DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

MALNAD COLLEGE OF ENGINEERING, HASSAN

Relay and High Voltage Laboratory Record

Name										
USN	4	M	C			E	E			
VII Semester				Batch - B						

Prepared by Dr. H. N. Suresh, Professor, Department of E&E Engineering
Malnad College of Engineering, Hassan, for local circulation

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

MALNAD COLLEGE OF ENGINEERING, HASSAN

Certificate

This is to certify that Mr./Ms. ____________________________________ has satisfactorily completed the course of experiments in ***Relay and High Voltage Laboratory (EE706)*** prescribed by Malnad College of Engineering, for VII Semester B. E. (Electrical & Electronics Engineering) Course in the High Voltage Laboratory of this Institution during the year 2019.

Date : Signature of the Faculty member in-charge of the batch

Name of the Candidate :

University Seat No. (USN) :

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

MALNAD COLLEGE OF ENGINEERING, HASSAN

Relay & High Voltage laboratory

INDEX

Expt. No.	Title of the Experiment	Date	Page No.	Remarks
1.	Operating characteristics and calculation of error in operation time of Overcurrent Electromechanical relay			
2. a)	Operating characteristics of static overvoltage relay			
b)	Operating characteristics of static undervoltage relay			
3. a)	Field Mapping using Electrolytic tank – An introduction			
b)	Field Mapping using Electrolytic tank – for Concentric Cable model			
4.	Current – Time Characteristics of fuse			
5.	Operating characteristics of Microprocessor based Over / Under voltage relay			
6.	Sparkover characteristics of air insulation subjected to high voltage AC, with sparkover voltage corrected to STP			
7.	Sparkover characteristics of air insulation subjected to high voltage DC under uniform field condition			
8.	Sparkover characteristics of air insulation subjected to high voltage DC under non-uniform field condition			
9.	High Voltage impulse generation - An Introduction			
10.	Sparkover voltage of air insulation subjected to high voltage Impulse, with sparkover voltage corrected to STP			
11.	Measurement of high voltage AC using Standard spheres			
12.	Breakdown strength of transformer oil using oil testing unit.			

List of Viva Questions

Typical Examination Questions

Marks Awarded

Signature of the Faculty in-charge

EXPERIMENT NO. DATE:

ELECTROLYTIC TANK – AN INTRODUCTORY STUDY

An electrolytic tank is used for electric field analysis of electrical systems. It actually provides an electro-conductive analogue for the real physical system of dielectric.

The analogy of Laplacian electrostatic and electric conduction fields provides the opportunity to measure the potential distribution by replacing the homogeneous, isotropic and linear dielectric by a conductive material with the same fundamental properties.

In both cases, Laplacian equation ($\nabla^2 V = 0$) is valid, assuming insulator devoid of charges initially. For electrostatic fields, the valid relation is

$$\overline{D} = \varepsilon \overline{E}$$

while for electric conduction fields, the condition satisfied is

$$\overline{J} = \sigma \overline{E}$$

As $\nabla^2 V = 0$ in both cases, the potential distribution will be identical in both the cases.

Electrolytic tank basically consists of an insulating tank material or a metal tank (in case of open – geometry problems, the tank serves as a reference potential i.e., zero), a metallic pin probe, an electrolyte and a potter. Potential is measured by dipping the pin probe into the electrolyte and connecting it to a high impedance voltmeter.

Equipotential contours are plotted by tracing the loci of equal potential points around HV electrode. Electric field lines can then be drawn perpendicular to equipotential lines at the intersection of the two.

Errors in electrolytic tank:

a. Modeling errors:

Approximations in arriving at the experimental model from the actual object will result in considerable errors, if approximations are crude. Also, if the probe is dipped totally into the electrolyte, considerable error is incurred as all points on the probe are equipotential. In 3-D model, this can be a serious error.

i) Probe shape:

Probe shape should not be distorted during experiment as this would distort the equipotential plot.

ii) Probe diameter:

In order to reduce error in marking equipotential points, the probe diameter should be minimal (approximately 46 SWG or 0.012 mm diameter)

iii) Wall error:

This is an extension of meniscus error. Near the model wall, two meniscuses are formed when the probe is nearby.

b. Electrolysis error:

If the excitation is decreased, there will be very large degree of electrolysis resulting in non-uniform electrolyte and hence increased errors. Also, if high frequency AC voltage is used, then errors due to skin effect will be present which are more prominent in 3-D models. It is generally believed that highest accuracy is obtained near 1 kHz.

c. Scaling errors:

Owing to practical considerations, the experimental model is often a miniature of the actual object and the error incurred is inversely proportional to the enlargement ratio (ratio of model size to object size). Often the area of interest is enlarged to know the nature of field. Ex. A void in a cable may be enlarged very much out of proportion. Hence, field distribution outside the void will be highly distorted.

d. Probe errors:

Ideally, the probe should not disturb the electrode surface. In practice, due to adhesion between probe and electrolyte, meniscus is formed and current lines are disturbed as shown in figure

e. Compatibility of electrolyte with electrode and probe:

If the electrolyte along with electrodes and probes are not compatible to each other, then the products of possible chemical reaction may be non-uniformly spread resulting in induced errors. Also oxide layer formed on the electrode walls (being very less conducting) will have a higher voltage drop across them and thereby will cause abnormal voltage distribution.

f. Bubble formation:

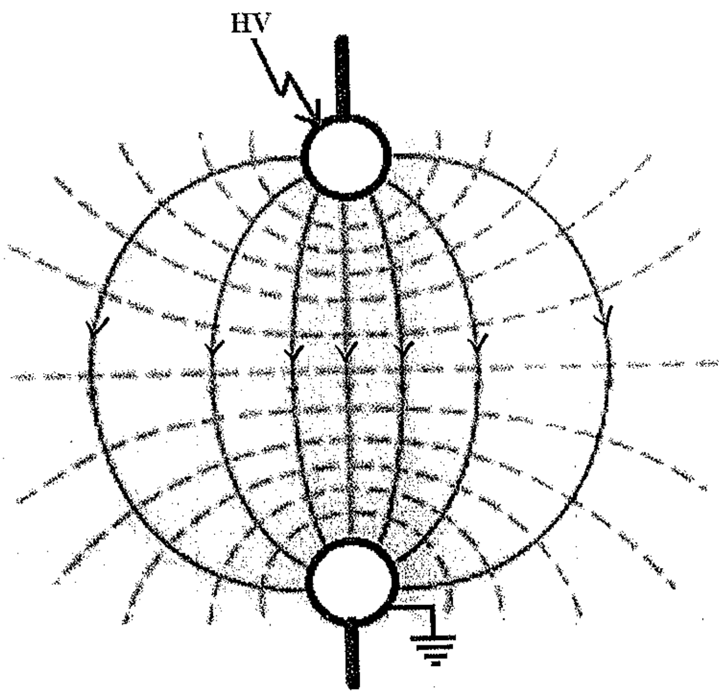
Bubble formation due to electrolysis and release of dissolved gas may result in errors due to distortion of current flow lines. Joule heating of electrolyte also might lead to bubble formation.

g. Current density:

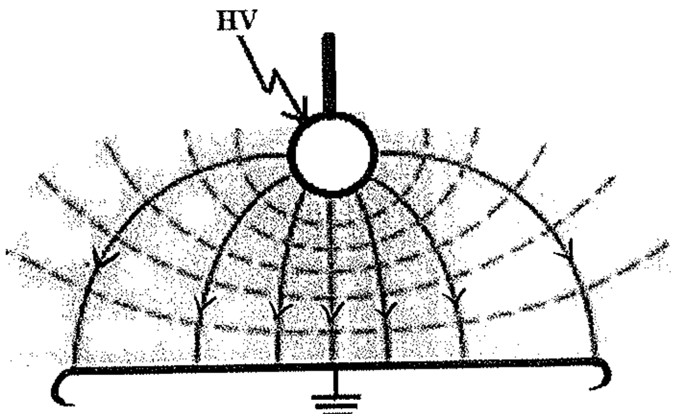
Current density should not be very low or very high. A very low current density would make current flow lines to deviate substantially from that in conductor medium, causing errors. Also a high current density would result in high heat generation, more electrolysis, more bubble formation and greater temperature differential and consequent higher errors incurred.

Electrolyte surface should be still with the level as required for the experiment. Ex. In a cable model, the surface of the electrolyte should be perpendicular to the axis of the model.

Equipotential lines - - - - - - - - - - - - - - -
Field lines ——————————

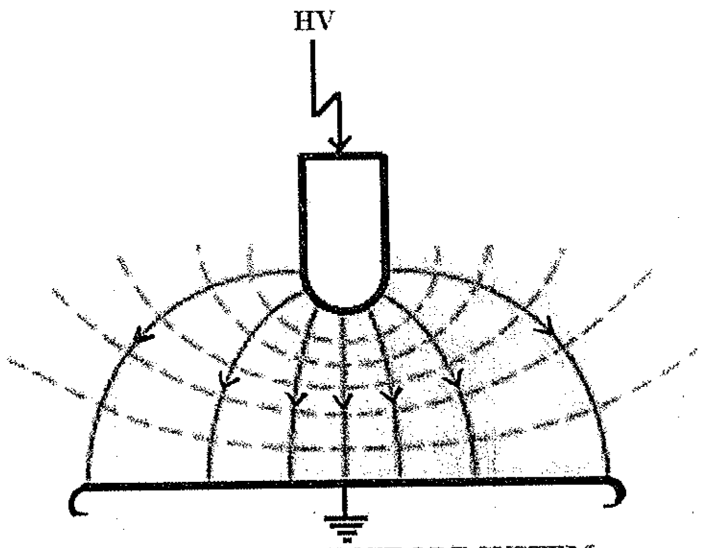


SPHERE - SPHERE ELECTRODE SYSTEM

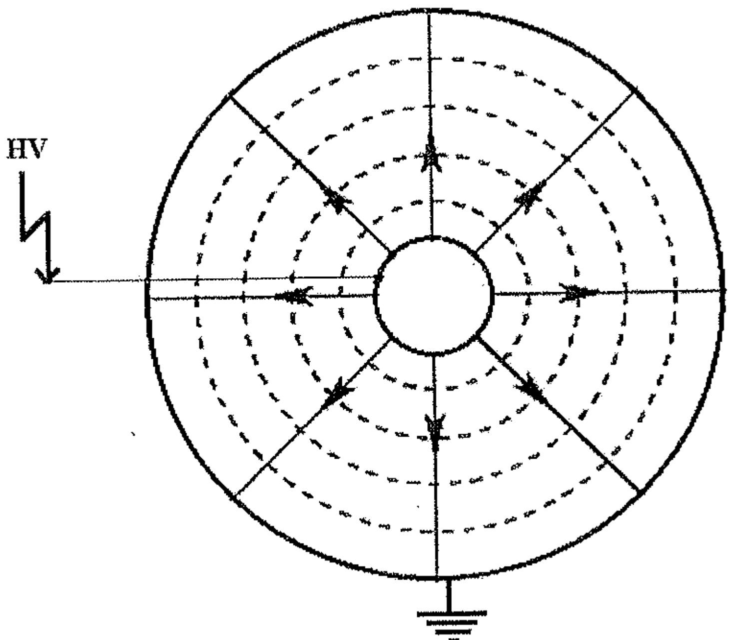


SPHERE - PLANE ELECTRODE SYSTEM

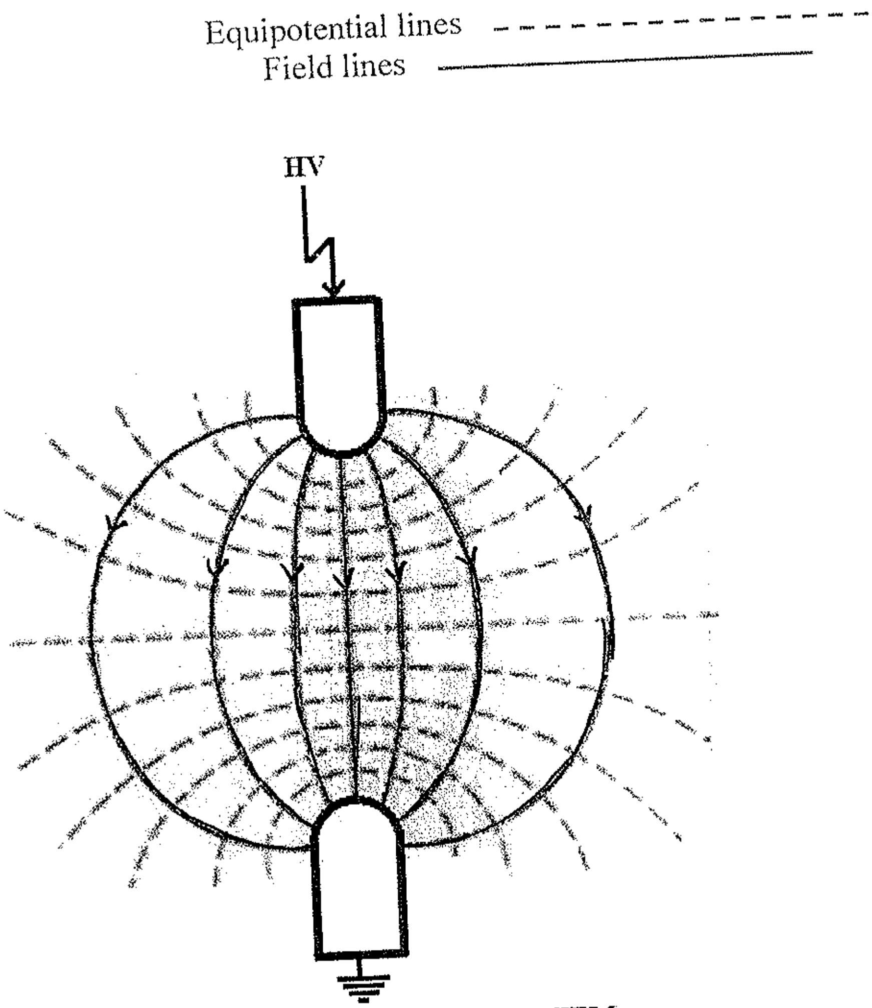
Equipotential lines - - - - - - - - - - - - - -
Field lines ————————————



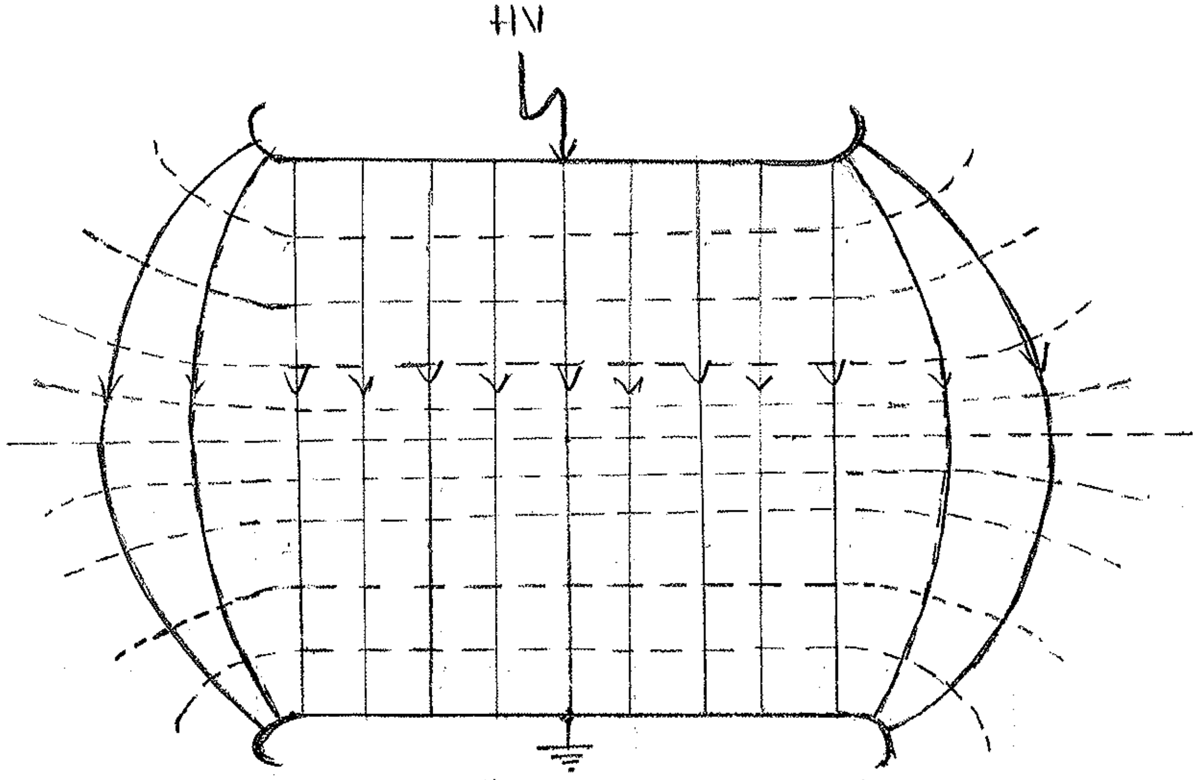
ROD - PLANE ELECTRODE SYSTEM



FIELD MAPPING OF CO-AXIAL CABLE MODEL

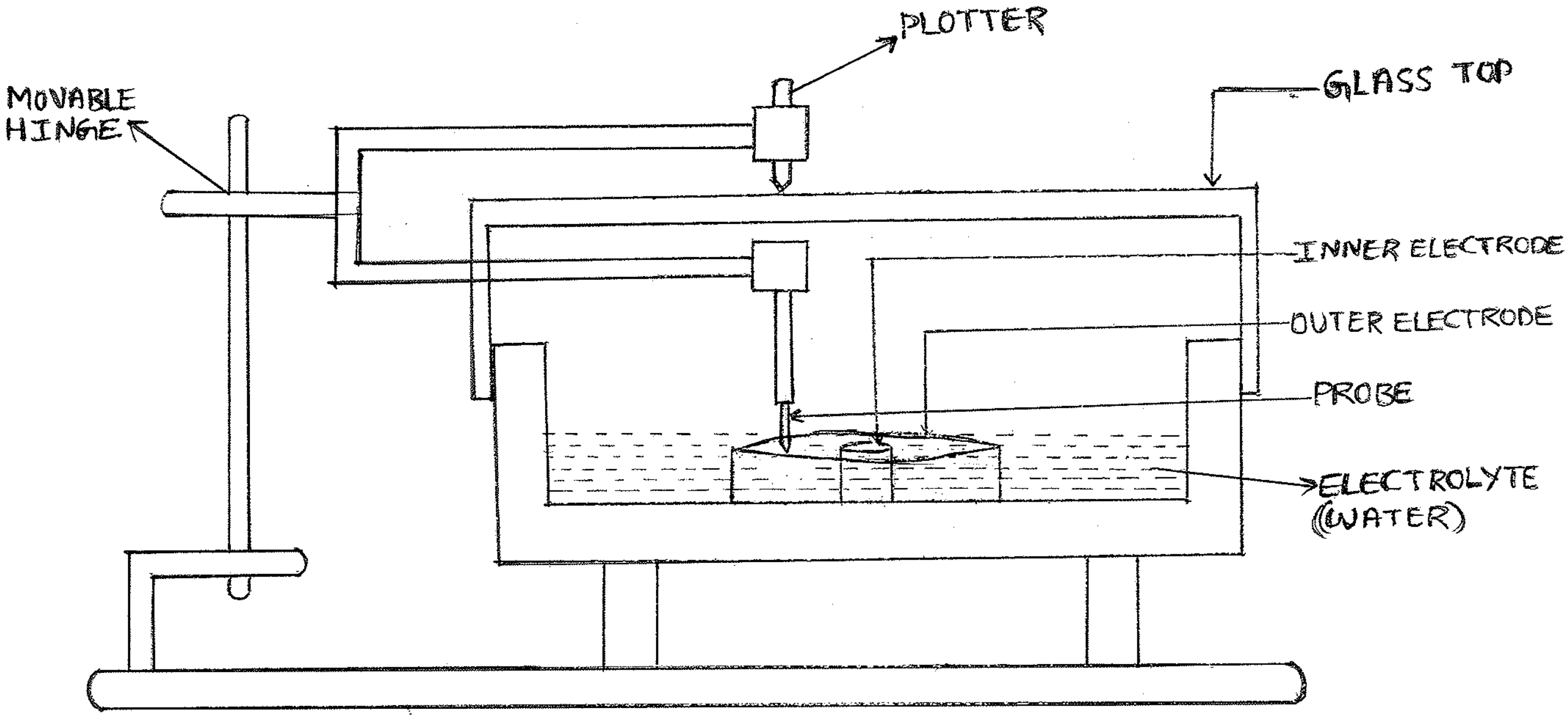


ROD - ROD ELECTRODE SYSTEM



PLANE - PLANE ELECTRODE SYSTEM

ELECTROLYTIC TANK



EXPERIMENT NO. DATE:

FIELD MAPPING USING ELECTROLYTIC TANK

Aim

To map electric field of a co-axial cable model using an electrolytic tank.

Apparatus

1. Electrolytic tank unit
2. Autotransformer
3. Multimeter (To be employed as a Digital voltmeter of high input impedance)
4. Spirit level
5. Connecting wires

Theory

A co-axial cable can be modeled as a concentric electrode system with inner radius 'a' and outer radius 'b'. The inner electrode is at potential V, while the outer is grounded. With a dielectric of permittivity ε in-between the two electrodes, the electric field intensity at any distance 'r' from the center of inner electrode is given by

$$|E| = \frac{V}{r \ln (b/a)}$$

Now, instead of the dielectric, if a conducting medium is present, then also the electric field at a distance 'r' is given by

$$|E| = \frac{V}{r \ln (b/a)}$$

Since, the field pattern has to be obtained inside the co-axial cable and the field pattern is identical when dielectric is replaced by a conducting medium, the conditions in a co-axial cable are simulated by a pair of concentric circular electrodes with tap water in between the electrodes. This simulation has the assumption that the co-axial cable has axial symmetry and does not exhibit any eccentricity. The voltage at different radial distances is measured with a digital voltmeter with the help of a thin probe dipping about 1mm below water, thereby minimizing field distortion effects.

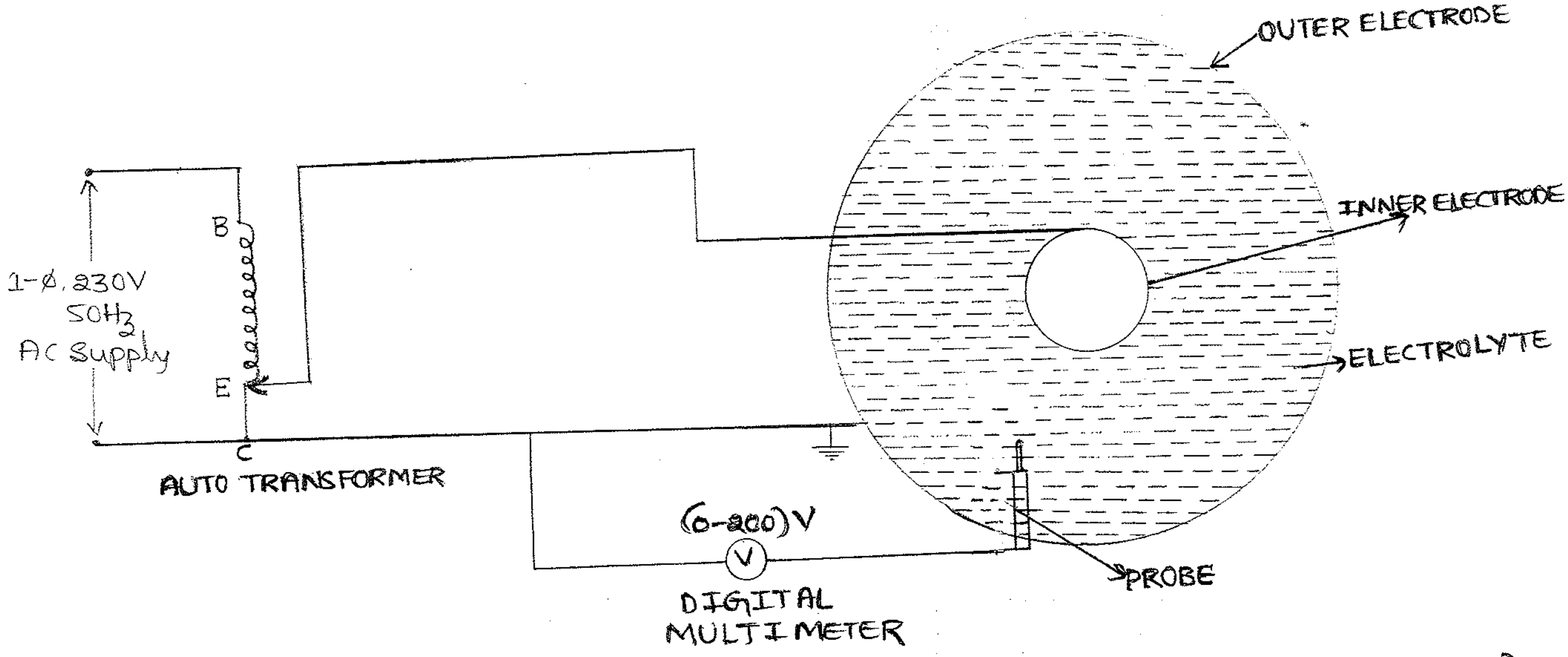


FIG. ELECTROLYTIC TANK (MODEL) TO MEASURE POTENTIAL DROP (RADIAL) INSIDE A COAXIAL CABLE

Procedure

1. Outer diameter of inner electrode and inner diameter of outer electrode are measured after arranging the experimental setup as shown in Figure

2. Electrodes are cleaned and tap water is filled in the space between the two electrodes.

3. Electrolytic tank plane is positioned horizontal using level adjusting arrangement after noticing any error in the leveling on using spirit level.

4. Electrodes are connected to the power supply with the help of wires terminated with crocodile clips. Crocodile clips are firmly connected to the electrodes ensuring that they do not touch the water. Outer electrode is grounded.

5. Probe needle is kept dipped just about 1 mm of water. The voltage applied to the inner electrode is adjusted to 15 V.

6. Mark the equipotential points (in the region between the electrodes) on the paper fixed on the glass top of the electrolytic tank, using the plotter.

7. Maintain the potential of the inner electrode constant at 15 V.

8. Equipotential lines (contours) are drawn by connecting equal potential points.

9. Lines of force (Electric field lines) are then drawn perpendicular to equipotential lines at the point of intersection of the two. Area between two equipotential lines and the radial lines of force are maintained to be curvilinear squares.

[*Note*: With side of curvilinear square being ΔL, capacitance of each small square per unit length

$$C_o = \frac{\xi_o \xi_r \,\Delta L}{\Delta L} = \xi_o \xi_r \quad F/m$$

For 'm' squares circumferentially and 'n' squares radially, there can be 'n' series sets of 'm' capacitors in parallel, thereby giving a total capacitance per unit length of

$$C = (m/n)C_o \quad = (m/n)\xi_o \xi_r \quad F/m$$

10. Count 'm' and 'n' values of curvilinear squares and calculate capacitance per unit length. Compare it with capacitance of the co-axial cable per unit length which is theoretically calculated using the relation

$$C = \frac{2\pi \xi_o \xi_r}{\ln(b/a)} \quad F/m$$

11. Electric potential and field at various radial distances is calculated using field map and then compared with their theoretical values at selected locations.

12. The characteristic variation of electric potential, electric field and percentage error are plotted as a function of radial distance.

Result

Observations and calculations:

Radius of the inner electrode a = ____________ cm

Radius of the outer electrode b = ____________ cm

Applied voltage to inner electrode = ____________ v

From the field plot,
Number of squares existing circumferentially, m = ____________

Number of squares existing radially, n = ____________

∴ Experimentally, total capacitance of the cable / unit length

$$\text{i.e., } C_{pr} = \left(\frac{m}{n}\right)\xi_o \xi_r \quad F/m$$

Theoretically, capacitance of cable / length C_{th} = $2\pi \varepsilon_o \varepsilon_r / \ln(b/a)$

= ____________ F/m

∴ Percentage error in capacitance calculation = $[(C_{pr} - C_{th}) / C_{pr}] \times 100$

Specimen calculation (for the case of equipotential contour of ________ V)

Radial distance, r = ____________ cm

∴, Theoretical potential, V_{th} = $V / [\ln(b/a)] \times \ln(b/r)$

=

∴, % Error in potential calculation = $[(V_{pr} - V_{th}) / V_{pr}] \times 100$

=

[Note: V is the applied voltage to inner electrode]

Radial distance R(cm)	Electric potential $V_{th}(V)$	Electric potential $V_{pr}(V)$	% Error = $[(V_{pr}-V_{th})/V_{pr}] \times 100$

In between radial distances ______ cm and ______ cm, there is a voltage difference of ______ V.

∴, Average field intensity at ___________ cm = ___________ V/cm

Theoretical field intensity at __________ cm = V / [r ln (b/a)] V/cm

= _________ V/cm

∴, Percentage error in electric field intensity = $[(E_{pr} - E_{th}) / E_{pr}] \times 100$

=

Mean Radial distance r_m (cm)	Field intensity theoretical, E_{th} (V/cm)	Field intensity practical, E_{pr} (V/cm)	% Error = $[(E_{pr}- E_{th})/ E_{pr}] * 100$

EXPERIMENT NO. DATE:

BREAKDOWN STUDIES USING HVAC

Aim

To determine the breakdown characteristic of Plane – Plane & Point - Plane electrode gap under HVAC application with ambient air as the insulating medium.

Apparatus

1. Autotransformer
2. HV transformer 230 V / 50 kV, 5 KVA
3. Control panel with accessories (to regulate the input to HV transformer)
4. Test object (Plane – Plane & Point - Plane electrode gap)

Theory

The necessity of generating high voltage arises due to three main reasons, namely

1. HV testing
2. Research and developmental studies
3. Industrial applications of HV technology

For electrical engineers, the main concern of the high voltage is in the area of insulation testing of various components used in a power system under different types of voltages namely

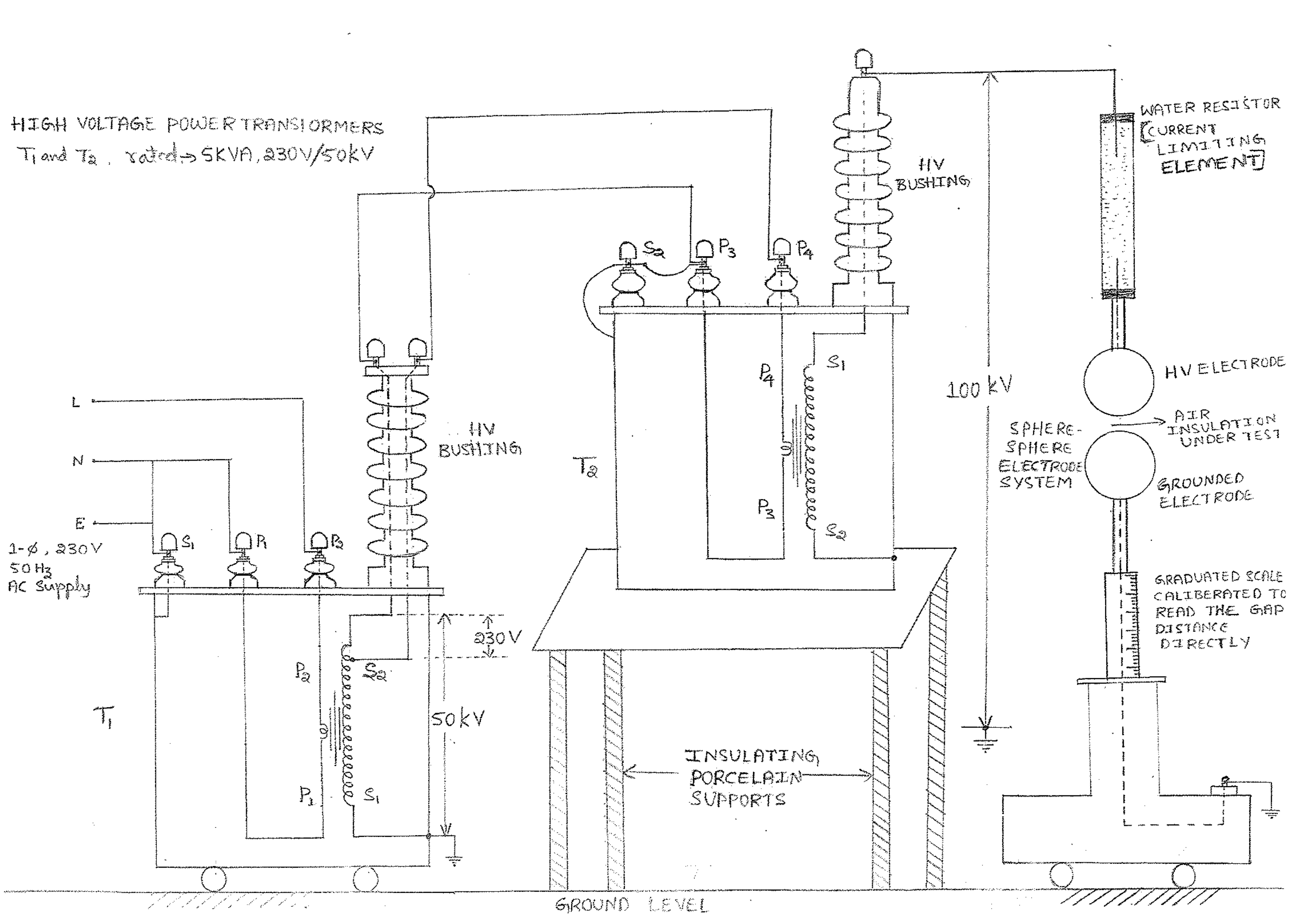
i. AC – power frequency
  - high frequency

ii. DC

iii. Impulse – lightning
  - switching

Therefore, test facilities need to have high voltage generators.

High voltages (AC, DC or Impulse) are required for several applications. For example, electron microscopes and X-ray tubes require high voltage DC of the order of 100 kV or more. CRO, TV tubes and lasers are other examples. High voltage AC of one million volts or more is required for testing of power apparatus rated for extra high transmission voltages.


HIGH VOLTAGE POWER TRANSIORMERS
T1 and T2 , rated→ 5KVA, 230V/50kV
L
N
E
1-Ø , 230V
50 Hz
AC Supply
S1
P1
P2
S2
T1
HV BUSHING
230V
50kV
T2
S2
P3
P4
S1
HV BUSHING
INSULATING PORCELAIN SUPPORTS
GROUND LEVEL
100 kV
WATER RESISTOR [CURRENT LIMITING ELEMENT]
HV ELECTRODE
AIR INSULATION UNDER TEST
SPHERE-SPHERE ELECTRODE SYSTEM
GROUNDED ELECTRODE
GRADUATED SCALE CALIBERATED TO READ THE GAP DISTANCE DIRECTLY

Procedure

1. Connections are made as in circuit diagram and objects constituting the test gap are cleaned and polished.

2. Test gap spacing is adjusted to the requirement.

3. Red light is switched ON to clear the area around the HV units.

4. Supply mains are switched ON and energy is supplied to the control panel.

5. Before starting the experiment, siren is initiated as an alarm, indicating the start of HV energization.

6. Press the HT ON button and using the *increase* button adjust the voltage applied to the test gap till the point of breakdown.

7. Note down the voltage at the instant of breakdown (as indicated by the corresponding AC meter on the control panel) and quickly de-energize the HV transformer by pressing HT OFF button.

8. Repeat the procedure for 5 trails with 2 minutes interval (so as to allow the de-ionization of the air insulation medium around the test object) between each application.

9. Green light is turned ON, indicating that the area surrounding the HV unit is open for personnel entry. Then, grounding of all the objects in the experimental setup is compulsorily done.

10. Test gap distance is then adjusted to a different value and the entire procedure is repeated.

11. The said procedure is repeated for both the set of electrode gap arrangements.

12. Finally, HT is switched OFF and supply mains are turned OFF.

13. Peak value of average spark over voltage (SOV) at Room Temperature and Pressure (RTP) is calculated.

14. SOV (peak value) obtained at RTP is subjected to corrections, so as to get its value corresponding to Standard Temperature and Pressure (STP).

15. Characteristic variation of corrected values of SOV (peak) is plotted against electrode gap distance.

Result

Observations:

Sphere - Sphere Electrode gap

Sl. No.	Electrode gap distance in Cm	Sparkover voltage (SOV) in kV(peak)	Average SOV in kV (Peak) at Room Temperature and Pressure (RTP)	Average SOV in kV (Peak) corrected to Standard Temperature and Pressure (STP)
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				

Specimen calculation:

Thermometer dry bulb temperature t_{DRY} = __________°C

Thermometer wet bulb temperature t_{WET} = __________°C

For the selected electrode gap spacing of __________cm,

Average spark over voltage at RTP = ___________ kV

To calculate spark over voltage at room temperature and pressure:

For trial No. ____,

Average Spark over voltage (RMS), SOV =

Average SOV (peak) at RTP =

To calculate corrected spark over voltage SOV (peak) in kV:

Thermometer dry bulb temperature, t_{DRY} = ________ °C

Thermometer wet bulb temperature, t_{WET} = ________ °C

From IS – 2071 / 1962; Absolute humidity, h = ________ g/m³

From IS 2071 / 1974;

Using h = ________ g/m³, and cure A – *meant for power frequency tests*

Humidity correction factor, H =

Atmospheric pressure in the lab (Barometer reading) P = ________ mmHg

Air density correction factor, δ = $(0.386 \times P) / (273 + t_{DRY})$

=

Air density correction factor, δ = ________

∴, Net correction factor, H / δ = ________

Corrected average SOV (peak) at STP = Average SOV (peak) in kV at RTP x (H / δ)

=

= ________ kV

Dr. H. N. SURESH
M.C.E., Hassan

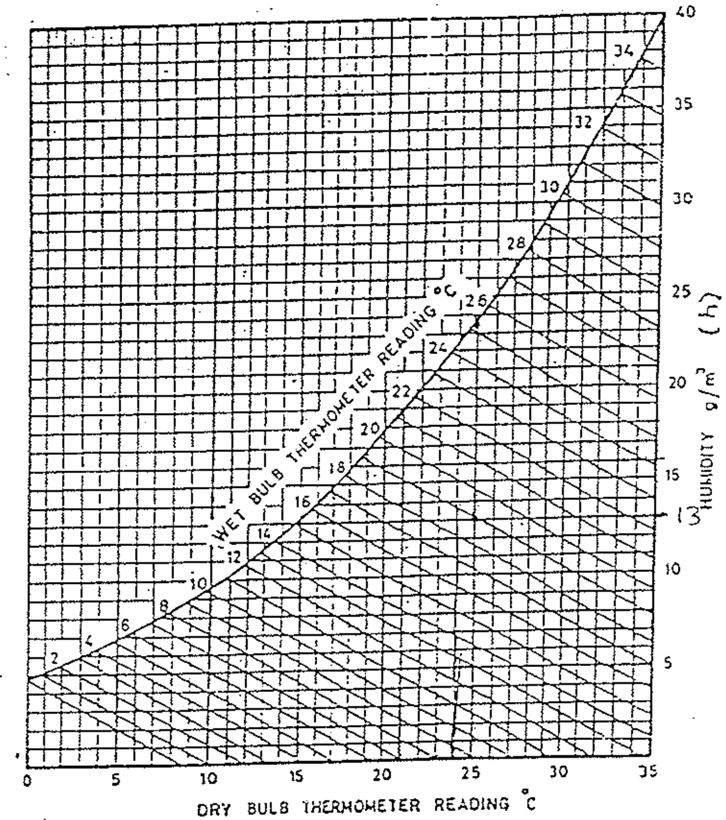
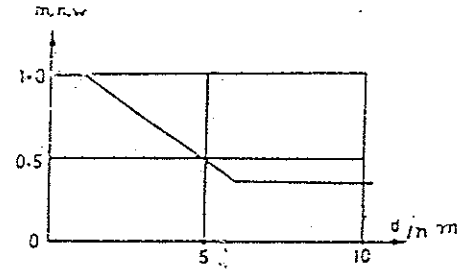


FIG. 1 DETERMINATION OF ABSOLUTE HUMIDITY

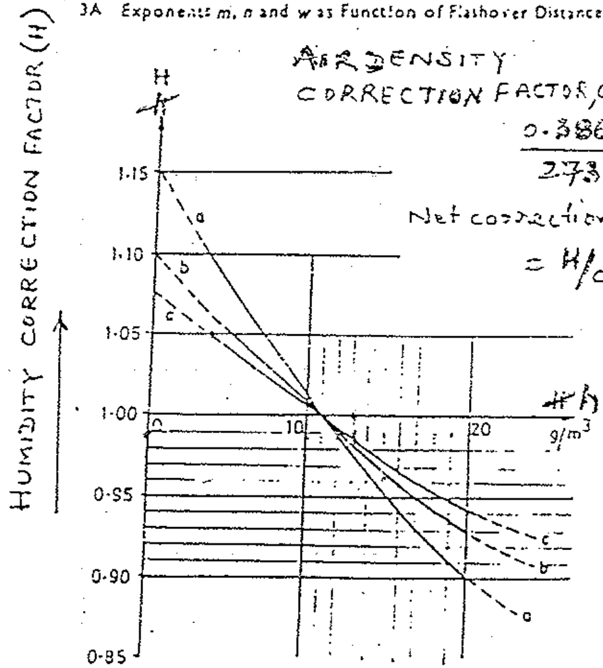
5.2.1.1 *Ripple factor* — The ratio of the ripple magnitude to the arithmetic mean voltage.

5.2.2 *Value of Direct Test Voltage* — The value defined by its arithmetic mean value.

NOTE — The maximum value of the test voltage may be taken approximately as the sum of the arithmetic mean value plus the ripple magnitude.



3A Exponents *m, n* and *w* as Function of Flashover Distance 'd'



AIR DENSITY CORRECTION FACTOR, δ = $\frac{0.386 \times P}{273 + t_{dry}}$

Net correction factor = H/δ

3B Factor *K* as Function of Absolute Humidity in g/m³

FIG. 3 AIR DENSITY AND HUMIDITY CORRECTION FACTORS

a) p.f. tests
b) +ve Impulse tests
c) -ve — " — " —

EXPERIMENT NO. DATE:

OPERATING CHARACTERISTICS OF DMT UNDER VOLTAGE STATIC RELAY

Aim

To study the operation of DMT under voltage static relay and to draw its operating characteristics.

Apparatus

1. DMT under voltage static relay testing kit involving
   - DMT under voltage static relay, Digital Voltmeter, Digital timer, Auto transformer (0-230 V), Isolation transformer (1:1) and Circuit breaker
2. Connecting leads

Theory

Under voltage relay:

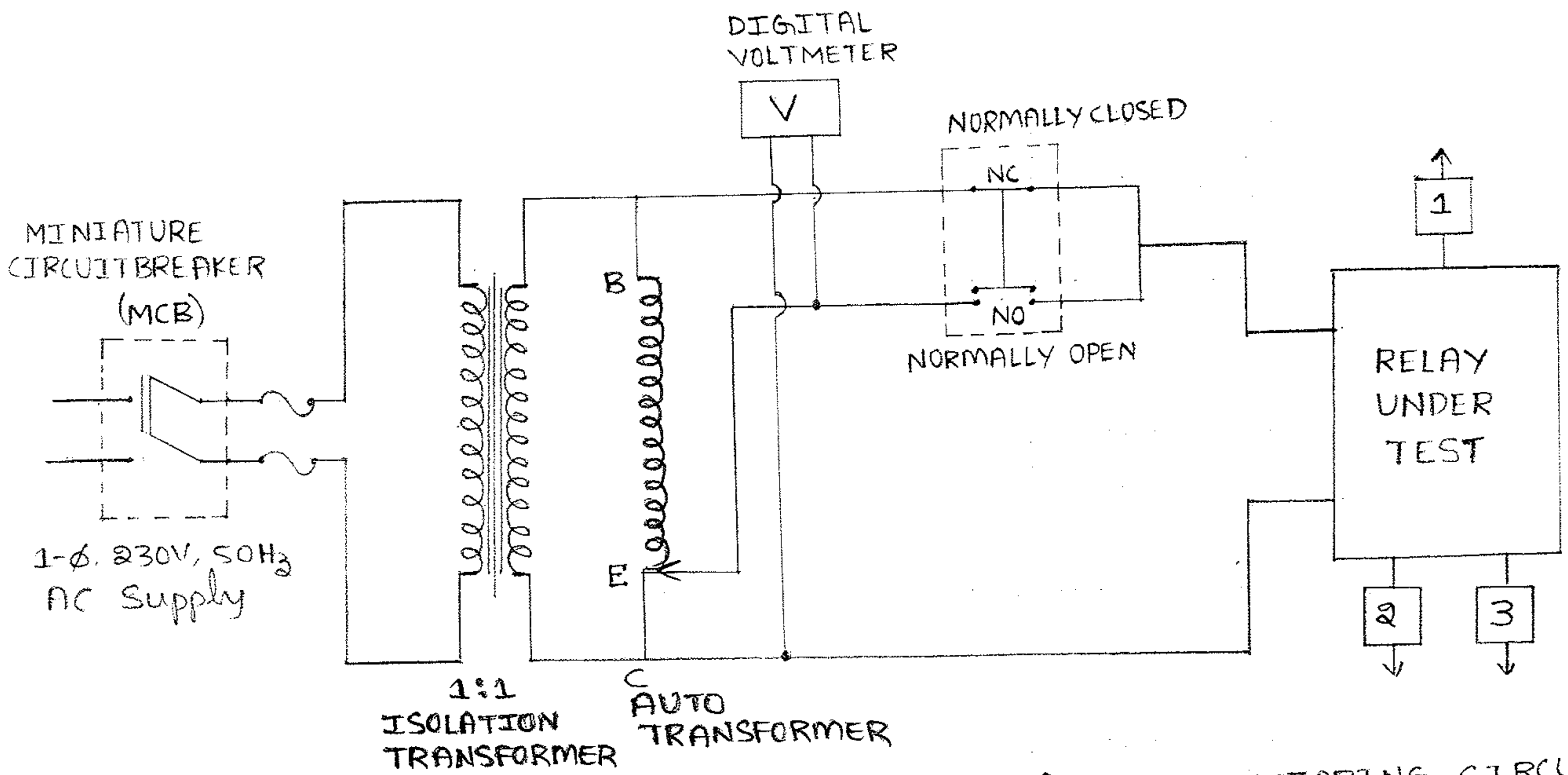
It is a type of relay that operates and opens the circuit breaker whenever the voltage in the system falls below a permissible limit.

The increased growth of power systems, both in size and complexity has brought about the need for fast and reliable relays to protect major equipment and to maintain system stability. The conventional protective relays are either electromagnetic or static type. The electromagnetic relays have several drawbacks such as high burden on instrument transformers, high operating time, contact problem, etc. Static relays have been increasingly used in recent years because of their inherent advantages of compactness, being lower burden, less maintenance and high speed.

Static Relays:

The term *Static Relay* is generally referred to a relay incorporating solid state components like diodes, transistors, resistors, capacitors, etc. In a static relay, the designed response is developed by electronic, magnetic or other components without mechanical motion. Static relay with output contacts is one having a contact in one or more of its output circuits. On the other hand, static relay without output contacts is one having no contact in its output circuit.

UNDERVOLTAGE STATIC RELAY



1) TRIP MONITORING CIRCUIT
2) TRIP CONTROL CIRCUIT
3) TIMER CIRCUIT

Basic construction of static protection relays:

Basically, protective relays are analogous to binary signal converter with measuring functions. The variable such as current, voltage, phase angle or frequency and desired voltage obtained by differentiating, integrating or other arithmetical operation, appear always as an analogous signals at the input of the measuring unit. The output will always have a binary signal i.e., either an open (or OFF) signal if the relay is not to trip or a close (or ON) signal if the relay is to trip. These output signals can therefore be easily evaluated by subsequent control elements requiring very little technical effort. Each protective relay is built up of individual elements in accordance with the basic block diagram.

The under voltage signals, which occur in analogous and therefore in the continuously variable form are first fed to the converter unit in the protective relay. This converts the measured under voltage signals, so that they can be easily processed by measuring element which follows. This measuring element will be operated when the input signal reaches a certain value less than that of minimum permissible value; providing a class signal at its output. The output element amplifies this binary input weak signal and transfers it to one or more controlled elements. The controlled elements carry out final switching functions like operation of circuit breaker, etc. Power is supplied to the measuring or output element by a feed element. This power is obtained either from an auxiliary voltage source or from the measuring circuit itself.

Procedure

1. In the relay testing kit, connections with respect to those from isolation transformer to autotransformer and then to relay operating coil as well as trip sensing mechanism are bound to be readily available. Hence, remaining connections required to be made are to energise the autotransformer from 1- phase, 230 V, 50 Hz AC supply. Therefore, as a first step, make connections from supply unit to relay operating system followed by digital voltmeter terminals connection on relay kit.

2. Select the required percentage of rated voltage (V_{set}) of the relay, below which protection is sought. This has to be done by operating the specific knob provided for that purpose on the front dial of the relay unit.

3. Make the choice of time setting (T_{set}) by operating the specific knob provided for that purpose on the front dial of the relay unit.

4. Switch on the MCB provided on the relay kit.

5. Push the selector knob to 'SET' mode, if it is otherwise.

6. Switch on circuit breaker by pressing the 'ON' button provided on the relay kit.

7. Press circuit breaker 'OFF' button followed by pressing timer 'RESET' button.

8. Voltage less than V_{set} are applied across input using autotransformer and now, push the selector knob to 'TEST' mode.

9. Then, press the circuit breaker 'ON' button and note down the operating time indicated on the digital timer at the end of relay operation.

10. Press circuit breaker 'OFF' button, followed by pressing the timer 'RESET' button. Now relay is ready for next trial.

11. The above procedure is repeated over various values of voltage less than V_{set}, so as to obtain Definite Minimum Time (DMT) characteristics of static under voltage relay.

12. The entire experiment procedure is repeated for different values of T_{set} and V_{set}.

Result

Observations:

Reference voltage = 80% V_n = 88 V ; = 110 V		
Time setting (S)	Load voltage (V)	Operating time (S)
3		
5		

EXPERIMENT NO. DATE:

OPERATING CHARACTERISTICS OF OVER VOLTAGE STATIC RELAY

Aim

To study the operation of over voltage static relay and to draw its operating characteristics.

Apparatus

1. Static over voltage relay testing kit involving
   - Over voltage static relay, Digital Voltmeter, Digital timer, Auto transformer (0-230 V), Isolation transformer (1:1) and Circuit breaker
2. Connecting wires

Theory

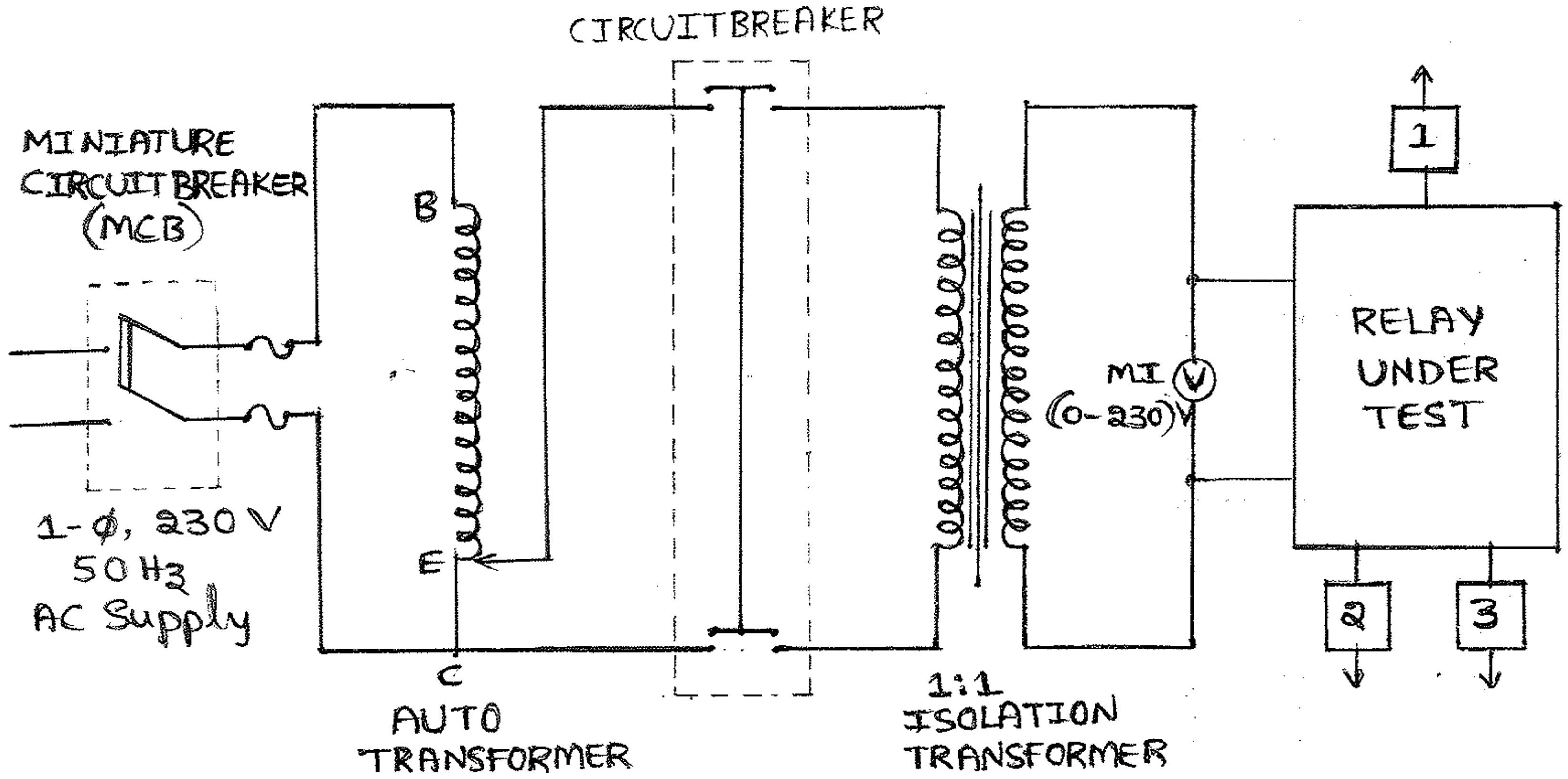
Over Voltage relay operates and opens the circuit breaker whenever the voltage in a system reaches above a permissible value.

The increased growth of power systems both in size and complexity has brought about the need for fast and reliable relays to protect major equipment and to maintain system stability. The conventional protective relays are either electromagnetic or static type. Since the electromagnetic relays suffer with drawbacks such as burden on instrument transformers, high operating time, contact problems, etc., static relays are being popularly used.

The term *static relay* refers to a relay, which incorporates solid-state components like transistors, diodes, etc., for measurement and comparison of electrical quantities. The static network is so designed that it gives an output signal in the tripping direction whenever a threshold condition is reached. The output signal inturn operates a tripping device, which is also electronic in nature.

The need for static relays arose because of the requirement of fast and reliable protective schemes for the modern power systems, which is growing both in complexity and fault levels. The semiconductor devices, such as transistors, have made it possible to achieve greater sensitivity and at the same time excellent mechanical stability which is not possible in case of electro-mechanical relays.

OVERVOLTAGE STATIC RELAY



1) TRIP MONITORING CIRCUIT
2) TRIP CONTROL CIRCUIT
3) TIMER CIRCUIT

Thus, by the use of static relays one can have:

a) Less burden on the current transformers and potential transformers, as compared to conventional electro-mechanical relays, since power consumption is low.
b) The process of operation of relay is fast.
c) Can have greater sensitivity, as amplification of signals can be obtained.
d) Can have high reset to pick-up ratio and reset is very quick.

Over voltage protection is normally provided for hydroelectric and gas turbine generators and not for steam turbine generators. The protection used is an AC over voltage relay, which has a pick-up value of 110% of the normal value and operates instantaneously at about 130% to 150% of the rated voltage. The relay unit should be compensated against the frequency and it should be energized from a potential transformer, other than one used for automatic voltage regulator. In practice, the operation of the relay introduces resistance in the generator or exciter field circuit and if over voltage still persists, the main generator breaker and the generator exciter field breaker is tripped.

Procedure

1. In the relay testing kit, connections with respect to those from autotransformer to isolation transformer and then to relay operating, trip sensing mechanism are bound to be available. Hence, remaining connections required to be made are to energize the autotransformer from 1-φ, 50 Hz, 230 V AC supply and make connections from relay operating kit to digital voltmeter terminals on relay kit.

2. Select the required percentage of rated voltage 'V_{set}' of the relay, above which protection is sought. This has to be done by operating the specific knob provided for that purpose on the front panel of the relay kit.

3. Make the choice of time setting by operating the specific knob provided on the front panel.

4. Switch on the MSB provided on kit.

5. Push the selector knob to 'SET' mode and 'RESET' the timer so as to nullify any previous recordings, if present.

6. A voltage 'V_{set}' is applied through autotransformer and circuit breaker is switched 'ON' (to operate). After a particular instant of circuit breaker operation, the flag is 'RESET', indicating the successful relay operation.

7. Then the selector knob is pushed to 'TEST' mode. The flag is 'SET' and circuit breaker is switched 'OFF'.

8. Again to know the exact operating time of relay, the circuit breaker is switched 'ON' and the time is noted. Then, circuit breaker is switched 'OFF' and selector knob is again pushed to 'SET' mode.

9. Steps 2 & 5 - 8 are repeated for various trials in order to obtain definite minimum time characteristic of static over voltage relay.

Result

Observations:

Reference Voltage (V)	Load voltage (V)	Time setting =	Average operating time (S)	Time setting =	Average operating time (S)
		Operating time (S)		Operating time (S)	

EXPERIMENT NO. DATE:

OPERATING CHARACTERISTICS OF ELECTROMECHANICAL TYPE OVER CURRENT RELAY

Aim

To study the operation of IDMT electromechanical type over current relay and draw its operating characteristics.

Apparatus

1. IDMT electromechanical type over current relay testing kit involving
   - IDMT electromechanical type over current relay, Digital Ammeter, Digital timer, Auto transformer (0-230 V) and Isolation transformer (1:1) and Circuit breaker

2. Connecting wires

Theory

An induction type over current relay consists essentially of an energy meter mechanism with slight modification to give required characteristics. The relay has two electromagnets. Upper electromagnet has two windings, one of which is primary and is connected to the secondary of a C.T. in the line to be protected and is tapped at intervals. Tappings are connected to a plug setting bridge by which the number of turns in use can be adjusted and thereby giving the desired current setting. The plug-bridge is usually arranged to give seven sections of tapping so as to give over current range from 50% to 200% in steps of 25%. Adjustment of current setting is made by inserting a pin between the springs loading jaw of the bridge socket at the tap value required.

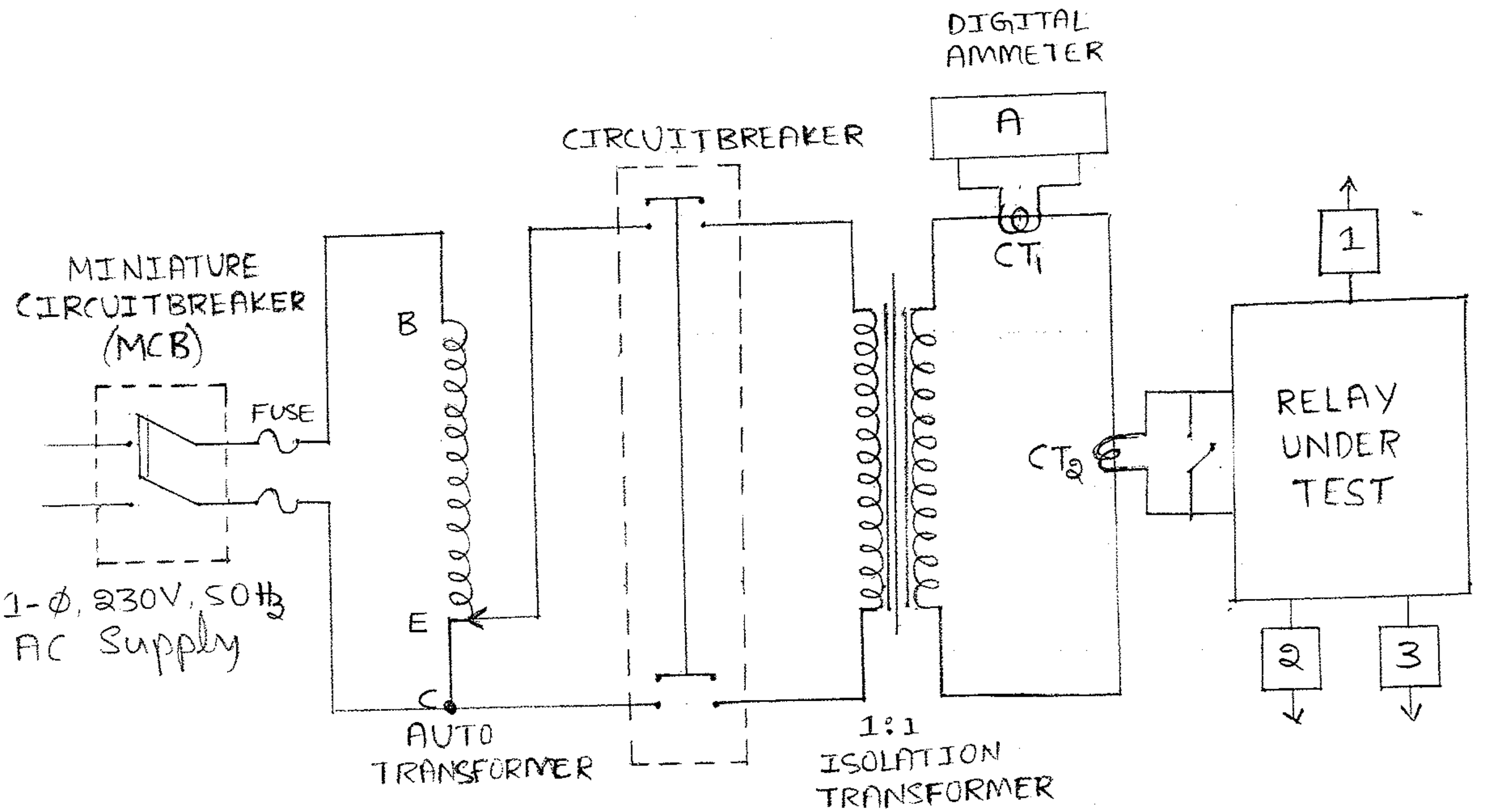
When the pin is withdrawn for the purpose of changing the setting value while the relay in service, the relay automatically adopts higher setting, thus the CTs secondary is not made to open. The secondary winding is energized by induction from the primary and is connected in series with the winding on the lower magnet.

Torque is given by the expression

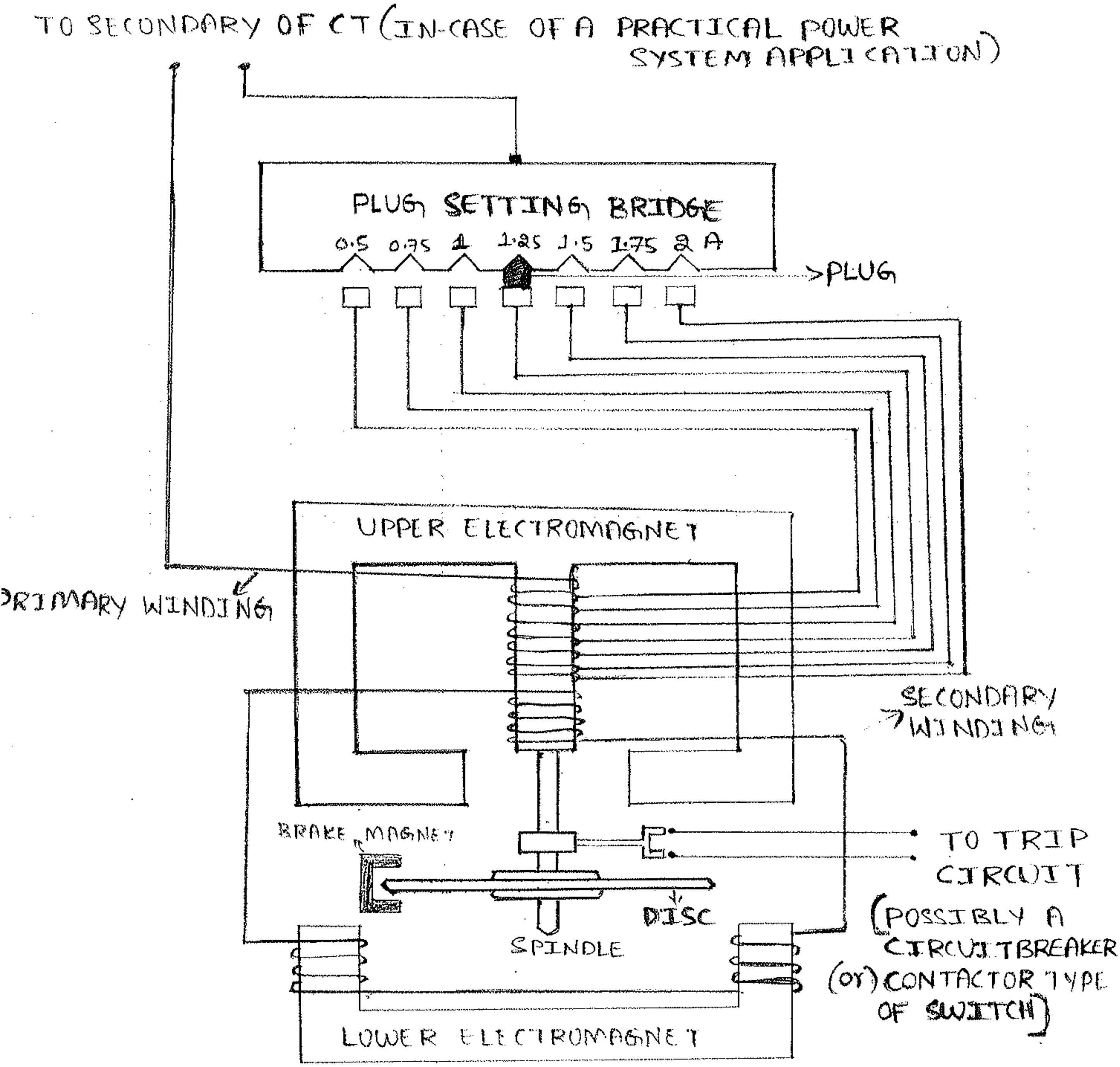
$$T = KI_{rms}^{2} - K_{2}$$

where, I_{rms} is the current through the coil and K_2 is the restraining torque of the spring. The disc spindle carries a moving contact which bridges two fixed contacts (trip circuit

ELECTROMECHANICAL TYPE OVERCURRENT RELAY



1) TRIP MONITORING CIRCUIT
2) TRIP CONTROL CIRCUIT
3) TIMER CIRCUIT


TO SECONDARY OF CT (IN-CASE OF A PRACTICAL POWER SYSTEM APPLICATION)
PLUG SETTING BRIDGE
0.5 0.75 1 1.25 1.5 1.75 2 A
PLUG
UPPER ELECTROMAGNET
PRIMARY WINDING
SECONDARY WINDING
BRAKE MAGNET
TO TRIP CIRCUIT
(POSSIBLY A CIRCUIT BREAKER (or) CONTACTOR TYPE OF SWITCH)
DISC
SPINDLE
LOWER ELECTROMAGNET

contacts) when the disc has rotated through a pre-set angle. Time to rotate the disc through a pre-set angle depends on the torque that varies as the current in the primary circuit. Therefore, more the torque lesser will be the time required. So the relay has inverse time characteristic. IDMT characteristic is obtained by saturating iron in the upper electromagnet so that there is practically no increase in flux after the current has reached a certain value.

Procedure

1. Connections are made as shown in the circuit diagram.
2. Select plug setting and time setting value. Then close the switch 'S' and allow load current I to flow. As soon as the switch is turned open, the disc starts rotating and this occurs when the load current exceeds the plug setting. At this moment start the stop clock.
3. When the rotating disc makes contact with the trip circuit, the indicator bulb glows. At this moment, stop the clock and note down the time taken for the disc to move this distance and the corresponding load current value.
4. For different load currents, note down the corresponding relay operating time.
5. Repeat the above procedure for different values of plug setting and time setting values.
6. Plot the operating characteristic of the relay with multiples of plug setting along x - axis and time of operation (in seconds) along y – axis. Mark the IDMT operating characteristics and dead zone.

Result

Observations:

Time Multiplier Setting (TMS)	Plug Setting, PS (A)	Load current, I_L (A)	Operating time, t_{PR} (S)	PSM = I_L / PS	Operating time obtained from ideal characteristic, t_{TH} (S)	% Error = $[(t_{PR} - t_{TH})/t_{PR}] \times 100$

EXPERIMENT NO. DATE:

BREAKDOWN STRENGTH OF TRANSFORMER OIL

Aim

To determine the breakdown strength of given sample of transformer oil.

Apparatus

1. Transformer 60 kV, 0.5 KVA
2. Oil testing kit.
3. 500 ml of transformer oil.
4. Transformer oil test cell.

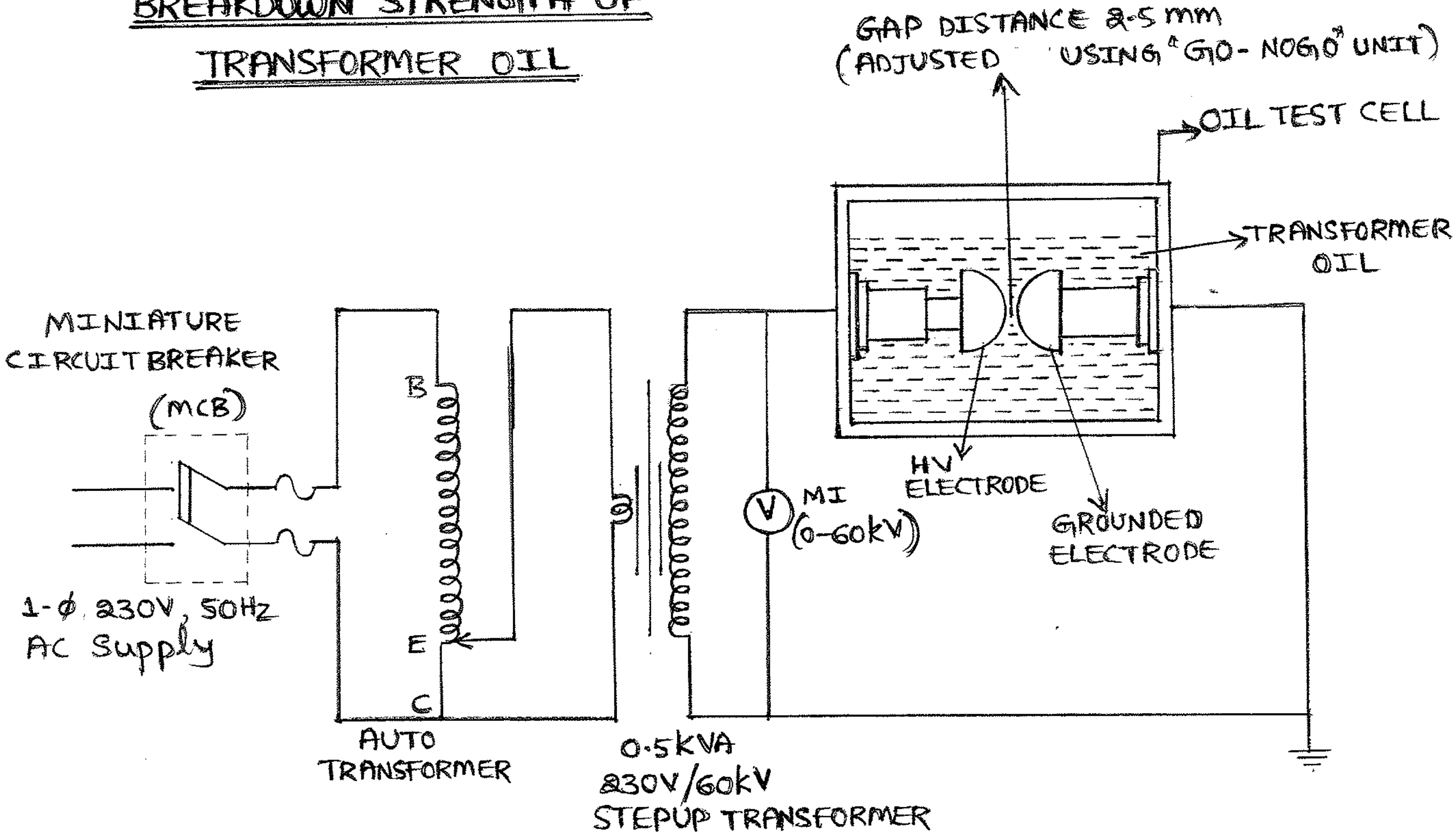
Theory

The test set which operates on 230 V, 50 Hz supply has mainly two transformers; A Toroidal wound autotransformer used to apply continuously variable voltage to other High Tension (H.T.) transformer. The H.T. transformer operates at a low flux density, ensuring distortion free output voltage. It is a 60 kV, 0.5 kA capacity transformer. It is so designed that the short circuit current of secondary is more than 20 mA at all voltages above 10 kV. The maximum short circuit current does not exceed 200 mA, thus preventing the unnecessary pitting of the electrodes. The test set consists of an overload relay which trips and disconnects the H.T. transformer when the breakdown occurs across the gaps. The oil or the insulating material to be tested has to be put in the cell only after removing the enclosure provided. When the enclosure is removed, it actuates a micro-switch, shutting off the supply to the unit. A zero return interlock arrangement makes it obligatory to bring the H.T. voltage to zero after every breakdown test. The panel board of the test set consists of a voltage control (forward and reverse) switch, a moving iron voltmeter to indicate the voltage applied in kV, three indicator lamps to indicate mains 'ON', H.T. 'ON' and H.T. 'OFF'. It also consists of mains switch, a H.T. 'ON' switch and a 'RESET' switch.

Test cell for transformer oil:

As per IS 6792/1972, the features of test cell and electrodes should be as follows:

BREAKDOWN STRENGTH OF TRANSFORMER OIL



- The cell, made of plastic (Perspex), shall be transparent and non-absorbent. It shall have an effective volume between 300 ml and 500 ml. It should perfectly be closed.
- The copper, brass, bronze, stainless steal polished electrodes shall be spherical surfaced of the shape and dimensions as given in figure. The electrode shall be mounted on a horizontal axis and shall be 2.5 mm apart. The axis of electrodes shall be immersed to a depth of 40 mm.

Precautions during sampling:

BS-148/1972 suggests the following precautions necessary for sampling:

- utmost care should be taken to avoid contamination of the sample with traces of external impurities such as dust and moisture.
- hands of the sampler should not come into contact with the sample.
- test should not be carried out on the sample until it is atleast as warm as the surrounding air.
- cotton waste or other fibrous material should not be used to wipe containers or test cell.

Procedure:

1. The gap between two spheres in the oil test cell is adjusted to 2.5 mm, using 'GO' and 'NO GO' gauges.

2. Test cell is cleaned and transformer oil to be tested is poured inside the cell taking all the precautions mentioned earlier.

3. Oil test cell is placed inside the fiber chamber.

4. Mains cord is then connected to the 230 V AC supply and the toggle switch on the panel is put to 'ON' position. The 'MAINS ON' as well as 'H.T. OFF' indicator lamps light up.

5. The 'H.T. ON' button is then pressed and the voltage control switch is turned to forward position. This will result in increase of excitation to the primary of H.T. transformer.

6. Once the voltage control switch is in forward position, internal motorized arrangement causes increase of voltage at the rate of approximately 2 kV/S.
7. The internal motorized arrangement advances the applied voltage across electrode till the breakdown occurs. Immediately after the breakdown, the 'H.T.

ON' lamp goes off and 'H.T. OFF' lamp lights up. The breakdown voltage is the voltage reached during the test at the time of breakdown.

8. Voltage reached during the test at the time of breakdown is noted down by pressing *memory push* button.

9. The above test is carried out again five times on the same cell filling. For the subsequent five tests, it is necessary to wait for five minutes before a new breakdown test is started. The electric strength of the oil is the arithmetic mean of the six results which have been obtained.

Tabulation

Trial No.	Breakdown voltage (kV) RMS	Breakdown voltage (kV) PEAK	Breakdown strength kV/cm	Average Breakdown strength kV/cm
1.				
2.				
3.				
4.				
5.				
6.				

Result

EXPERIMENT NO. DATE:

OPERATING CHARACTERISTICS OF MICROPROCESSOR BASED OVERVOLTAGE AND UNDERVOLTAGE RELAY

Aim: To study the characteristics of microprocessor based overvoltage/undervoltage relay.

Apparatus:

- Microprocessor based overvoltage/undervoltage relay, Digital Voltmeter, Digital Timer, Auto Transformer (0-230V), Isolation Transformer (1:1) and Circuit Breaker.
- Connecting Wires.

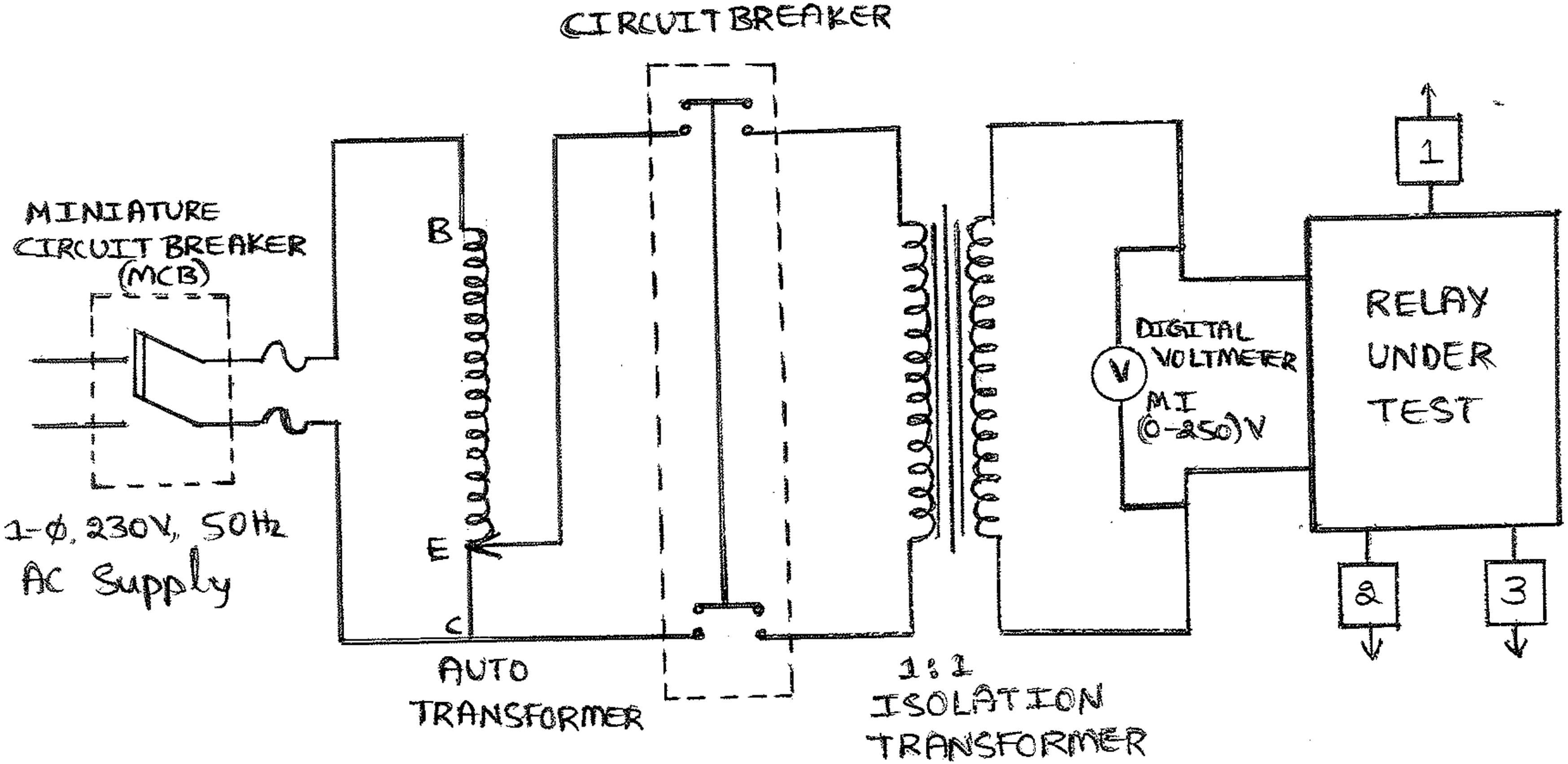
Theory:

Microprocessor Based Relay:

Computer hardware technology has tremendously advanced since early 1970's and new generations of computers tend to make digital computer relaying a viable alternative to the traditional relay systems. The advent of microprocessors in the 1970's initiated a revolution in the schemes. With the development of economically powerful and sophisticated microprocessors, there is a growing interest in developing microprocessor based protective relays which are more flexible because of being programmable and superior to conventional electromagnetic and static relays.

In the Microprocessor based digital relaying scheme, three-phase alternating quantities received from a power system through PT's and CT's are sampled simultaneously or sequentially at uniform time intervals(4 to 32 samples per cycle). These analog signals are then converted into digital form through an A/D(analog to digital converter). After conversion into digital form, signals are transferred to the digital processor. Digital signals are in the form of coded square pulses that represent discrete data. These signals are in binary form. Digital processors are set with pre-specified values. In co-ordination with the control and data outputs, the digital processor compares the dynamic inputs with the pre-specified values and decides to generate an alarm signal and, if required, a trip signal, to the output device.

MICROPROCESSOR BASED OVERVOLTAGE AND UNDERVOLTAGE RELAY



1) TRIP MONITORING CIRCUIT
2) TRIP CONTROL CIRCUIT
3) TIMER CIRCUIT

Microprocessor Based Over Voltage and Under Voltage Relays:

Microprocessor based relays are extensively used in the power industry. They operate when the circuit voltage exceeds (in case of Over Voltage)/ dips (in case of under voltage) a pre-determined value. The microprocessor uses a multiplexer for sensing the fault in a number of circuits and sub-circuits.

The PT helps in stepping the fault voltage to a desired value. This signal is then fed to the precision rectifier which rectifies these signals. The output of the rectified voltage signals is fed into the multiplexer. The microprocessor (micro-computer) then sends command for switching on the desired channel of the multiplexer circuit in order to obtain the rectified voltage in the particular circuit.

After this, since the microprocessor needs digital signals, the output of the multiplexer is fed to the analog – digital converter (ADC). Again, the microprocessor sends signal to the ADC for starting the conversation and reads the end of the conversation signal to examine whether the conversion is over and compares the signal with the pre-determined value.

Thus on the occurrence of the voltage above or below the pre-determined value, the relay sends the trip signal to the circuit breaker.

Procedure:

1. Switch ON the power supply and ensure that all the meters and relays are energized with auxiliary power supply.
2. Switch on the circuit breaker using "ON" push button.
3. Regulate the voltage with voltage regulator to a fault voltage level of 105% of reference voltage (110V).
4. Now the trip indicator will start blinking as an indication of fault command initiated on the relay to trip.
5. Keeping the regulator in the same position, switch off the circuit breaker.
6. Test the time interval meter for its working condition by keeping the rotary switch in test mode.
7. Reset the timer to zero.
8. Switch ON the circuit breaker & time interval meter simultaneously.
9. Note down the voltmeter and time interval meter readings after the tripping of the relay.
10. Switch OFF the circuit breaker and timer and repeat the experiment for different fault voltage levels increased in steps of 10 volts.
11. Tabulate the meter readings as shown in the tabular column and plot he graph.

Result:

Observations:

Settings for MV12 Relay:

- *Reference voltage settings: 110V*
  Reference voltage may be selected through jumper available on the PCB inside the relay.
  For ex: For reference voltage of 110V, Jumper position is 1.

- *Over voltage / Under voltage settings:*
  1. To select over voltage setting (Default setting), select the DIP switches as "ON OFF OFF OFF" inside the PCB of the relay.
  2. To select Under Voltage setting, select the DIP switches as "OFF OFF OFF OFF".

- *Selection of trip time characteristics:*
  1. Default (Over Voltage): Normal Inverse – 3.5 seconds.
     Switch position "ON OFF OFF OFF".
     DIP switches are available on the PCB of the relay.
  2. Under Voltage: Normal Inverse – 5.7 seconds.
     Switch Position "OFF OFF OFF OFF".
     High set features must be disabled.

- *Setting of fault voltage level: FOR MV12:*
  1. $V_s = 1 \pm (0.05 + \sum a) V_n$.
     Where V_s = Set voltage level (fault voltage level) in volts.
     a = Weight of switch in ON position.
     $V_s = 1 + (0.05 + \sum a) V_n$ for Over Voltage.
     $V_s = 1 - (0.05 + \sum a) V_n$ for Under Voltage.
  2. Default fault voltage level setting : 105% of V_n.
  3. Position of the switches : "OFF OFF OFF OFF".

Tabulation:

Over Voltage Relay:

110% of 110V = 121V   TMS =

Reference Voltage	Load Voltage	Operating Time

Under Voltage Relay:

90% of 110V = 99V   TMS =

Reference Voltage	Load Voltage	Operating Time

EXPERIMENT NO. DATE:

BREAKDOWN STUDIES USING HIGH VOLTAGE DC

Aim

To determine the breakdown characteristic of Plane – Plane & Point - Plane electrode gap under high voltage DC application with ambient air as the insulating medium.

Apparatus

1. Cascaded unit of HV transformers
   (involving two transformers, with each of them rated 230 V / 50 kV, 5 KVA)
2. 140 kV Diode rectifier unit
3. Capacitor filter rated 140 kV
4. Control panel with accessories (to regulate the input to cascade transformer unit)
5. Test object (Plane – Plane & Point - Plane electrode gap, with air as insulation)

Theory

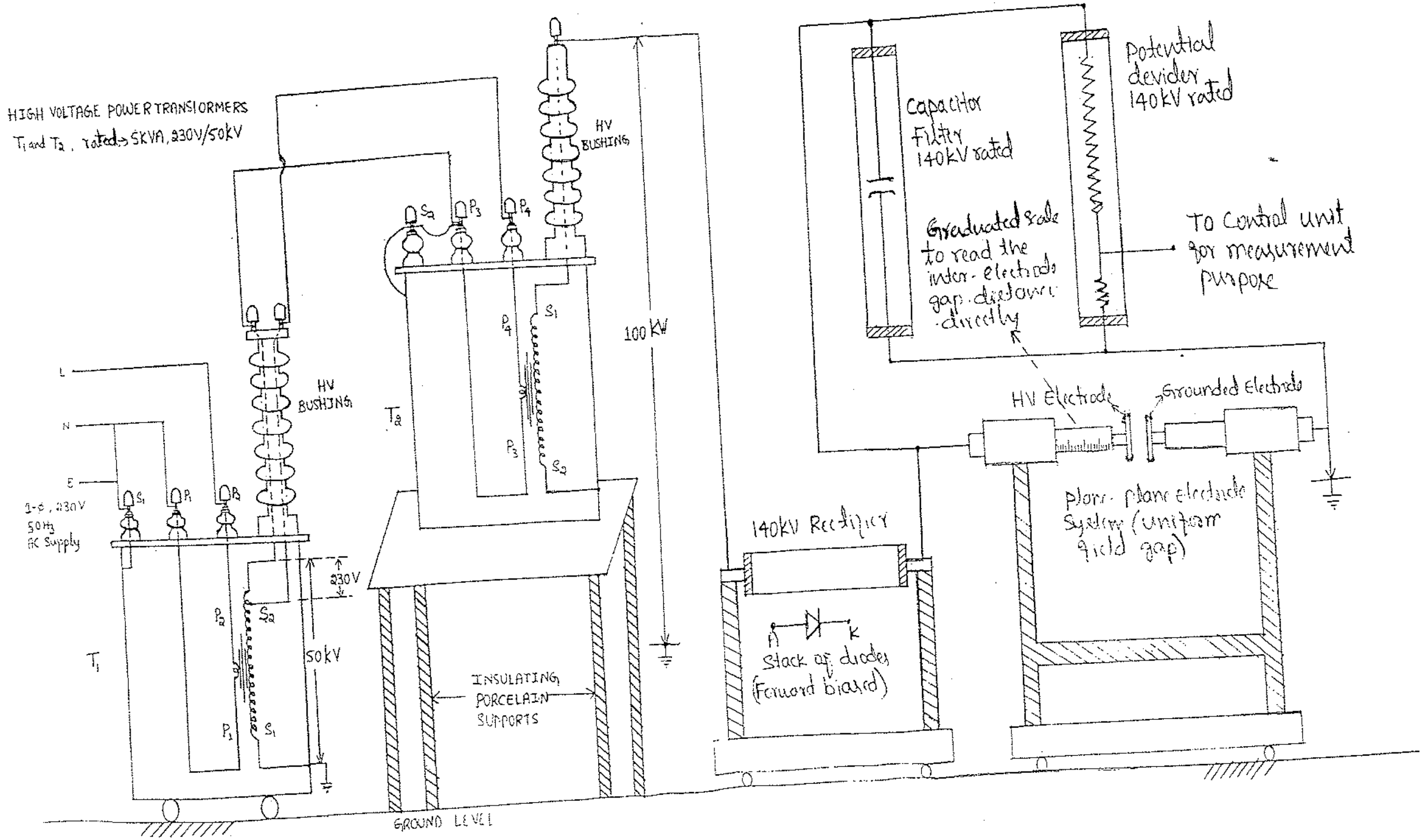
Generation of high DC voltages is mainly required in research work in the area of pure and applied physics. Sometimes, high direct voltages are needed in insulation testing on cables and capacitors. Impulse generator charging units also require high DC voltages of about 100 kV to 200 kV. High DC voltages from AC sources are produced using either half wave rectifiers or full wave rectifiers. When higher DC voltages are required a Voltage doubler circuit or Voltage multiplier circuit (in the form of Cockcroft – Walton type) is employed. For a n stage Voltage multiplier circuit, f being the supply frequency, I representing the load current and C is the stage capacitance (assuming all stage capacitance to be equal),

Total ripple $\delta V_{total} = I / fC \; [n(n+1)/2]$

Total voltage drop over n stages, $\Delta V_{Total} = I / fC \; [2/3\, n^3 + ½\, n^2 + 1/6\, n]$

Optimum number of stages for minimum voltage drop, $n_{opt} = \sqrt{V \max fC / I}$

Very high DC voltages are also developed on the electrostatic principle. Van de Graff generators and Electrostatic generators are such electrostatic machine which generates very high voltages. However, Van de Graff generators support only small output current.


HIGH VOLTAGE POWER TRANSIORMERS
T1 and T2 , rated→5KVA, 230V/50kV
L
N
E
1-φ , 230V
50Hz
AC Supply
S1
P1
P2
S2
T1
230V
50kV
HV
BUSHING
T2
S2
P3
P4
S1
100 KV
INSULATING
PORCELAIN
SUPPORTS
GROUND LEVEL
140kV Rectifier
A
K
Stack of diodes
(Forward biased)
Capacitor
Filter
140kV rated
Potential
devider
140kV rated
To Control unit
for measurement
purpose
Graduated scale
to read the
inter-electrode
gap distance
directly
HV Electrode
Grounded Electrode
Plane-plane electrode
System (uniform
field gap)

Procedure

16. Connections are made as in circuit diagram and objects constituting the test gap are cleaned and polished.

17. Test gap spacing is adjusted to the requirement.

18. Red light is switched ON to clear the area around the HV units.

19. Supply mains are switched ON and energy is supplied to the control panel.

20. Before starting the experiment, siren is initiated as an alarm, indicating the start of HV energization.

21. Press the HT ON button and using the *increase* button adjust the voltage applied to the test gap till the point of breakdown.

22. Note down the voltage at the instant of breakdown (as indicated by the corresponding DC meter on the control panel) and quickly de-energize the HV transformer by pressing HT OFF button.

23. Repeat the procedure for 5 trails with 2 minutes interval (so as to allow the de-ionization of the air insulation medium around the test object) between each application.

24. Green light is turned ON, indicating that the area surrounding the HV unit is open for personnel entry. Then, grounding of all the objects in the experimental setup is compulsorily done.

25. Test gap distance is then adjusted to a different value and the entire procedure is repeated.

26. The said procedure is repeated for both the set of electrode gap arrangements.

27. Finally, HT is switched OFF and supply mains are turned OFF.

28. Average spark over voltage (SOV) at Room Temperature and Pressure (RTP) is calculated.

29. SOV obtained at RTP is subjected to corrections, so as to get its value corresponding to Standard Temperature and Pressure (STP).

30. Characteristic variation of corrected values of SOV is plotted against electrode gap distance.

Result

Observations:

Case 1. Plane – Plane Electrode gap
(with high voltage DC of positive polarity):

Sl. No.	Electrode gap distance in Cm	Sparkover voltage (SOV) in kV	Average SOV in kV at Room Temperature and Pressure (RTP)	Average SOV in kV corrected to Standard Temperature and Pressure (STP)
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				

Case 2. Point – Plane Electrode gap
(with high voltage DC of positive polarity as excitation):

Sl. No.	Electrode gap distance in Cm	Sparkover voltage (SOV) in kV	Average SOV in kV at Room Temperature and Pressure (RTP)	Average SOV in kV corrected to Standard Temperature and Pressure (STP)
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				

Observations:

Case 1. Plane – Plane Electrode gap
(with high voltage DC of negative polarity):

Sl. No.	Electrode gap distance in Cm	Sparkover voltage (SOV) in kV	Average SOV in kV at Room Temperature and Pressure (RTP)	Average SOV in kV corrected to Standard Temperature and Pressure (STP)
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				

Case 2. Point – Plane Electrode gap
(with high voltage DC of negative polarity as excitation):

Sl. No.	Electrode gap distance in Cm	Sparkover voltage (SOV) in kV	Average SOV in kV at Room Temperature and Pressure (RTP)	Average SOV in kV corrected to Standard Temperature and Pressure (STP)
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				
1.				
2.				
3.				
4.				
5.				

Specimen calculation:

Thermometer dry bulb temperature t_{DRY} = ________°C

Thermometer wet bulb temperature t_{WET} = ________°C

For the selected electrode gap spacing of ________cm,

Average sparkover voltage at RTP = ________ kV

To calculate spark over voltage at room temperature and pressure:

For trial No. ____.

Average Spark over voltage, SOV =

Average SOV at RTP =

To calculate corrected spark over voltage SOV in kV:

Thermometer dry bulb temperature, t_{DRY} = ________ °C

Thermometer wet bulb temperature, t_{WET} = ________ °C

From IS – 2071 / 1962; Absolute humidity, h = ________ g/m^3

From IS 2071 / 1974; Using h = ________ g/m^3, and

curve B – meant for positive DC tests or Curve C- meant for negative DC tests

Humidity correction factor, H =

Atmospheric pressure in the lab (Barometer reading) P = ________ mmHg

Air density correction factor, δ = (0.386 x P) / (273 + t_{DRY})

=

Air density correction factor, δ = ________

∴, Net correction factor, H / δ = ________

Corrected average SOV at STP = Average SOV in kV at RTP x (H / δ)

=

= ________ kV

EXPERIMENT NO. DATE:

CURRENT – TIME CHARACTERISTIC OF FUSE

Aim

To obtain the current – time characteristic of fuse.

Apparatus

1. Ammeter - MI (0 – 6) A
2. Voltmeter - MI (0 – 300)V
3. Fuse mounting unit
4. Rheostat (0 – 4.6)Ω/18 A
5. Stop clock
6. Fuse wire – 6A rating
7. Autotransformer

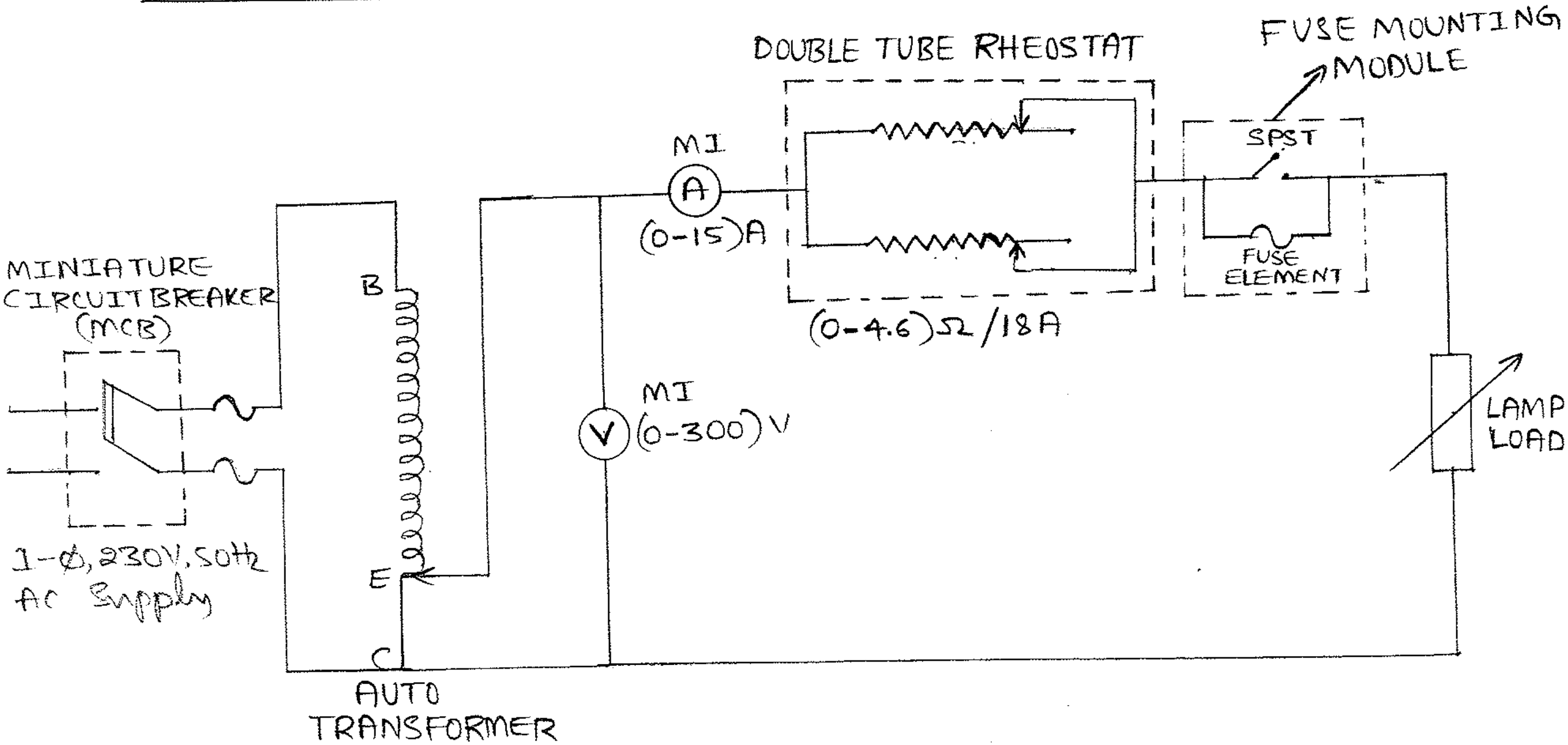
Theory

Fuse is a simple protective device that works for current interruption, if current through it become excessive. Hence, it protects the equipment from the effects of excessive high currents such as overheating, firing, physical damage etc. Its working and construction is simple. It is used for overload and short circuit protection in medium voltage range up to 66 kV.

A fuse, basically, is a small piece of metal connected between two terminals mounted on the insulated base. Fuse is always connected in series with circuit of appliance to be protected. A small piece of metal constituting a fuse is called fusing element.

Fusing element carries the normal working current safely, but melts due to excessive current under abnormal conditions like overload and short circuit. As it is in series, melting of fusing element causes current interruption and breaking of the circuit; thereby protecting the equipment from excessive current. Fusing element melts due to heat produced by the excessive current. So, the melting point of fusing element plays an important role in the design of fuse.

CURRENT-TIME CHARACTERISTIC OF FUSE



The fuse has inverse time -- current characteristics. This means, as the magnitude of fault current is higher, smaller is the time taken by the fuse to melt. When fault current is low, the time taken by the fuse is more.

Fusing factor is ratio of minimum fusing current to current rating of the fuse. Since minimum fusing current is more than the fuse current rating, the fusing factor is always greater than 1.

Procedure

1. Connections are made as shown in the circuit diagram.
2. Main supply switch is closed with SPST in closed position.
3. Autotransformer is used for adjusting the supply voltage to 230 V.
4. Current through the ammeter is adjusted by cutting-out resistance in the rheostat.
5. Open the SPST switch (so that the current flow through the fuse) and instantly start the clock to note down the time required for the fuse to melt. Note the ammeter reading as fusing current.
6. After the fuse melts and breaks, switch off the main supply and close the SPST switch. Leave the rheostat to cool for 5 minutes.
7. Place a new fuse link. Repeat the experiment for the current slightly higher than the earlier current setting.
8. Repeat the procedure for various current settings. For each case, note down the fusing current and melting time respectively.
9. Plot the characteristics variation of melting time (seconds) versus fusing current (amperes).
10. From the fuse characteristic, determine the minimum value of fusing current corresponding to asymptotic portion of the characteristic. Calculate fusing factor as the ratio of minimum fusing current to the rated current of the fuse.

Observations

Length l_1 of the fuse link = ______ cm			Length l_2 of the fuse link = ______ cm	
Sl. No.	Fusing current (Ampere)	Melting time (Seconds)	Fusing current (Ampere)	Melting time (Seconds)
1.				
2.				
3.				
4.				
5.				

Result

Minimum fusing current = ____________ amperes

Current rating of fuse = ____________ amperes

Fusing factor = Minimum fusing current / Current rating of fuse

Fusing factor =

Thus, current – time characteristics of fuse is obtained and the fusing factor is calculated to be _________ for length l_1 of the fuse. Similarly, fusing factor is calculated to be _________ for length l_2 of the fuse

Inferences

EXPERIMENT NO. DATE:

ALTERNATING HIGH VOLTAGE MEASUREMENT USING STANDARD SPHERES

Aim

To measure Alternating High Voltage (HVAC) using Standard spheres.

Apparatus

1. Sphere – Sphere electrode gap with gap reading arrangement
2. HV AC source (Cascaded unit of two HV transformers, each rated 230V/50kV, 5 KVA)
3. Control panel with accessories to regulate the input to HV transformer

Theory

A uniform field spark gap will always have a sparkover voltage within a known tolerance band under normal, constant atmospheric conditions. Hence, a spark gap can be used for measurement of peak value of the voltage, if the gap distance is known. Normally, only sphere gaps are used for voltage measurements. In certain cases, uniform field gaps and rod gaps are also used, but their accuracy is less. The spark gap breakdown especially is independent of voltage waveform and hence is highly suitable for all types of waveforms from DC to impulse voltage of short rise terms (rise time ≥ 0.5 μS). Sphere gap can be used either vertically with lower sphere grounded or horizontally with either sphere connected to the source voltage or one sphere grounded. The two spheres used are to be identical in size and shape. The voltage to be measured is applied between the two spheres and distance or spacing between them gives a measure of the sparkover voltage. A series resistance (may be in the form of water resistor) is usually connected between source and the sphere gap to limit the breakdown current and to suppress unwanted oscillations in the source voltage. The standard diameters for the spheres are 2, 5, 6.25, 10, 12.5, 15, 50, 75, 100, 150 and 200 cm.

Various factors that affect the sparkover voltage of a sphere gap are:

1. ***Nearby earthed object***: The effect of nearby earthed objects is investigated by *Kuffel* by enclosing the earthed sphere inside an earthed cylinder. It is observed that the sparkover voltage is reduced.

2. ***Effect of atmospheric condition***: Sparkover voltage of an electrode gap depends on the air density which varies with the change in both temperature and pressure.

3. ***Effect of irradiation***: Illumination of sphere gap with ultra violet or X-rays aids easy ionization in gaps. The effect of irradiation is pronounced for small gap spacing. Irradiation is necessary for smaller sphere gaps of gap spacing less than 1 cm for obtaining consistent values.

4. ***Effect of polarity and waveform***: It has been observed that the spark over voltage for positive and negative polarity impulses is different. Similarly, the wave front and wave tail duration also influences the breakdown voltage. As per the literature, for wave front time of less than 0.5 μs and wave tail time of less than 5 μs, the breakdown voltages are not consistent.

Procedure

1. Connections for HVAC measurement using sphere of 15 cm diameter are made as shown in the circuit diagram.

2. Both the test spheres are cleaned and polished. Sufficient care is taken to avoid dirt on the surface.

3. The electrode gap distance i.e., distance between the spheres, is set to a known value.

4. As a precautionary measure, red light is switched 'ON'. Siren is initiated to clear the surrounding near the test bay, before starting the experiment.

5. Main supply is switched on. The HT ON button is pressed. The voltage of the HV transformer is raised to an arbitrarily selected value. If the sparkover takes place between the spheres gaps at this voltage, the HT of the transformer is switched off and the set value of the gap distance will be tabulated.

6. If the sparkover does not take place at this voltage, then HT will be turned OFF. The light signal is changed from red to green indicating the condition to be normal. The test object is grounded and the gap distance between the two spheres is reduced a bit.

7. Again steps 4 and 5 are followed. If the sparkover takes place earlier than the previous trail's voltage selection, HT is turned OFF. Green light is switched on and manual grounding of the sphere object is done. Then, gap distance between the spheres is increased a bit..

8. For three applications of same voltage application, find the gap distance at which sparkover takes place and record them.

9. Repeat the procedure for different values of voltage selections, say V_1, V_2 and so on. Note each of the gap distance at which sparkover occurs.

10. Determine the average of gap distance causing the sparkover under each case of common voltage application.

11. Plot the variation of gap spacing versus sphere gap sparkover voltage based on the table 7.4 (IS: 1876 of 1962) (Reference: *M.S. Naidu and V. Kamaraju, High voltage engineering, Tata, Mc-Graw hill*).

12. From this plot, obtain the value of the voltage for each of average gap distance of the experiment. Thus, high voltage (AC) impressed between the test spheres is measured.

Circumference of standard sphere, = ________________ cm

i.e., πd = ________________ cm

$\therefore$, Diameter of standard sphere, d = ________________ cm

Trail 1: Output voltage of HV transformer (as displayed on control panel): __________ kV

Sl. No.	Electrode gap distance (cm)	Average sparkover distance (cm)	High voltage measured (in kV) based on standard (IS: 1876 of 1962) breakdown characteristic
1.			
2.			
3.			

Trail 2: Output voltage of HV transformer (as displayed on control panel): __________ kV

1.			
2.			
3.			

Result

- Spark over voltage using a standard sphere diameter of 15 cm at a critical spacing of ______ cm is measured (based on **IS: 1876 of 1962**) to be (under trial 1) __________ kV.

- Sparkover voltage using a standard sphere diameter of 15 cm at a critical spacing of ______ cm is measured (based on **IS: 1876 of 1962**) to be (under trial 2) __________ kV.

EXPERIMENT NO. DATE:

HIGH VOLTAGE IMPULSE GENERATION – AN INTRODUCTION

Transient over voltage due to lightning and switching surges cause steep buildup of voltage on transmission lines and other electrical apparatus. Experiments have shown that these transient voltages have a rise time of 0.5 - 10μs and time to decay (to 50% of the peak value) of the order of 30 - 200μs. These wave shapes are arbitrary, but unidirectional. The general wave shape is given in Fig. 5.1.

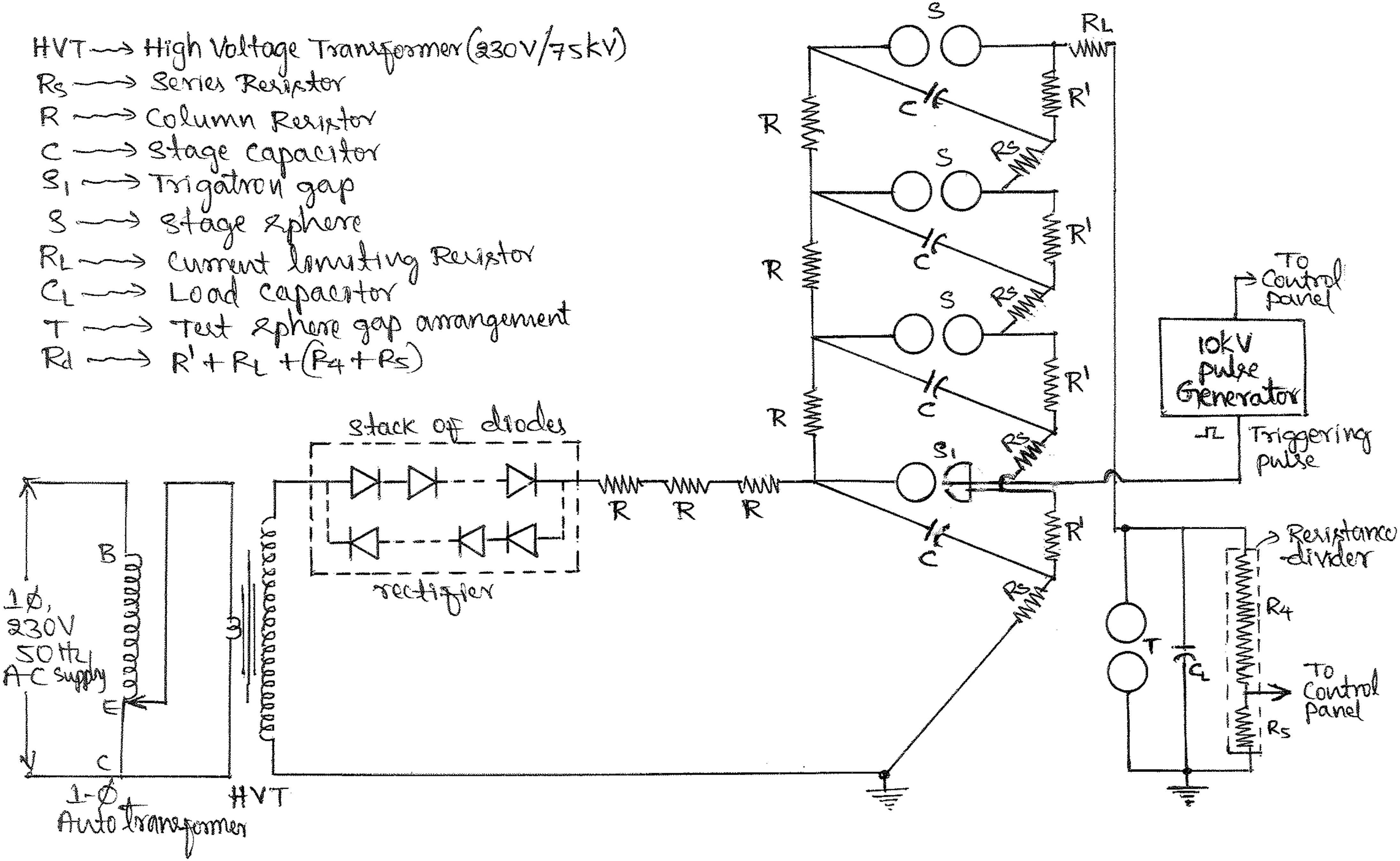
Impulse voltage waves are specified by their rise time, fall or tail time and value of peak voltage. Indian standard specifications define 1.2/50 μs wave as the standard lightning impulse wave. The tolerances that can be allowed in the front time and tail time are ± 30% and ±20% respectively.

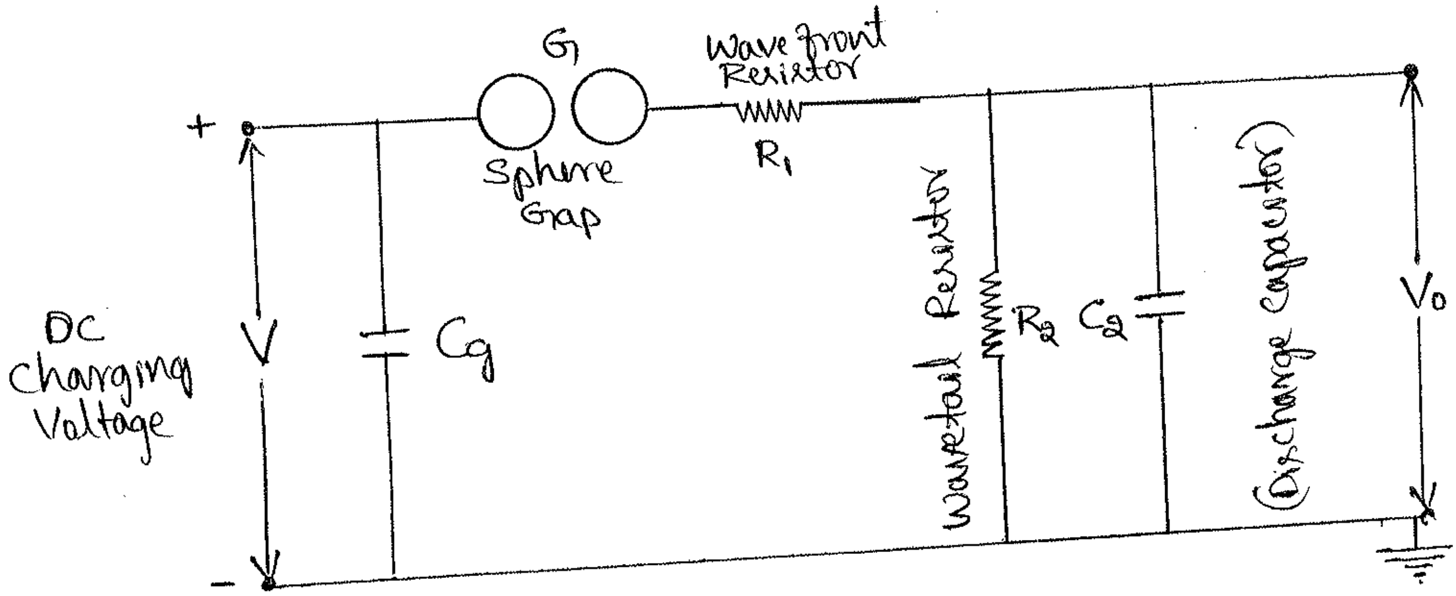
An impulse generator is specified by

1. Nominal output voltage
2. Number of stages (n)
3. Nominal gross energy stored which is equal to ½ $C_g V_0^2$
   where, C_g = Discharge capacitance of the generator = C/n
   and V_0 = Nominal output voltage.

Cost and size of the impulse generator increases at a rate square or cube of the voltage rating. Hence, for producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series. This type of arrangement was first proposed by Marx. A modified Marx circuit used for a four stage impulse generator is shown in Fig. 6.2. Using Marx's principle, a charging voltage V can be magnified depending on the number of stages. In this arrangement capacitors C (called stage capacitances) are charged in parallel through resistances of high value and are discharged in series through the spark gaps. At the end of the charging period, all the points at one end of the sphere gaps will be at a potential equal that of the DC source and positive with respect to earth. The other end points are at earth potential. Once the first stage spark gap breaks down due to its triggering, the discharge is initiated, resulting in simultaneous breakdown of all the remaining gaps. The potential at the end point of the first spark gap changes from positive to zero and that on the other end from 0 to negative. So there will be a potential difference of 2V. This results in the breakdown of the next sphere gap in

HVT → High Voltage Transformer (230V/75kV)
R_s → Series Resistor
R → Column Resistor
C → Stage capacitor
S_1 → Trigatron gap
S → Stage sphere
R_L → Current limiting Resistor
C_L → Load capacitor
T → Test sphere gap arrangement
R_d → $R' + R_L + (R_4 + R_s)$




G
Wave front Resistor
R1
Sphere Gap
+
−
DC Charging Voltage
V
Cg
Wavetail Resistor
R2
C2
(Discharge capacitor)
V0

the sequence. The process is cumulative and the output at the 4th stage attains a potential of -4V. Hence, by Marx's principle, impulse output voltage of opposite polarity (opposite to the polarity of charging voltage) and high magnitude is obtained.

Exercises:

- Identify the important components constituting the multi stage impulse generator in the lab and mention their ratings.

- Write the specifications of the existing impulse generator.

- Write the equivalent circuit of a single stage generator

- Mention the expression for output voltage, approximate time to front and time to tail.

- Mention the standard switching impulse voltage wave and impulse current wave along with their tolerances.

Table 7.4 *Sphere gap sparkover voltages in kV (peak) in air for ac, dc, and impulse voltage of either polarity for symmetrical sphere gaps at temperature: 20°C and pressure: 760 torr*

Gap spacing (cm)	*Sphere diameter (cm)*								*Remarks*
	5	*10*	*15*	*25*	*50*	*100*	*150*	*200*	
0.5	17.5	16.9	16.5						For spacings less than 0.5 D, the accuracy is ± 3% and for spacing ≥ 0.5 D, the accuracy is ±5%.
1.0	32.2	31.6	31.3	31.0					
1.5	46.1	45.8	45.5	45.0					
2.0	58.3	59.3	59.2	59.0					
2.5	69.4	72.4	72.9	73.0					
3.0	(79.3)	84.9	85.8	86.0					
4.0		107.0	111.0	113.0	112.0				
5.0		128.0	134.0	138.0	138.0	137.0	137.0	137.0	
8.0		(177)	194.0	207.0	214.0				
10.0				248.0	263.0	266.0	267.0	267.0	
12.0				286.0	309.0				
14.0				320.0	353.0				
16.0				352.0	394.0				
18.0					452.0				
20.0					495.0	504.0	511.0	511.0	
25.0					558.0	613.0	628.0	632.0	
30.0						744.0	741.0	746.0	
35.0						812.0	848.0	860.0	
40.0						902.0	950.0	972.0	
50.0						1070.0	1140.0	1180.0	
60.0						(1210)	1320.0	1380.0	
70.0							1490.0	1560.0	
80.0							(1640)	1730.0	
90.0								1900.0	
100.0								2050.0	

LIST OF VIVA QUESTIONS

High Voltage Technology

1. Mention the order of voltages that are designated as HV, EHV and UHV.
2. What are the advantages of transmitting electrical power at higher voltages?
3. State the merits of HVDC transmission. Mention few HVDC projects in India.
4. Mention few apparatus employing high voltages?
5. What is the difference between a conventional and a HV Capacitor?
6. What is the need for generating high voltages in a laboratory?
7. Explain the difference between a conductor and an insulator with few examples.
8. Distinguish a dielectric and an insulator.
9. Mention the basic classification of HV insulating medium. Recognize few insulating materials in the laboratory.
10. Why the HV terminations of HV transformer are structured as a spherical one?
11. Mention the ratings of HV transformer and Rectifier unit.
12. How to achieve the polarity reversal of HVDC in the DC unit available in the laboratory?
13. Give examples of few important solid, liquid and gaseous insulating materials along with their ε_r and E_{cr} values.
14. Distinguish self-restoring and non-self -restoring types of insulation.
15. Explain the significance of relative permittivity of the insulating medium.
16. Define α and γ.
17. What is an electrical discharge? Distinguish the terminologies: Townsend discharge, Corona discharge, Glow discharge and Arc.
18. What are the salient features of Townsend theory and Streamer theory of gaseous insulation breakdown?
19. State Paschen's law and draw a typical Paschen's curve and mention BDV_{min} and corresponding P-d product for air medium.
20. What is the purpose served by an electrolytic tank? Justify the use of water as an electrolyte in the field mapping experiment.
21. Name the practical system simulated by parallel electrode system.
22. Define electric field intensity and its significance. State E_{cr} values of few important insulating media.
23. Does electrolytic tank technique represents an analytical method or numerical method of determining the electric field?
24. Name few numerical methods for electric field calculations.
25. Mention the basic classification of high voltages.
26. What are the advantages of cascading HV transformers of smaller voltage ratings?
27. What is a Tesla coil? Mention its applications.
28. What is the need to generate high voltage impulse in a laboratory?
29. What is the necessity and operation principle of multi-stage Marx circuit?
30. Draw a typical impulse voltage wave (both positive and negative polarity) and recognize the wave front time and wave tail time.
31. Specify standard impulse voltage as per IS and mention the tolerances on their values.
32. Write an equivalent circuit of a single stage impulse generator along with the expression for the output voltage.
33. What are the factors that contribute to the introduction of oscillations in the output of impulse voltage generator?
34. State approximate expressions for wave front and wave tail time of impulse voltage.
35. Distinguish Lightning impulse (LI) and switching impulse (SI) voltages along with their typical front and tail time values.

36. What is the need of generating impulse currents in a laboratory?
37. Draw the layout diagram of LI current generator?
38. Mention standard LI current wave along with the tolerances.
39. State few applications of high current.
40. What are the factors that can affect the HV measurements?
41. Mention different devices used for the measurement of high voltage AC, DC and Impulse voltages?
42. Mention the correction factors that need to be applied for HV measurements and explain how they are applied.
43. Define Percentage Relative Humidity (%RH).
44. Compare the different types of potential dividers. .
45. Distinguish type tests and routine tests.
46. What are the different types of tests that are conducted on HV bushing, cable and insulator?
47. What is the order of current involved in a Short Circuit test of HV circuit breaker?
48. Mention the general safety precautions to be observed during the conduction of high voltage testing in a laboratory.

Protective relays

1. What is a relay? Mention few protective devices other than relay.
2. Distinguish primary and secondary protections.
3. What is the difference between unit and non-unit type of protections?
4. Mention different relay characteristics.
5. Explain the qualities of an ideal relay.
6. Define pickup and reset value of a relay.
7. What is reset or dropout ratio of a relay?
8. Explain the terms over reach and under reach with respect to a relay operation.
9. Explain IDMT and DMT characteristics of a relay.
10. Mention the typical speed of operation of a practical electromechanical relay?
11. What is the significance of TMS?
12. In case more than one relay is used, how the relay operations are discriminated?
13. What is a fuse? Mention the properties on which melting time of the fuse depends.
14. As a protective device, can a fuse replace a relay? If not, why?
15. What is the difference between a Distance relay and a Differential relay?
16. On what parameters does the effective distance relaying depend?
17. Explain the significance of %biasing in case of a Differential relay.
18. Name the protection scheme employed for the protection of an Alternator stator winding?
19. What are R-X diagrams? How they are useful?
20. Write the R-X diagram of a typical distance relay and explain.
21. What is a Buchholz's relay?
22. Mention the incipient faults against which protection is possible using a Buchholz's relay.
23. How does a solid-state (static) relay differ from an electromechanical relay?
24. Write a block diagram representation of a typical static relay operating principle.
25. Explain the working philosophy of a numeric relay.
26. What are the measures adopted for testing of transformer oil for its breakdown strength assessment, as per the standards?
27. What are the factors against which a feeder is to be protected?
28. Mention the abnormal conditions for which a practical Induction motor is subjected to, during its operation.

- Dr. H. N. Suresh

TYPICAL EXAMINATION QUESTIONS

- Conduct a suitable experiment on the given electromechanical over current relay to draw its operating characteristic. Choose the plug setting of __A and TMS value of__ .

- Perform the experiment on Microprocessor based over current relay for over current setting of 50 - 200% I_n and normal inverse 3.0 s trip time characteristic. Obtain the operating characteristic for these settings of the relay.

- Conduct a suitable experiment on the given electromechanical type under voltage relay to draw its DMT characteristic.

- Conduct a suitable experiment on the given electromechanical type over voltage relay to draw its DMT characteristic.

- Perform the experiment on Microprocessor based OV relay for a fault voltage setting of 105% V_n and normal inverse 3.5 s trip time characteristic. Obtain the operating characteristic for these settings of the relay.

- Conduct a suitable experiment to obtain the current – time characteristic for a given 4A fuse wire and determine its fusing factor.

- Conduct a suitable experiment to determine the dielectric strength of transformer oil.

- Conduct a suitable experiment on the given Negative sequence relay to demonstrate its operation for the different degrees of negative sequence current.

- Define standard lightning impulse voltage wave. Obtain the breakdown voltage (at STP) versus electrode gap distance characteristic in air under the application of high voltage impulse for sphere – sphere electrode configuration.

- Mention the specifications of the high voltage source in the lab. Obtain the breakdown voltage (at STP) versus electrode gap distance characteristic in air under the application of alternating high voltage for plane – plane electrode configuration.

- Mention the specifications of the high voltage source in the lab. Obtain the breakdown voltage (at STP) versus electrode gap distance characteristic in air under the application of alternating high voltage under non-uniform field conditions.

- Mention the specifications of the high voltage source in the lab. Obtain the breakdown voltage (at STP) versus electrode gap distance characteristic in air under the application of alternating high voltage under uniform field conditions.

- Estimate the energy rating of the impulse voltage generator in the lab. Generate an impulse voltage output and determine its magnitude corrected to STP.

- How do you specify an impulse voltage generator? Generate alternating high voltage output and apply it across the spherical electrodes gap of __cm to initiate the breakdown. Determine the corresponding peak breakdown voltage corrected to STP.

- Generate an arbitrary alternating high voltage of magnitude V_1. Conduct a suitable experiment involving standard spheres, to measure the voltage V_1 corresponding to STP. Use the relevant table of peak voltage, sphere diameter and electrode gap distance data.

- Obtain the equipotential plot of the co-axial cable model (using electrolytic tank) at a radial distance of 8 cm from the center of the model. Determine the percentage error between the theoretical and practical potential values of electric potential at this radial distance.

- Conduct a suitable experiment to determine the electric potential for a co-axial cable model (using electrolytic tank) at radial distances of 6 cm and 8 cm from the center of the model. Using this data, workout the percentage error between the theoretical and practical electric field intensity values at 7 cm radial distance.
