(b)	A solid specimen of dielectric has a dielectric constant of 4.2, and tan δ as 0.001 at a frequency of 50 Hz. If it is subjected to an alternating field of 50 kV/cm, calculate the heat generated in the specimen due to the dielectric loss.	[02]	CO3	L3
2 (a)	Describe Electromechanical Breakdown in Solid Dielectrics	[05]	CO3	L2
(b)	Discuss Suspended Particle Theory.	[05]	CO3	L2
3	Analyze series RLC type Impulse Generator and obtain the expression for output voltage. Mention its advantages and disadvantages.	[10]	CO5	L4
4	Explain multistage impulse generator. Also describe the modified circuit. Mention its advantages and disadvantages.	[10]	CO5	L4
5 (a)	With a help of neat Figure, Illustrate Trigatron Gap and Tripping Circuit.	[06]	CO5	L3
(b)	A 33 kV, 50 Hz high voltage Schering bridge is used to test a sample of insulation. The various arms have the following parameters on balance. The standard capacitance 500 pF, the resistive branch 800 ohm and branch with parallel combination of resistance and capacitance has values 180 ohms and 0.15 μF. Calculate the value of the capacitance of this sample, its parallel equivalent loss resistance, the p.f. and the power loss under these test conditions.	[04]	CO6	L3
6	Describe the partial discharge detection using straight detectors. Show the discharge patterns with neat figures.	[10]	CO6	L2
7	Classify and explain the testing of isolators and circuit breakers	[10]	CO6	L3

Course Outcomes		PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1:	Summarize the need for generating High Voltages	1	1	2	2	1	1	1	2	2	2		3
CO2:	Quote the Industrial Applications of high Voltage	2	3	2	3	2	2	1	2	1	2		2
CO3:	Classify the Insulating media and understand the properties and breakdown strength	2	3	2	3	2	3	1	2	1	2	1	2
CO4:	Explain the principle and operation of HVAC and HVDC generating circuits.	3	3	3	3	3	3	1	3	1	2		3
CO5:	Interpret origins of over voltage and protection against them.	3	3	3	3	2	3	1	3	1	2		2
CO6:	Demonstrate the Testing of electrical apparatus by high voltage application	3	3	3	3	2	2	1	2	2	3	1	3

Cognitive level	KEYWORDS
L1	List, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.
L2	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend
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L4	Analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer.
L5	Assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize.

PO1 - *Engineering knowledge*; PO2 - *Problem analysis*; PO3 - *Design/development of solutions*; PO4 - *Conduct investigations of complex problems*; PO5 - *Modern tool usage*; PO6 - *The Engineer and society*; PO7- *Environment and sustainability*; PO8 – *Ethics*; PO9 - *Individual and team work*; PO10 - *Communication*; PO11 - *Project management and finance*; PO12 - *Life-long learning*

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		Marks	OBE CO	OBE RBT
1 (a)	Discuss Thermal Breakdown in solid dielectrics with supporting equations and curves	[08]	CO3	L2

Breakdown voltages of solids increases with its thickness. But upto a certain thickness above which the heat generated in the dielectric due to the flow of current determines the conduction.

The heat generated under dc stress E is given as

$$W_{dc} = E^2 \sigma \quad W/cm^3$$

where σ is the dc conductivity of the specimen.

Under ac fields, the generated heat

$$W_{ac} = \frac{E^2 f \epsilon_r \tan\delta}{1.8 \times 10^{12}} \quad W/cm^3$$

where f = frequency in Hz,
δ = loss angle of dielectric material
E = rms value

The heat dissipated (W_T) is given by

$$W_T = C_V \frac{dT}{dt} + \text{div}\,(K\,\text{grad}\,T)$$

where C_V = specific heat of the specimen
T = temperature of the specimen
K = thermal conductivity of the specimen
t = time over which the heat is dissipated.

Equilibrium is reached when W_{dc} or $W_{ac} = W_T$.

Breakdown occurs when W_{dc} or W_{ac} exceeds W_T

Thermal instability is shown in Fig. 2.

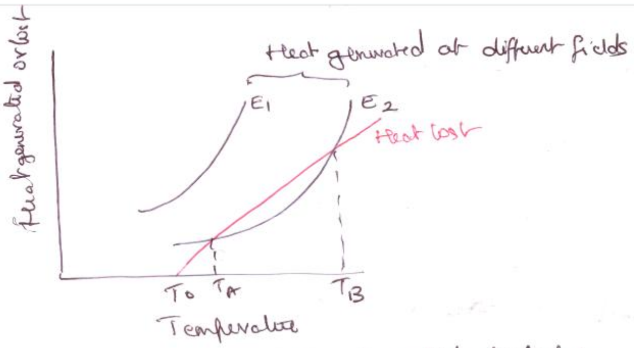


Fig 2. Thermal instability in solid dielectrics

(b) A solid specimen of dielectric has a dielectric constant of 4.2, and tan δ as 0.001 at a frequency of 50 Hz. If it is subjected to an alternating field of 50 kV/cm, calculate the heat generated in the specimen due to the dielectric loss. [02] CO3 L3

δ is in radian

$$W_{ac} = \frac{E^2 f \epsilon_r \tan\delta}{1.8\times10^{12}} \quad W/cm^3$$

$$= \frac{(50\times10^3)^2 \times 50 \times 4.2 \times (0.001)}{1.8\times10^{12}}$$

$$\therefore W_{ac} = 0.291 \ mW/cm^3$$

2 (a) Describe Electromechanical Breakdown in Solid Dielectrics [05] CO3 L2

When solid dielectrics are subjected to high electric fields, electrostatic compressive force can exceed the mechanical compressi[ve] strength and breakdown occurs.

If the ~~mater~~ specimen of thickness d_0 is compressed to thickness d under an applied voltage V, then the electrically developed compressive stress is in equilibrium if

$$\epsilon_0 \epsilon_r \frac{V^2}{2d^2} = Y \ln\left[\frac{d_0}{d}\right] \longrightarrow (1)$$

where Y is the Young's modulus.

From Eqn (1) $$V^2 = d^2 \left[\frac{2Y}{\epsilon_0 \epsilon_r}\right] \ln\left[\frac{d_0}{d}\right] \longrightarrow (2)$$

Substituting in eqn (2), the highest apparent electric stress before breakdown,

$$E_{max} = \frac{V}{d_0} = 0.6\left[\frac{Y}{\epsilon_0 \epsilon_r}\right]^{1/2} \rightarrow (3)$$

$\frac{V}{d} = \sqrt{2 d \ln(1.67) \times \frac{Y}{\epsilon_0 \epsilon_r}}$ (≈ 1)

$d = 0.6\, d_0$

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

The equation (3) is only an approximate, because Y is dependent on mechanical stress.

(b)	Discuss Suspended Particle Theory.	[05]	CO3	L2

The presence of solid impurities cannot be avoided in liquids. The permittivity of these particles (ϵ_2) will be different from the permittivity of the liquid (ϵ_1).

Assuming spherical particles of radius r, & E is the applied field, the particles experience a force F, where

$$F = \frac{1}{2} r^3 \frac{(\epsilon_2 - \epsilon_1)}{2\epsilon_1 + \epsilon_2} \text{ grad } E^2$$

This force is directed towards areas of maximum stress, if $\epsilon_2 > \epsilon_1$, and force will be in the direction of areas of lower stress if $\epsilon_2 < \epsilon_1$.

If the number of particles present are large, they align and form a stable ~~strong~~ chain, creating the bridge between the electrodes and thus leading to breakdown.

The impurity particles reduce the breakdown strength, and larger the size of the particles, lower were the breakdown strengths.

3	Analyze series RLC type Impulse Generator and obtain the expression for output voltage. Mention its advantages and disadvantages.	[10]	CO5	L4

Analysis of single stage impulse generator – expression for output impulse voltage (Series R-L-C type / Model generator)

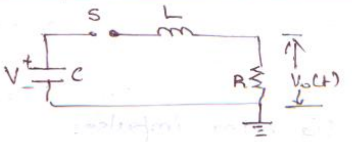


Fig. 2.(a).

The output voltage will be the product of ~~current flowing &~~ Resistance R and the current flowing through it.

Since the circuit elements are in series ~~the~~ same current flows through all the elements.

Thus the current through the resistor can be obtained as follows:

Sum of all voltage drops $V = \frac{1}{C}\int_0^t i\,dt + Ri + L\frac{di}{dt} \rightarrow (1)$

With initial condition at $t=0$, being $i(0)=0$ & net charge in the circuit $q=0$, Applying laplace transform to both sides of Eq(1)

$$\frac{V}{s} = \frac{1}{Cs}I(s) + RI(s) + Ls\,I(s)$$

$$\text{or} \quad I(s) = \frac{V}{L}\left[\frac{1}{s^2 + \frac{Rs}{L} + \frac{1}{LC}}\right]$$

$\left(L(sI(s) - i(0)) \right)$

$$\frac{V}{s}\left\{\frac{1}{\frac{1}{Cs} + R + Ls}\right\} = I(s)$$

$$\frac{V}{L}\left\{\frac{1}{\frac{1}{LC} + \frac{Rs}{L} + s^2}\right\} = I(s)$$

The voltage across the resistor R (which is o/p voltage) is,

$$V_o(s) = I(s)R$$

$$= \frac{V}{L}\left[\frac{1}{s^2 + \frac{Rs}{L} + \frac{1}{LC}}\right] \times R, \rightarrow (2)$$

For an overdamped condition, $R/2L \geq 1/\sqrt{LC}$.

Hence, the roots of equation $s^2 + \frac{Rs}{L} + \frac{1}{LC}$ are

$$\alpha = s_1 = \frac{-R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}$$

$$\beta = s_2 = \frac{-R}{2L} - \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\frac{-\frac{R}{L} \pm \sqrt{\left(\frac{R}{L}\right)^2 - \frac{4}{LC}}}{2}$$

$$-\frac{R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}$$

Eqn(2) can be written as,

$$V_o(s) = \frac{VR}{L}\left[\frac{1}{(s-\alpha)(s-\beta)}\right]$$

Now $\dfrac{V R/L}{(s-\alpha)(s-\beta)}$

Partial fractions

i.e $V_o(s) = \dfrac{-VR/L \,/\, \beta-\alpha}{s-\alpha} + \dfrac{VR/L \,/\, (\beta-\alpha)}{s-\beta}$

$\beta-\alpha = -2\left[\left(\frac{R}{2L}\right)^2-\frac{1}{LC}\right]^{1/2}$

$= \dfrac{V\left(\frac{R}{2L}\right) \Big/ \left(\frac{R^2}{4L^2}-\frac{1}{LC}\right)}{s-\alpha} - \dfrac{V\left(\frac{R}{2L}\right) \Big/ \left(\frac{R^2}{4L^2}-\frac{1}{LC}\right)}{s-\beta}$

$$V_o(s) = \frac{V\left(\frac{R}{2L}\right)}{\left(\frac{R^2}{4L^2}-\frac{1}{LC}\right)}\left\{\frac{1}{s-\alpha}-\frac{1}{s-\beta}\right\} \longrightarrow (3)$$

Applying inverse Laplace transform to Eqn (3), we get

$$v_o(t) = \frac{V\left(\frac{R}{2L}\right)}{\left[\frac{R^2}{4L^2}-\frac{1}{LC}\right]^{1/2}}\left[\exp(-\alpha t)-\exp(-\beta t)\right] \longrightarrow (4)$$

$$\therefore v(t) = V_0\left[\exp(-\alpha t)-\exp(-\beta t)\right] \longrightarrow (5)$$

where $\mathbf{V_o} = \dfrac{V\left(\frac{R}{2L}\right)}{\left[\frac{R^2}{4L^2}-\frac{1}{LC}\right]^{1/2}} = \dfrac{V}{\left[1-\frac{4L}{R^2C}\right]^{1/2}} \longrightarrow (6)$

The wavefront and wavetail times are controlled by changing the values of R and L simultaneously.

Advantage:

* Simplicity of the circuit

Disadvantage:

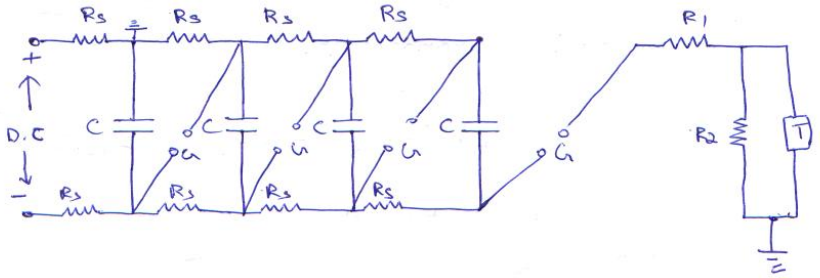
* Waveshape control is not flexible and independant
* Circuit is altered when test object is capacitive, and waveshape changes.

4 Explain multistage impulse generator. Also describe the modified circuit. Mention its advantages and disadvantages. [10] CO5 L4

A single stage capacitor & its charging unit may be too costly, and the size becomes very large.

The cost and size of impulse generator increases at a rate of square or cube of the voltage rating.

For producing very high voltages, a bank of capacitors are charged in parallel & then discharged in series. This arrangement was proposed by Marx and nowadays modified circuits are used. The schematic diagram of Marx circuit & its modification are shown in Fig 3 (a) & Fig. 3(b) respectively.



C – Capacitance of generator
G – Spark Gap
R_s – Charging resistors
$R_1 R_2$ – Wave shape resistors.

Fig 3. (a) Schematic diagram of Marx circuit arrangement for multistage impulse generator.

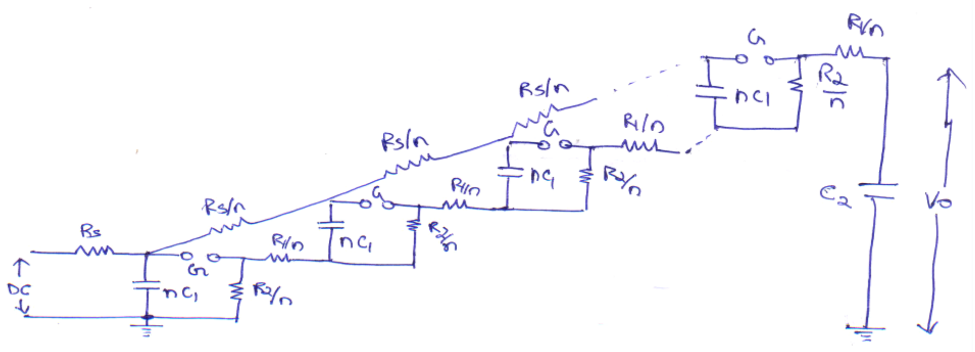


Fig 3. (b). Multistage impulse generator incorporating the series and wave tail resistances within the generator

Usually R_s is chosen to limit charging current to about 50 to 100mA, and capacitance C is chosen such that the product CR_s is about 10s to 1min.

The gap spacing G is chosen such that the breakdown voltage of the gap G is greater than the charging voltage V.

Thus all capacitances are charged to the voltage V in about 1minu when impulse generator is to be discharged, the gaps G are made to spark over simultaneously by some external means.

All capacitors are now connected in series and discharge into test object. This discharge time constant CR_1/n (for n stages) will be very very small (micro seconds), compared to charging time constant CR_s which will be few seconds.

In Fig 3.(a) waveshaping circuit is connected externally to the capacitor unit.

In Fig 3.(b), the resistances R_1 and R_2 are incorporated inside the unit.

R_1 is divided into n equal parts and put in series with gap, R_2 is also divided into n parts and arranged across each capacitor.

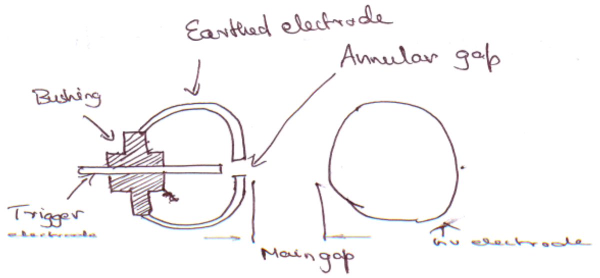
Advantage of Modified circuit

* Saves space, cost is reduced
* Control resistors are small, efficiency is high

Disadvantage of Modified circuit

* Wide variation of waveshape becomes difficult

5 (a)	With a help of neat Figure, Illustrate Trigatron Gap and Tripping Circuit.	[06]	CO5	L3



IMP :- Both circles should be equal in size.

Fig. 10 a Trigatron gap.

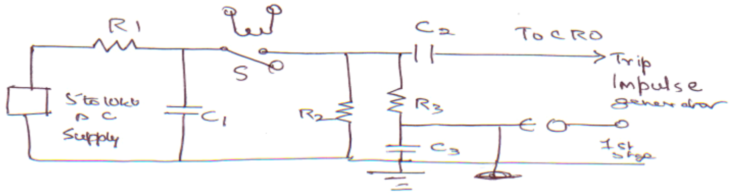


Fig 10.b. Trigatron gap and tripping circuit

Three electrode gap requires larger space. The trigatron gap shown in Fig 10. requires much smaller voltage for operation compared to the three electrode gap.
It consists of high voltage spherical electrode of suitable size, an earthed electrode and trigger electrode.

Trigatron is connected to a pulse circuit as shown in Fig 10.b. Tripping of impulse generator is caused by spark between trigger electrode and earthed sphere. This trigatron is polarity sensitive and a proper polarity pulse should be applied for correct operation.

(b) A 33 kV, 50 Hz high voltage Schering bridge is used to test a sample of insulation. The various arms have the following parameters on balance. The standard capacitance 500 pF, the resistive branch 800 ohm and branch with parallel combination of resistance and capacitance has values 180 ohms and 0.15 μF. Calculate the value of the capacitance of this sample, its parallel equivalent loss resistance, the p.f. and the power loss under these test conditions. [04] CO6 L3

Data: $C_s = 500pF$, $R_1 = 800\Omega$, $R_2 = 180\Omega$, $C_2 = 0.15\mu F$

Now $C_p = C_s \frac{R_2}{R_1} = 500\times10^{-12} \times \frac{180}{800} = 112.5\times10^{-12}F = 112.5pF$

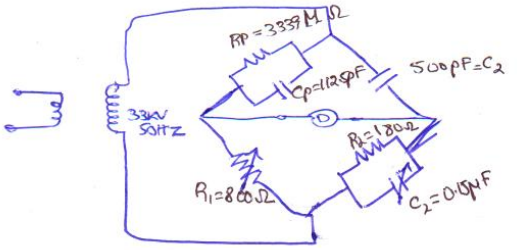
$$R_p = \frac{R_1}{\omega^2 C_2 C_s R_2^2} = \frac{800}{(314)^2 \times 0.15\times10^{-6} \times 500\times10^{-12} \times (180)^2} = 3339\ M\Omega$$

$p.f = \cos\phi = \sin(90-\phi) = \sin\delta$

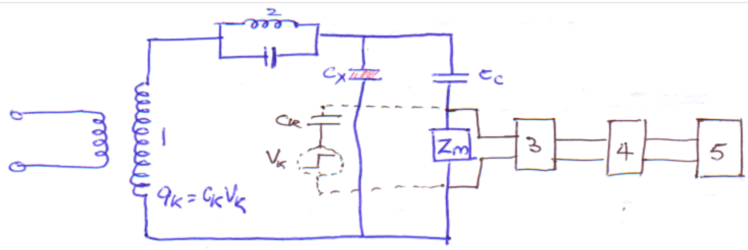
when δ is small, $\tan\delta \approx \sin\delta$

$\therefore$ Power Factor $\tan\delta = \frac{1}{\omega C_p R_p} = \frac{1}{314 \times 112.5\times10^{-12} \times 3339\times10^6} = 0.0085$

$$\text{Power Loss} = \frac{V^2}{R_p} = \frac{(33\times10^3)^2}{3339\times10^6} = 0.326\ W$$



6	Describe the partial discharge detection using straight detectors. Show the discharge patterns with neat figures.	[10]	CO6	L2



1 – HV testing transformer
2 – Filter
3 – Band pass filter
4 – Amplifier
5 – Display unit (CRO or pulse counter)

C_x – Sample or test piece
C_c – Coupling condenser
Z_m – Detector impedance
V_k – Calibrating pulse
C_k – Calibrating capacitor
q_k – Calibrator charge.

Fig. 8. Straight discharge detection circuit.

Simplified circuit for detecting partial discharges is shown in Fig. 8.
A high voltage transformer free from internal discharge is used as supp
A resonant filter is used to prevent any pulses starting from the capacitance of windings & bushings of transformer.

The signal developed across Z_m is passed through band pass filter and amplifier and displayed on a CRO or counted by a pulse counter.

The ~~disp~~ discharge pattern displayed on the CRO screen of a partial discharge detector with an elliptical display is shown in Fig. 9.

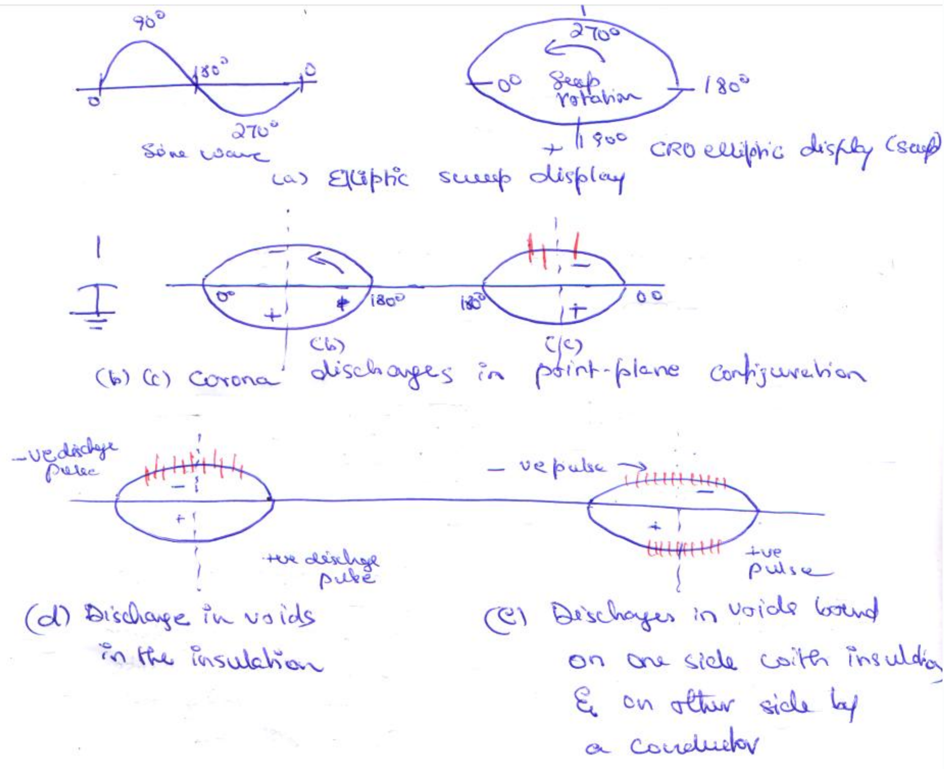


Fig. 9. Partial discharge patterns.

In narrow band detection Z_m is a parallel L-C circuit tuned to 500kHz

In wide band detection Z_m is an R-C network connected to a double tuned transformer

Narrow band resolution is about 35 pulses per quadrant and wide band resolution is about 200 pulses per quadrant

7 Classify and explain the testing of isolators and circuit breakers [10] CO6 L3

Short Circuit Tests

These tests consist of determining the making and breaking capacities at various load currents and rated voltages. In the case of isolators, the short circuit tests are conducted only with the limited purpose to determine their capacity to carry the rated short circuit current for a given duration; and no breaking or making current test is done.

The different methods of conducting short circuit tests are:

1. Direct Tests
   a. using a short circuit generator as the source
   b. using the power utility system or network as the source.
2. Synthetic Tests
   a. Direct Testing in the Networks or in the Fields
   b. Direct Testing in Short Circuit Test Laboratories
   c. Synthetic Testing of Circuit Breakers
   d. Composite Testing
   e. Unit Testing
   f. Asymmetrical Tests

Direct Testing in the Networks or in the Fields:

Circuit breakers are sometimes tested for their ability to make or break the circuit under normal load conditions or under short circuit conditions in the network itself. This is done during period of limited energy consumption.

The advantages of field tests are:

i. The circuit breaker is tested under actual conditions.

ii. Special occasions like breaking of charging currents of long lines, very short line faults, interruption of small inductive currents, etc. can be tested by direct testing only.

The disadvantages of field tests are:

i. The circuit breaker can be tested at only a given rated voltage and network capacity.

ii. The necessity to interrupt the normal services and to test only at light load conditions.

Direct Testing in Short Circuit Test Laboratories:

In order to test the circuit breakers at different voltages and at different short circuit currents, short circuit laboratories are provided. The schematic layout of a short circuit testing laboratory is given in Fig. 1. It consists of a short circuit generator in association with a master circuit breaker, resistors, reactors and measuring devices.

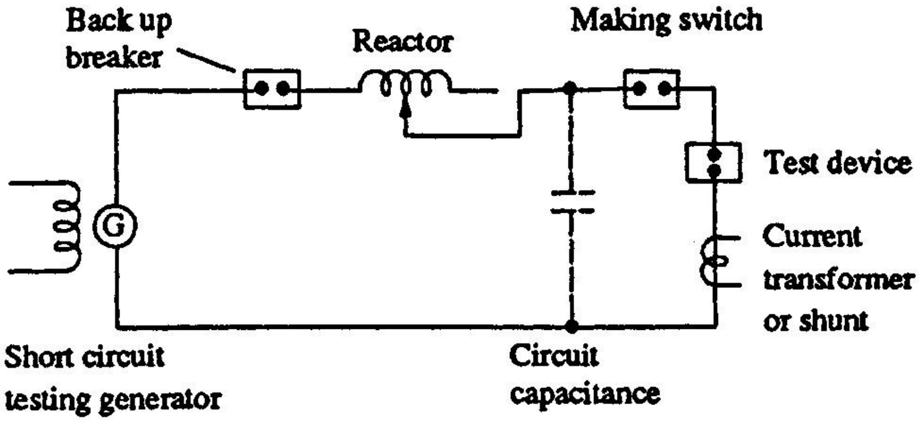


Fig.1. Schematic diagram showing basic elements of a short circuit testing laboratory

A make switch initiates the short circuit and the master circuit breaker isolates the test device from the source at the end of a predetermined time set on a test sequence controller. Also, the master circuit breaker can be tripped if the test device fails to operate properly. Short circuit generators with induction motors as prime movers are also available.

Synthetic Testing of Circuit Breakers:

Due to very high interrupting capacities of circuit breakers, it is not economical to have a single source to provide the required short circuit and the rated voltage. Hence, the effect of a short circuit is obtained as regards to the intensity of the current and the recovery voltage as a combination of the effects of two sources, one of which supplies the a.c. current and the other the high voltage. In the initial period of the short circuit test, the a.c. current source supplies the heavy current at a low voltage, and then the recovery voltage is simulated by a source of comparatively high voltage of small current capacity. A schematic diagram of a synthetic testing station is shown in Fig. 2. With the auxiliary breaker (3) and the test breaker (T) closed, the closing of the making switch (1) causes the current to flow in the test circuit breaker.

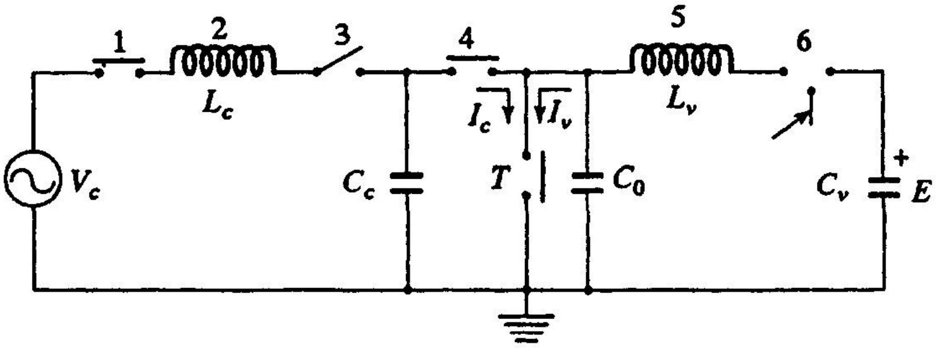


Fig. 2 Schematic diagram of synthetic testing of circuit breakers

Composite Testing:

In this method, the breaker is first tested for its rated breaking capacity at a reduced voltage and afterwards for rated voltage at a low current. This method does not give a proper estimate of the breaker performance.

Unit Testing:

When large circuit breakers of very high voltage rating (220 k V and above) are to be tested and where more than one break is provided per pole, the breaker is tested for one break at its rated current and the estimated voltage. In actual practice, the conditions of arc in each gap may not be identical and the voltage distribution along several breaks may be uneven. Hence, certain uncertainty prevails in the testing of one break.

Asymmetrical Tests:

One test cycle is repeated for the asymmetrical breaking capacity in which the d.c. component at the instant of contact separation is not less than 50% of the a.c. component.

Course Outcomes		PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
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L4	Analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer.
L5	Assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize.

PO1 - *Engineering knowledge*; PO2 - *Problem analysis*; PO3 - *Design/development of solutions*; PO4 - *Conduct investigations of complex problems*; PO5 - *Modern tool usage*; PO6 - *The Engineer and society*; PO7- *Environment and sustainability*; PO8 – *Ethics*; PO9 - *Individual and team work*; PO10 - *Communication*; PO11 - *Project management and finance*; PO12 - *Life-long learning*