LAB MANUAL

HIGH VOLTAGE ENGINEERING LAB

ELECTRICAL ENGINEERING DEPARTMENT

NATIONAL INSTITUTE OF TECHNOLOGY
KURUKSHETRA

PREFACE

High Voltage Engineering Laboratory is situated on the ground floor of Electrical Engineering Department, NIT Kurukshetra. This lab facilitates conduct of UG and PG lab courses and some project work of both UG and PG students.

UG COURSES CONDUCTED IN THE LAB

Semester	Lab Course (Course Code)	Hours in week per section (E1-E8)
5th Semester	High Voltage Engineering Lab (EEPE31B)	2 Hours
8th Semester	High Voltage Engineering Lab (ET-408)	3 Hours

PG COURSES CONDUCTED IN THE LAB

Semester	Lab Course (Course Code)	Hours in week
1st Semester	Advanced Power Systems Lab (MEE2L01)	4 Hours

LAB OFFICERS

Lab Coordinator
Dr. Ashwani Kumar Sharma

Lab Professor In-charge
Dr. Saurabh Chanana
Prof. Atma Ram Gupta

LAB STAFF

Technical Assistant
Mr. Nikhil Kumar

LIST OF MAJOR EQUIPMENTS

1. H. V. A. C. Test Set 100KV
2. H. V. D. C. Test Set 140 KV
3. H. V. Impulse Test Set, 2-Stage 280 KV
4. Partial Discharge Kit
5. 4 Channel Digital Oscilloscope
6. Fluke Earth Resistance Tester
7. 100KVA Motorized Fully Automatic Insulating Oil Testing Machine

LABORATORY DISCIPLINE AND SAFETY REGULATION

1. No student is allowed to work in the Laboratory in the absence of either the Professors or the Technician. Minimum two persons must be present in the same room
2. Before entering a High Voltage setup one must convince himself by personal observation that all the conductors which can assume high potential & lie in the contact zone are earthed. And that all the main leads are interrupted.
3. Switch off the power of the Generator and visually check the earthing before entering the test area.
4. No student should be allowed to change the connection of the generator without the supervision of the Professor or the technician.
5. Sufficient clearance from the surrounding should be provided for the test object (at least 2 meters/500 kV).
6. Do not close the door of the test area when there is anyone inside. Lock the door immediately after you leave the test area.
7. Make very sure that no one is inside the test area before the power to the GENERATOR is turned on.
8. Press the "HIGH VOLTAGE" red button on control panel in case of any abnormalities or danger.
9. Switch off all the supplies before you leave the laboratory.

SAFETY MEASURES

1. **Equipment Protection**: Protection against insulation failure is provided by some means of disconnecting the test set from the supply such as (i) fuses, (ii) overload contactor and (iii) earth leakage protection devices.
2. **Safety Earthing**: The Safety Earthing must be provided in such a way that the Impulse Generator is fully earthed. The earth resistance must be less than 0.5 ohm.
3. **Safety Inspection**: The lecturer-in-charge should be responsible that periodic safety checks are carried out. A suggested checklist is as follows:
   - 3.1 Earth Resistance < 0.5 ohm;
   - 3.2 Operation of Overload Contactors.
   - 3.3 Fire Extinguisher
   - 3.4 Insulating Mat.
   - 3.5 Insulating Strength of the Earthing Stick.
   - 3.6 Insulation against Possible Shocks. (Example: Cable Insulation, etc.)
   - 3.7 First-Aid Box.

LAB MANUALS

HIGH VOLTAGE ENGINEERING LAB (ET-408)

India has gone for 765 KV AC transmission and ± 800 KV DC transmissions with other intermediate voltage levels of 400 KV, 220 KV, 132 KV and 66KV, 33 KV and 11 KV at the distribution level. All the electrical equipments operating at all voltage levels must conform to the IEEE/ISI standards of insulation level. This requires the testing procedure to be carried out at the industry or the institutions to test the designed levels of the insulation. Therefore, there is essential requirement of HV labs for the testing purposes. High voltage labs have lot of applications such as:

- Testing of insulation at all levels of voltages
- Testing of CTs, PTS, isolators
- Testing of cables, CBs, insulators
- Testing of generators and transformers
- Measurement of capacitance and tan delta of insulators.
- Partial discharge measurements.
- Oil testing, gas testing, and dissolved gas analysis

Experiments conducted at H.V. Lab of Electrical Engineering Department We have three test sets as 280 KV impulse test set, 140 KV (peak) DG test set, and 100 KV AC test set with PD measurement. The list of the experiments conducted in the HV lab of our department is as follows.

LIST OF EXPERIMENTS

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2.	To Measure Earth Resistance of High Voltage Lab and High Tension Supply Pole	11
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EXPERIMENT NO - 01

LAYOUT OF HIGH VOLTAGE LAB

CONTENTS:

1. Objectives: 07
2. Equipment's required: 07
3. Expected outcome of experiment: 07
4. Theory: 07
5. Rating: 09
6. Methodology for measurements: 09
7. Precautions: 09
8. Measurements and results: 09

1. OBJECTIVE:

- To study the layout of high voltage lab.

2. EQUIPMENT REQUIRED:

- Measuring Tape

3. EXPECTED OUTCOME OF EXPERIMENT:

- The student will learn about the lab area for the placement of HV equipments
- They will understand the minimum clearance required between the equipments
- Safety precautions to be taken in the HV lab and standard layout design

4. THEORY:

High voltage laboratories are an essential requirement for making acceptance tests for the equipment that go into operation in the extra high voltage transmission systems. In addition, they are also used in the development work on equipment for conducting research, and for planning to ensure economical and reliable extra high voltage transmission systems. Here a brief review of the planning and layout of testing laboratories and some problems and limitations of the test techniques are presented.

High voltage laboratories, in addition to conducting tests on equipment, are used for research and development works on the equipment. This includes determination of the safety factor for dielectrics and reliability studies under different atmospheric conditions such as rain, fog, industrial pollution, etc., at voltage higher than the test voltage required. Sometimes, it is required to study problems associated with test lines and other equipment under natural atmospheric or pollution conditions, which cannot be done indoors. Research activities usually include the following:

- Breakdown phenomenon in insulating media such as gases, liquids, solids, or composite systems

- Withstand voltage on long gaps, surface flashover studies on equipment with special reference to the equipment and materials used in power systems
- Electrical interference studies due to discharges from equipment operating at high voltages
- Studies on insulation co-ordination on H.V. Power Systems
- High current phenomenon such as electric arcs and plasma physics. Usually, high voltage laboratories involve tremendous cost. Hence, planning and Layout have to be carefully done so that with the testing equipment chosen, the Investment is not high and the maximum utility of the laboratory is made.

Layout of High Voltage Laboratories:

Each laboratory has to be designed individually considering:

- Type of equipment to be tested
- Available space, other accessories needed for tests, storage space required
- Earthing, control gear and safety precautions require most careful consideration
- The control room should be located as to include good overall view of the laboratory
- The main access door to test area must accommodate the test equipment and objects have adequate interlocking arrangements and warning system to ensure to the personnel

Classification of High Voltage Laboratories:

Depending on the purpose and resources (finances) available labs can be classified into three types:

1. Small Laboratories
2. Medium Size Laboratories
3. Large General Laboratories

1. Small Laboratories:

- A small laboratory is one that contains D.C. or power frequency test equipment of less than 10KW/10KVA rating.
- Impulse equipment of energy rating of about 10KJ or less.
- Voltage rating can be about 300KV for A.C., single unit or 500 to 600KV A.C. for cascade units, ±200 to 400 KV D.C. and less than 100KV impulse voltage.
- Normally equipment is meant for housing in a room or hall of size 15m x 10m x 8m.
- Small laboratories are meant for Engineering Colleges and Industries.

2. Medium Size Laboratories (An industrial Laboratories):

Such a laboratory may initially contain:

- Power frequency testing facility: 200 to 600KV, but its KVA rating will be much higher 100 to 1000KVA.
- The impulse voltage generator could be of 20 to 100KJ or more

3. **Large General Laboratories:**

These laboratories are meant to carry out testing and undertake research work. The basic facilities available will be:

- One or more H.V. test halls
- Corona and pollution test chambers
- Outdoor test area for test on large sized equipment, transmission line and towers
- Controlled atmospheric test room/chambers
- The size/rating of the test equipment will be quite large (up to few KVA or MVA)

Note: *The approximate working clearances recommended are as follows:*

- *A.C. power frequency voltages : 200 KV (rms)/m*
- *D.C. voltages : 275KV/m*
- *Impulse voltages : 500KV/m*
- *For switching surges, the clearance is worked out from the following approximate formula*

$$d = (2V)^2$$

Where d is in meter and V is in MV.

5. **<u>RATINGS</u>:**

Equipment	Ratings
1. 2 stage impulse generator	280 kV
2. AC test set with PD measure	100 kV AC
3. DC test set	140 kV DC
4. panel -1 for impulse generator testing	
5. panel -2 for AC and DC testing	

6. **METHODOLOGY OF MEASUREMENTS:**

- With the help of measuring tape, all dimensions are measured.

7. **PRECAUTIONS:**

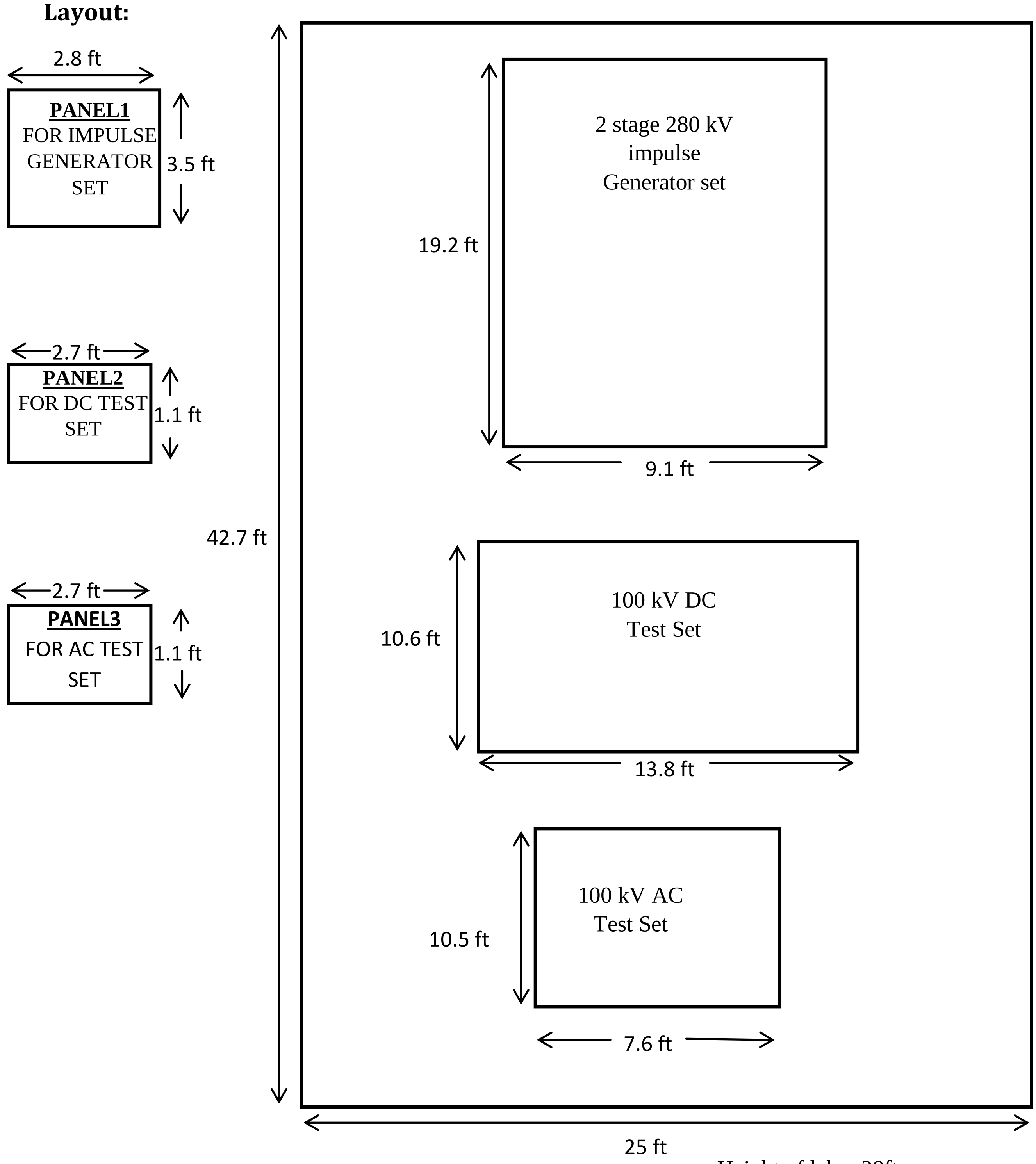
- Measurements should be done two to three times to avoid error.

8. **MEASUREMENTS AND RESULTS:**

Measurements:

Sr. No	Equipment	Clearance from the wall	Clearance from the adjacent equipment
1			
2			
3			

Layout:



Height of lab – 28ft

Height of panel 1 – 3.1ft

Height of panel 2 & 3 – 3.8ft

Fig: 1.1 Layout of High Voltage Lab

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EXPERIMENT NO - 02

TO MEASURE EARTH RESISTANCE OF HIGH VOLTAGE LAB AND HIGH TENSION SUPPLY POLE

CONTENTS:

1. Objective: 11
2. Equipment's required: 11
3. Expected outcome of experiment: 11
4. Theory: 11
5. Circuit diagram: 13
6. Methodology for measurements: 13
7. Measurements: 14
8. Results and discussion: 15

1. OBJECTIVE:

- Measurement of earth resistance of HV lab and main supply panel ground resistance using earth resistance tester.

2. EQUIPMENT'S REQUIRED:

- FLUKE Earth Ground Resistance Tester.

3. EXPECTED OUTCOME OF EXPERIMENT:

After completion of this experiment

- The students will understand the application of earth resistance tester for measuring the earth resistance of HV lab and the panel of supply.
- The students will compare the measured values with the standard values of the resistance.

4. THEORY:

This instrument is equipped with a 3-pole as well as a 4-pole resistance measurement which renders measurements of resistances of earthing systems possible, as well as measurements of the soil resistivity of geological strata. As a special function the instrument offers measurements with an external current transformer, with which a measurement of single resistance branches in interlinked networks (lightning protection and high voltage pylons with cabling) can be performed without separating parts of the system.

To ensure most feasible interference suppression during measurements, the instruments is equipped with 4 measuring frequencies (94 Hz, 105 Hz, 111 Hz, 128 Hz), with automatic switch over if necessary (AFC-Automatic Frequency Control). The corresponding measuring frequency used for a specific measurement can be called and displayed with "DISPLAY MENU" after the measurement. Additionally, one of the four measuring frequencies can be selected and permanently set in special cases. In that case in order to stabilize the display, an average measurement can be carried out for up to 1 minute by keeping the "START TEST" button pressed.

To determine the earthing impedance(R), a measurement with a frequency close to the mains frequency (55 Hz) is carried out. At the activation of it through user's code, this measuring frequency is activated automatically.

To keep the instrument as simple as possible at the time of delivery, all special functions, such as LIMIT input, BEEPER programming, measurement of earthing impedance(R) etc., are not activated at delivery. They can be activated with the personalized user's code.

Wenner's Method:

Four electrodes are set up in line in the ground, equally spaced at a distance "a" from one another. A generator is used to inject a measurement current "I" between the two outer electrodes (E and H). The potential V is then measured with a voltmeter between the two central electrodes (S and ES). The measurement instrument used is a traditional earth Ωmeter capable of injecting the current and measuring the V value. The resistance value R read on the Ωmeter can be used to calculate the resistivity by applying the following simplified formula:

$$\rho = 2\,\pi\,A\,R$$

Where:

ρ = the average soil resistivity to depth A in: Ω-cm.

π = 3.1416.

A = the distance between the electrodes in cm.

R= the measured resistance value in Ω from the test instrument

Measuring Soil Resistance

To test soil resistivity, connect the ground tester as shown in Fig. 2.1. Four earth ground stakes are positioned in the soil in a straight line, equidistant from one another. The distance between earth ground stakes should be at least three times greater than the stake depth. The Fluke1625 earth ground tester generates a known current through the two outer ground stakes and the drop in voltage potential is measured between the two inner ground stakes. The tester automatically calculates the soil resistance using Ω's Law ($V=IR$).

5. CIRCUIT DIAGRAM:

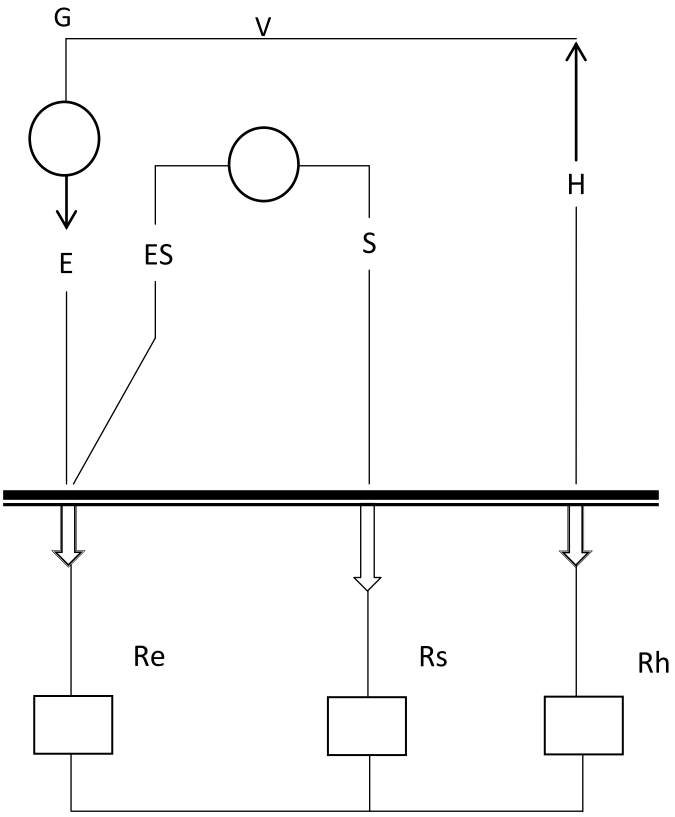


Fig 2.1: Earth Resistances Measurement-Method (Two Probe Method)

Remarks for Setting the Earth Spikes:

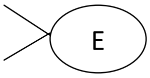
Before setting the earth spikes four probe and auxiliary earth electrode make sure that the probe setting outside the probe is set outside the potential gradient area of earth electrode and auxiliary earth electrode. Such a condition is normally reached by allowing a distance of more than 20 meters between the earth electrode and the earth spikes as well as of the earth spikes to each other.

An accuracy test of the result is made with another measurement following repositioning of auxiliary earth electrode or probe. If the value remain same, the distance is sufficient else the probe or the auxiliary earth electrode must be repositioned till we get a constant value. Spike wires should not run too close to each other.

6. METHODOLOGY FOR MEASUREMENT:

3-pole/4-pole Measurement of Earth Resistance:

6.1 Turn central rotary switch to position “Re 3 pole” or “Re 4 pole” the instrument is to be wired according to picture and notices given on the display: A flashing of the sockets symbols (EE) , (ES) , (S) , (H)

6.2 Or  , points to an incorrect or incomplete connection of the measuring lead.
6.3 Press "START TEST" button now fully automated test sequence of all relevant parameters like auxiliary earth electrode; probe and earth electrode resistance is implemented and finished with the display of the result R_e.
6.4 Connect the probes at a distance of 20 meters away from each other and test equipment.
6.5 The probes should be properly connected deep in earth for better conductivity.
6.6 Read out measured value R_e.
6.7 Call R_S and R_h with "DISPLAY MENU".

Nature of Equipment:

Time Average Measurement

If there is a warning "measured value unstable" after a test sequence, most likely it is caused by interference signal. Nevertheless to get reliable values the instrument offers the possibility of averaging over a long period.

1. Select a fixed frequency
2. Keep the "Start Test" button pressed until the warning disappears.
3. Pole Measurement with longer Earth Electrodes connecting Leads:

Use one of the accessory cable drums as earth electrode connecting lead. Spool-off cable completely and compensate fine resistance.

7. MEASUREMENTS:

Sr. No	Method	Observation
1	The resistance of HT supply pole:	
	a) 4-pole method	R_E =
		R_S =
		R_H =
2	The resistance of HV lab:	
	a) 4-pole method	R_E =
		R_S =
		R_H =

Standard values of Earthing Resistance

Sr. No	Level of voltage	Earthing Resistance
1.	11 KV	
2.	33 KV	
3.	66 KV	
4.	132 KV	
5.	220 KV	
6.	400 KV	

8. RESULT AND DISCUSSION:

- Earth resistance should be as per the international standard and should be below 5 ohm. Its experimental value is obtained as 1.798 Ω which is as per the international standards.

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EXPERIMENT NO - 03

TO STUDY BREAKDOWN OF AIR USING 100 KV AC TEST SET USING SPHERE – SPHERE GAP, SPHERE – PLANE GAP, POINT – PLANE GAP

CONTENTS:

1. Objectives: 16
2. Equipment's required: 16
3. Expected outcome of experiment: 16
4. Theory: 16
5. Circuit diagram: 19
6. Methodology for measurements: 20
7. Measurements: 21
8. Results and discussion: 22

1. OBJECTIVES:

- To Study Breakdown of Air Using 100 kV AC Test Set Using
  - Sphere – Sphere Gap
  - Sphere – Plane Gap
  - Point – Plane Gap

2. EQUIPMENT REQUIRED:

- 100 kVA , 0.23/100 kV AC Cascaded Transformer
- Measuring Capacitor
- Measuring Resistor
- Measuring Spark Gap
- Control Panel having DSTM Voltmeter and AC Leakage Meter

3. EXPECTED OUTCOME OF EXPERIMENT:

- Knowledge of the high voltage (HV) power equipment subjected with spark over voltage.
- Ability to measure DSM Peak Voltage and AC Leakage Current instantaneously. Ability to estimate the breakdown voltages with respect to the sphere gap.

4. THEORY:

100 kVAC test set comprises of a capacitor which charges from the secondary of transformer. As shown in circuit diagram given above, the capacitor is charged to V_{max}, the maximum A.C voltage of the secondary of the high voltage transformer in the conducting half cycle. In the other half cycle, the capacitor is discharged into the load. The value of the capacitor C is chosen such that the time constant CR is at least 10 times that of the period of the A.C supply.

Fig: 3.1 Control Setup, Transformer, Sphere Gap

4.1 Sphere-Sphere:

The standard sphere gap is the one of the standard methods for the measurement of peak value of DC, AC and Impulse voltages and is used for

Fig: 3.2: Sphere - Sphere Gap

Checking the high voltage power equipment and other voltage measuring devices used in high voltage test circuits. Two identical metallic spheres are separated by certain distance form a sphere gap. Also, the gap length between the spheres should not exceed a sphere radius. If these conditions are satisfied and the specifications regarding the shape, mounting, clearances of the spheres are met, the results obtained by the use of sphere gaps are reliable to within ±3%. It has been suggested in standard specification that in places where the availability of ultraviolet radiation is low, irradiation of the gap by radioactive or other ionizing media should be used when voltages of magnitude less than 50 kV are being measured or where higher voltages with accurate results are to be obtained. In this arrangement one sphere normally shall be connected directly to earth. Low Ωic shunts may be connected between the sphere and earth of special purpose. The surfaces of spheres shall be cleaned and dried but need not be polished. In normal use the surfaces of spheres become roughened and pitted. The surface should be rubbed with fine abrasive paper and the resulting dust removed with lint-free cloth any trace of oil or grease should be removed with a solvent. Moisture may condense on the surface of the sparking points in conditions of high relative humidity causing measurements to become erratic. So the spheres are made with their surfaces are smooth and their curvatures as uniform as possible. The curvature should be measured by a spherometer at various positions over an area enclosed by a circle about the sparking point. The sphere and sparking points on the two spheres are those which are at minimum distances. Sphere gaps can be arranged in vertically, typically with the lower sphere grounded (earthed), and horizontally from each other. The surroundings do have an effect on the breakdown voltage, as they alter the field configuration. Standard clearances are specified for spheres of various sizes in both configurations. These clearances reduce the effect of the surroundings to less than the specified accuracy (e.g. 3%).

4.2 Sphere-Plane:

A sphere-plane electrode system was designed and used for the measure the breakdown voltage and electric field in all types of insulating materials. This electrode arrangement is considered as a non-uniform field because the surfaces of both the electrodes are not similar.

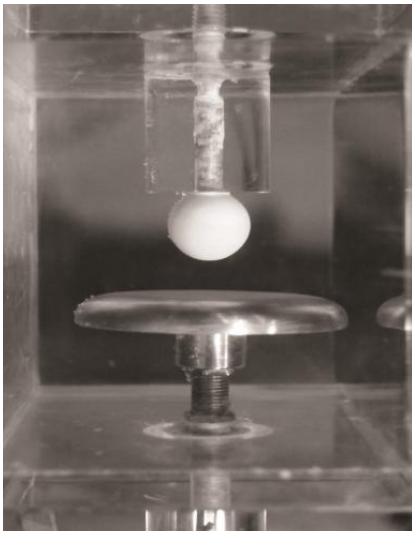


Fig: 3.3: Sphere – Plane Gap

4.3 Point-Plane:

In this arrangement the ground effect also affects the breakdown voltage of the rod-plate air gaps but in a quite different way than the Polarity Effect. The values of the breakdown voltage depend on the maximum value of the field strength in the gap between the electrodes, as well as the corona leakage current through the gap. According to the Polarity Effect the breakdown voltage is considerably higher in the arrangement with negative polarity on the rod because of the intensive corona effects. The ground effect the breakdown voltage is higher in the arrangement with the rod grounded because the maximum value of the field strength is lower. Ground effect is intense in small rod-plate air gaps, while the influence of Breakdown Voltage of Insulating Materials, the corona leakage current and the Polarity Effect appears in longer air gaps. This electrode arrangement is considered as a non-uniform field because the surfaces of both the electrodes are not similar.

Fig: 3.4 Point – Plane Gap

5. <u>CIRCUIT DIAGRAM:</u>

5.1 Sphere – Sphere Gap:

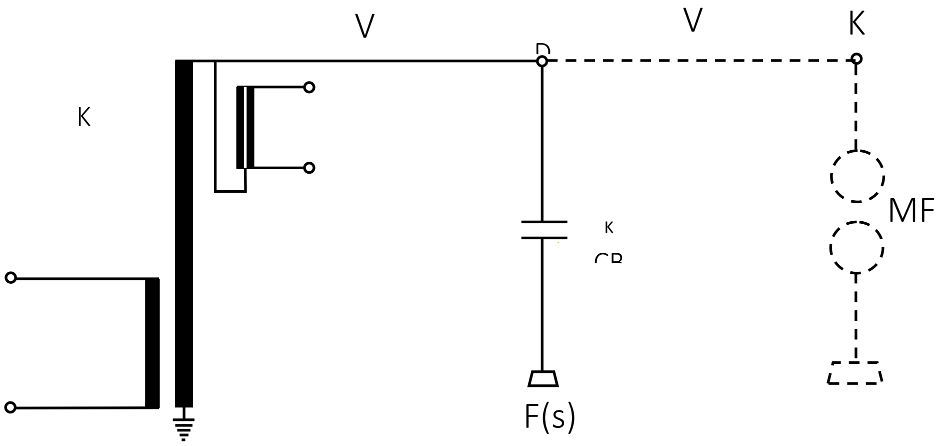


Fig: 3.5: Sphere – Sphere Gap

5.2 Sphere – Plane Gap:

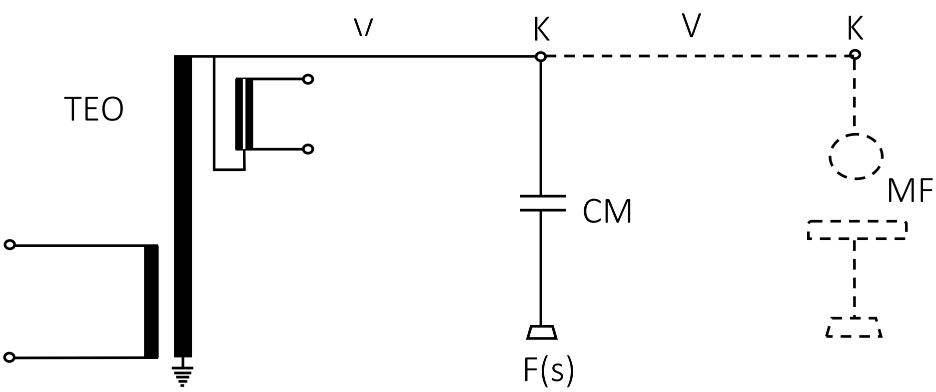
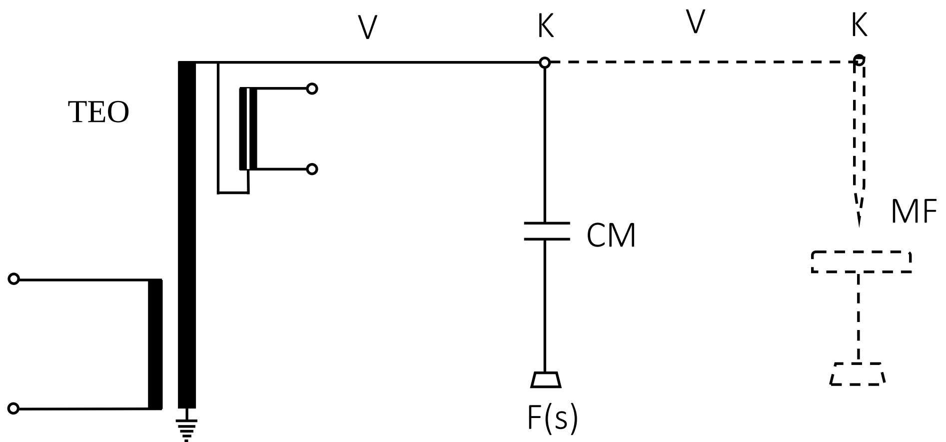


Fig: 3.6: Sphere – Plane Gap

5.3 Point – Plane Gap:



TEO = TEST TRANSFORMER
CM = MEASURING CAPACITOR
V = CONNECTING ROD
K = CONNECTING CUP
F(s) = FLOOT PEDESTAL
MF = MEASURING SPARKGAP

NOTE: MEASURING SPARKGAP (MF) TO BE CONNECTED WHENEVER REQUIRED HENCE AS SHOWN IN DOTED LINE

Fig: 3.7 Point – Plane Gap

6. METHODOLOGY OF MEASUREMENTS:

6.1 Switch on the panel control switch, then main switch.
6.2 After that switch on the primary switch. The earth switch will come down.
6.3 Then switch on the secondary switch. Set voltage to zero if it is not zero.
6.4 Switch on oscilloscope. Adjust the distance between sphere gaps/sphere–plane gaps/point-plane gaps to 10 mm.
6.5 Raise the potential in steps. On giving supply to trigger circuit it produces spark.
6.6 Note down the DSTM reading, input voltage and charging current and discharging current.
6.7 Repeat the above steps for various settings of sphere gap distance i.e. for 15, 20, 25, 30, 35 and 40 mm.
6.8 Observe the Impulse voltage pulse produced on the oscilloscope. Now reduce the voltage fast. Wait for the discharge voltage to become zero.
6.9 Once it comes to zero switch off the secondary switch, primary switch and after that switch off the control switch and then panel main switch.
6.10 Plot the graph between breakdown voltage and sphere gap spacing.

7. MEASUREMENTS:

7.1 Sphere – Sphere Gap:

Sr. No.	Gap Spacing (mm)	Regulating Transformer Output Voltage (V)	Regulating Transformer Output Current (A)	DSM Peak Voltmeter (kV)	AC Leakage Current Meter (mA)
1					
2					
3					
4					
5					

7.2 Sphere – Plane Gap:

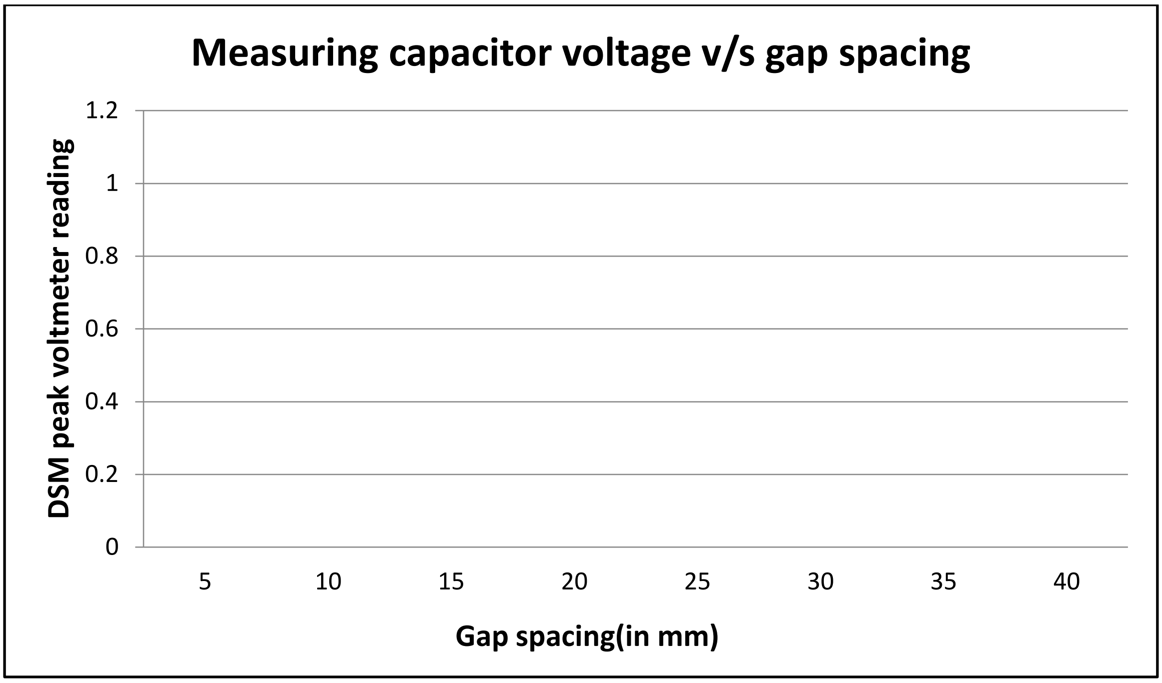
Sr. No.	Gap Spacing (mm)	Regulating Transformer Output Voltage (V)	Regulating Transformer Output Current (A)	DSM Peak Voltmeter (kV)	AC Leakage Current Meter (mA)
1					
2					
3					
4					
5					

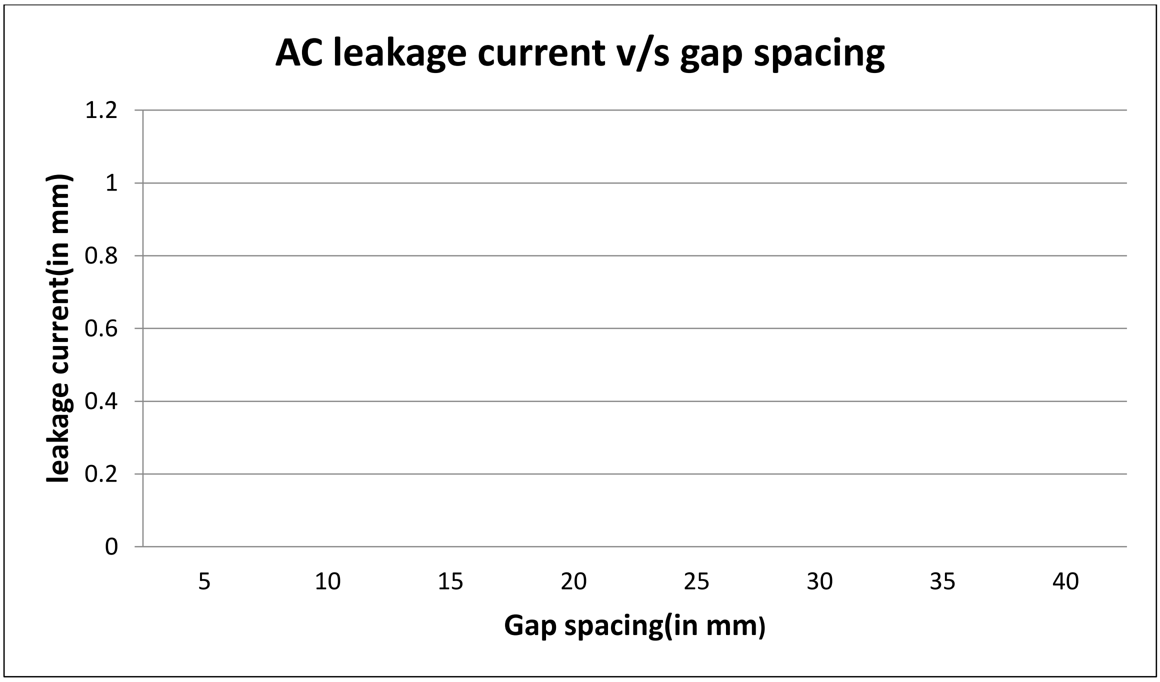
7.3 Point – Plane Gap:

Sr. No.	Gap Spacing (mm)	Regulating Transformer Output Voltage (V)	Regulating Transformer Output Current (A)	DSM Peak Voltmeter (kV)	AC Leakage Current Meter (mA)
1					
2					
3					
4					
5					

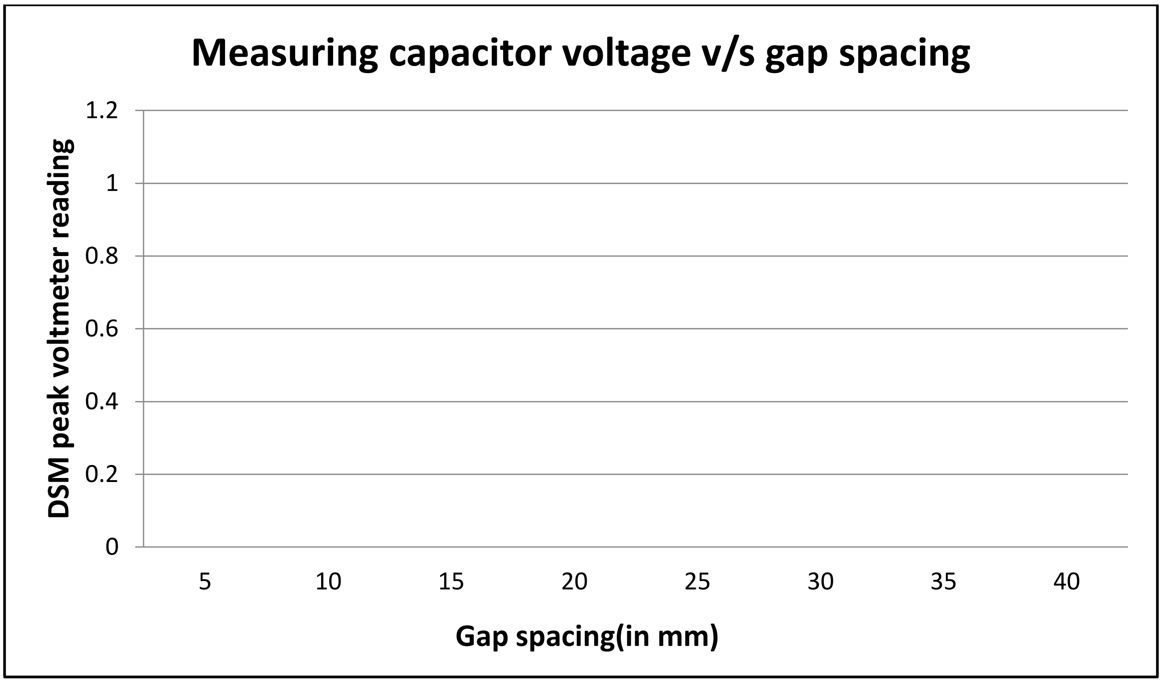
8. RESULT AND DISCUSSION:

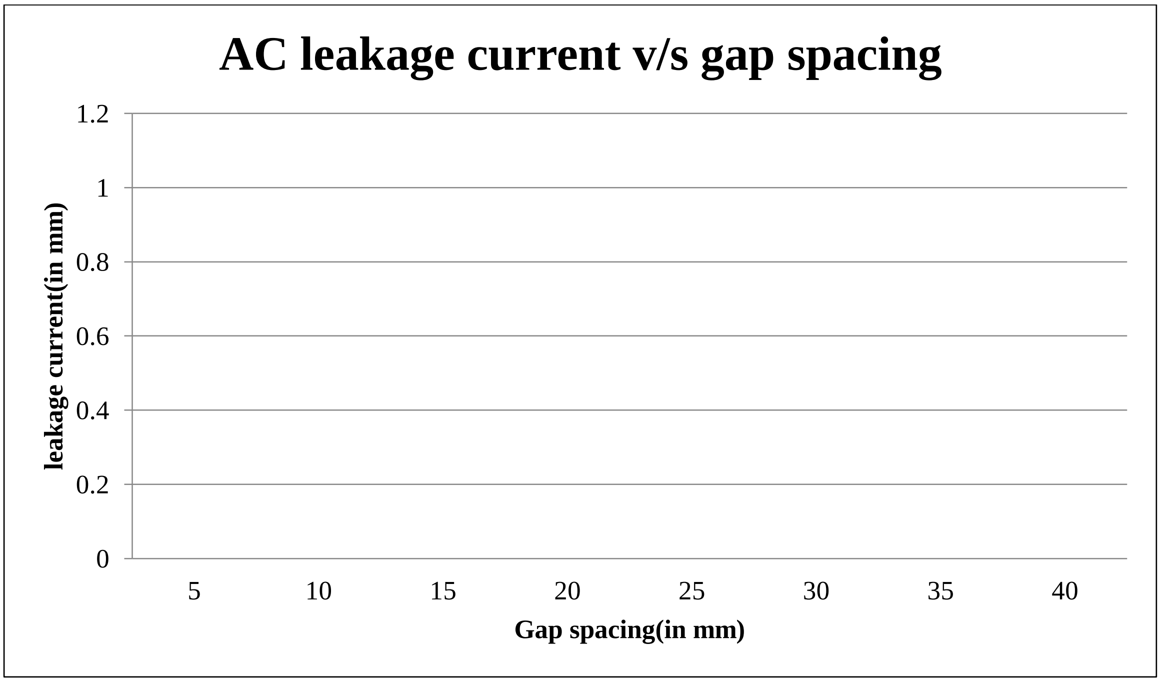
8.1 Sphere – Sphere Gap:



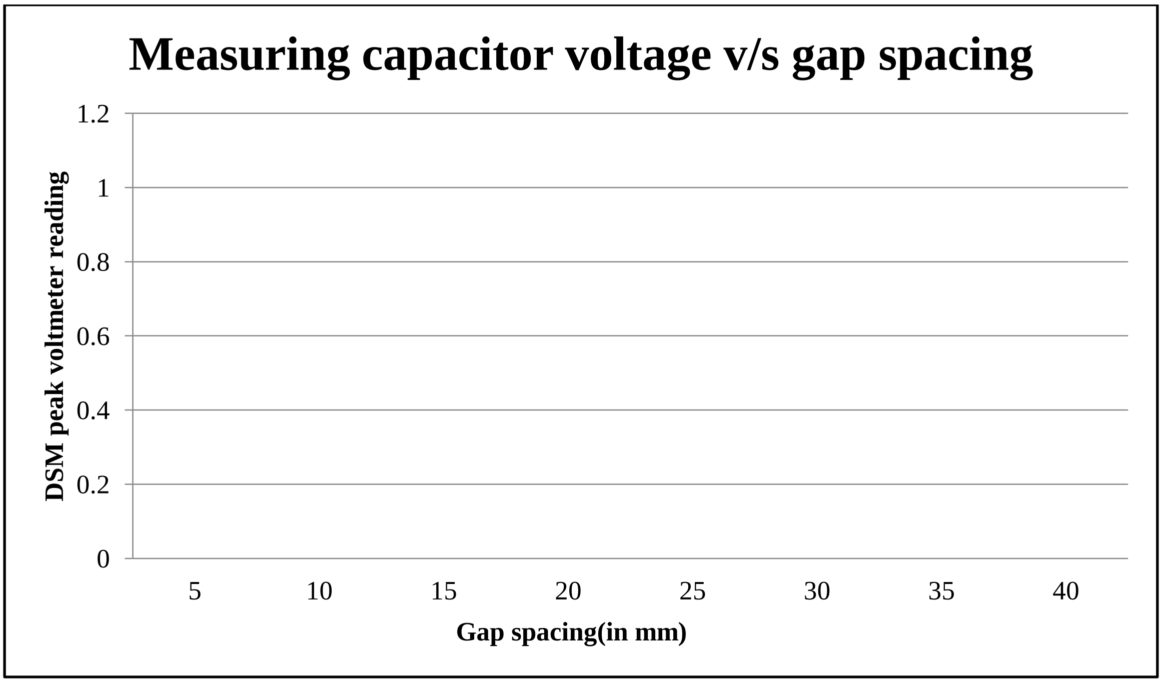


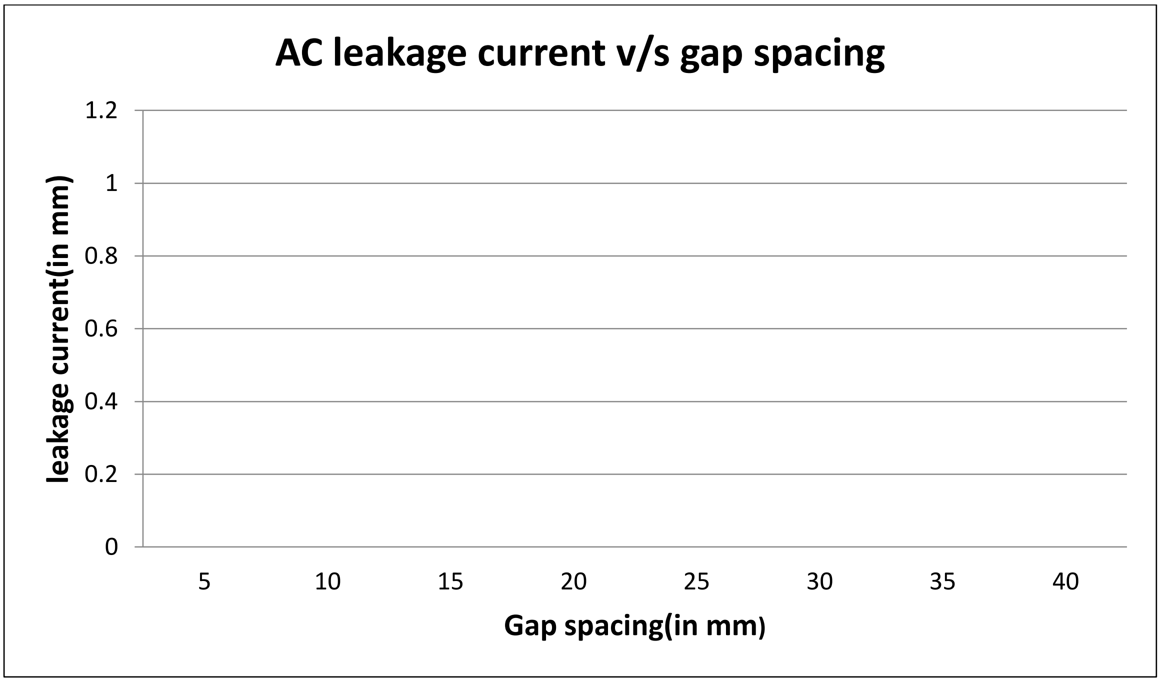
8.2 Sphere – Plane Gap:





8.3 Point – Plane Gap:





Discussion:

Various graphs between voltage across capacitor and current through it with applied input voltage have been drawn.

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EXPERIMENT NO - 04

GENERATION OF HVDC WITH THE HELP OF 140 KV, DC SET-UP

CONTENTS:

1. Objectives: 25
2. Equipment's required: 25
3. Expected outcome of experiment: 25
4. Theory: 25
5. Circuit diagram: 27
6. Methodology for measurements: 27
7. Observation: 28
8. Graphs: 30
9. MATLAB simulation: 32
10. Results: 32

1. OBJECTIVE:

- Generation of HVDC with the Help of 140 kV, DC Set-Up

2. EQUIPMENT REQUIRED:

- 100 kVA , 0.230/100 kV AC Transformer
- Silicon Rectifier.
- Smoothing Capacitor
- Measuring Resistor
- Measuring Spark Gap
- Support Insulator
- Capacitive Potential Divider

3. EXPECTED OUTCOME OF EXPERIMENT:

After completing the experiment student will be able to:

- Generation of HVDC using capacitive potential divider.
- Draw Various Graphs between voltage across capacitor and current through it with applied input voltage for both charging and discharging. One would also be able to verify that after some time with increase in voltage current become constant and steady state achieved.

4. THEORY:

Generation of high direct voltages are required in the testing of high voltage direct current apparatus as well as in testing the insulation of cables and capacitors where the use of alternating voltage test sets become impractical due to the steady high charging currents. Impulse generator charging units also require high direct voltages as their input.

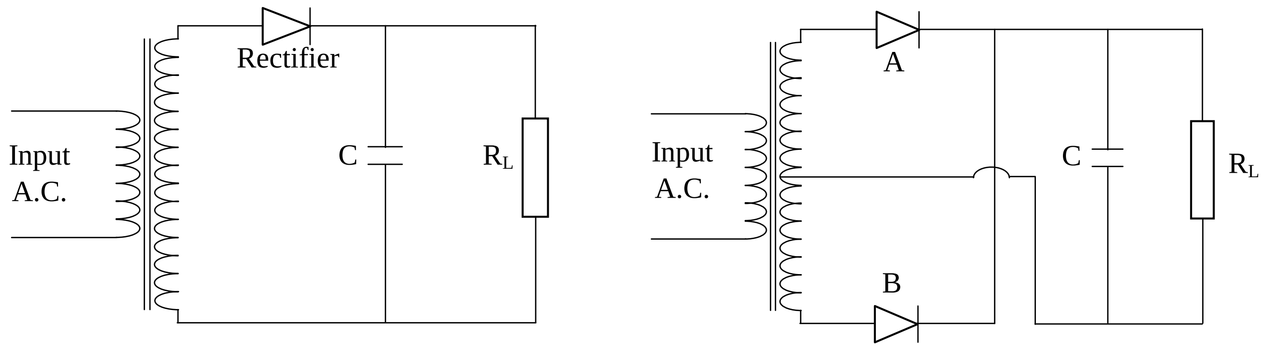
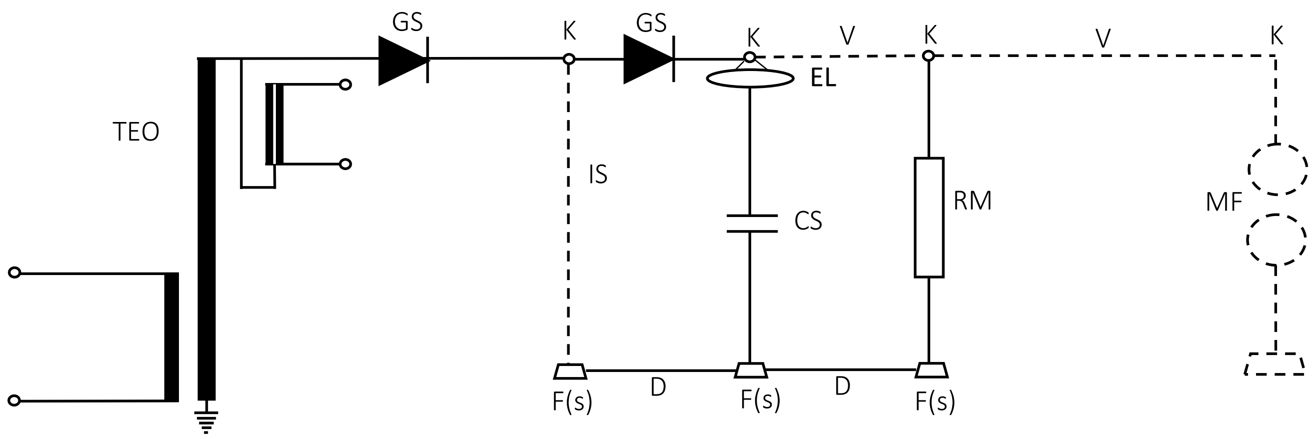


Fig: 4.1 Rectifier Circuits

One of the simplest methods of producing high direct voltages for testing is to use either a half-wave for full wave rectifier circuit with a high alternating voltage source. The rectifiers used must be high voltage rectifiers with a peak inverse voltage of at least twice the peak value of the alternating voltage supply. In theory, a low pass filter may be used to smooth the output, however when the test device is highly capacitive no smoothing is required. Even otherwise only a capacitance may be used across the test device for smoothing. Figure shows the half-wave and the full wave arrangements.
In half wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, mean voltage is lower. Half-wave rectification requires a single diode in a single-phase supply, or three in a three-phase supply. Rectifiers yield a unidirectional but pulsating direct current; half-wave rectifiers produce far more ripple than full-wave rectifiers, and much more filtering is needed to eliminate harmonics of the AC frequency from the output.

As shown in circuit diagram given above, the capacitor is charged to Vmax, the maximum A.C. voltage of the secondary of the high voltage transformer in the conducting half cycle. In the other half cycle, the capacitor is discharged into the load. The value of the capacitor C is chosen such that the time constant CR is at least 10 times that of the period of the A.C. supply. The rectifier valve must have a peak inverse rating of at least 2 Vmax. To limit the charging current, an additional resistance R is provided in series with the secondary of the transformer.

5. CIRCUIT DIAGRAM:



TEO = TEST TRANSFORMER
GS = SILICON RECTIFIER
CS = SMOOTHING CAPACITOR
RM = MEASURING RESISTOR
MF = MEASURING SPARKGAP
ES = SUPPORTING INSULATOR
EL = ELECTRODE
V = CONNECTING ROD
K = CONNECTING CUP
F(s) = FLOOT PEDESTAL
D = SPACER BAR

NOTE: MEASURING SPARKGAP (MF) TO BE CONNECTED WHENEVER REQUIRED, HENCE AS SHOWN IN CHAIN DOTED LINE

Fig: 4.2: Circuit Diagram of HVDC 140 KV Setup

6. METHODOLOGY FOR MEASUREMENT:

6.1 Switch on the panel control switch, then main switch.
6.2 After that switch on the primary switch. The earth switch will come down.
6.3 Then switch on the secondary switch. Set voltage to zero if it is not zero. Switch on oscilloscope. Raise the applied input voltage in steps.
6.4 On giving supply to trigger circuit it produces spark.
6.5 Note down the, input voltage, voltage across capacitor and charging current.
6.6 Now decrease the applied input voltage in steps. Note down the, input voltage, voltage across capacitor and discharging current.
6.7 Repeat the above steps for various settings now reduce the voltage fast. Wait for the discharge voltage to become zero.

7. OBSERVATIONS:

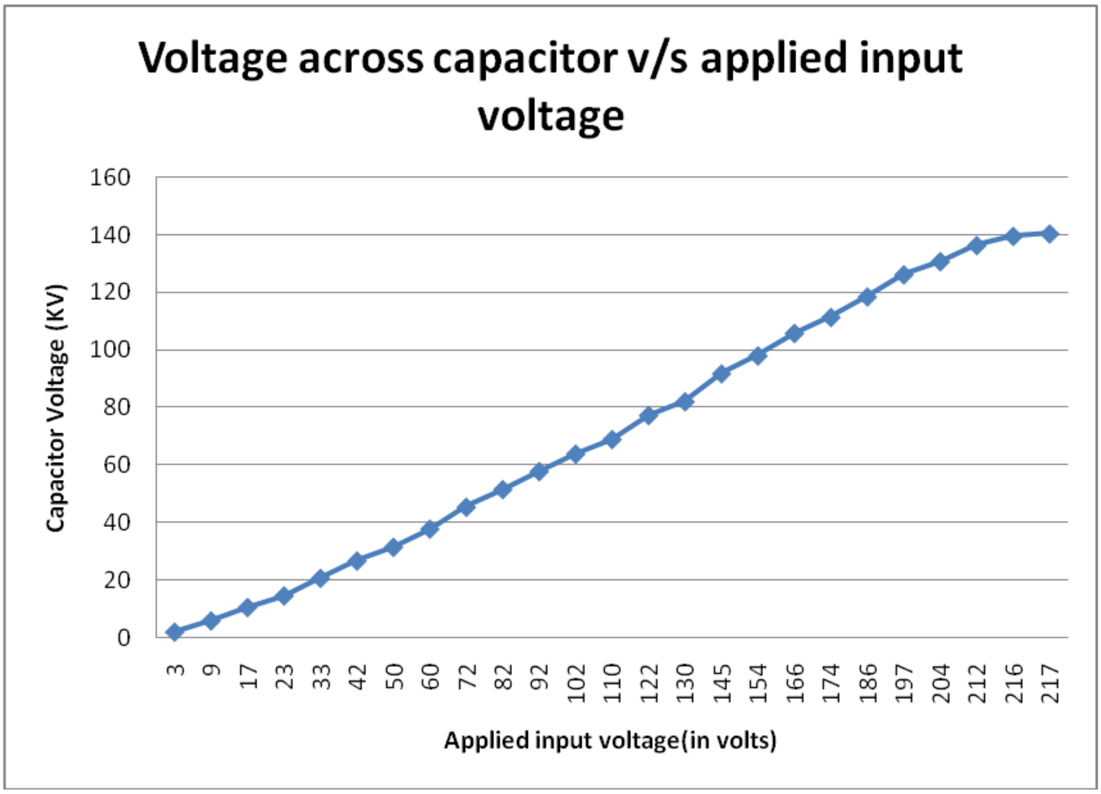
During Charging:

Sr. No	Capacitor Voltage(kV)	Input applied(V)	Charging current of capacitor(A)
1	2.25	03	0
2	6.14	9	0
3	10.8	17	0.1
4	14.82	23	0.2
5	20.93	33	0.3
6	26.91	42	0.4
7	31.69	50	0.5
8	37.99	60	0.6
9	45.57	72	0.7
10	51.72	82	0.8
11	57.98	92	0.9
12	64.02	102	1.0
13	69.10	110	1.1
14	77.40	122	1.2
15	82.18	130	1.3
16	91.88	145	1.5
17	98.11	154	1.6
18	105.9	166	1.7
19	111.45	174	1.8
20	118.57	186	1.8
21	126.24	197	1.9
22	130.79	204	1.9
23	136.40	212	1.9
24	139.56	216	1.9
25	140.42	217	1.9

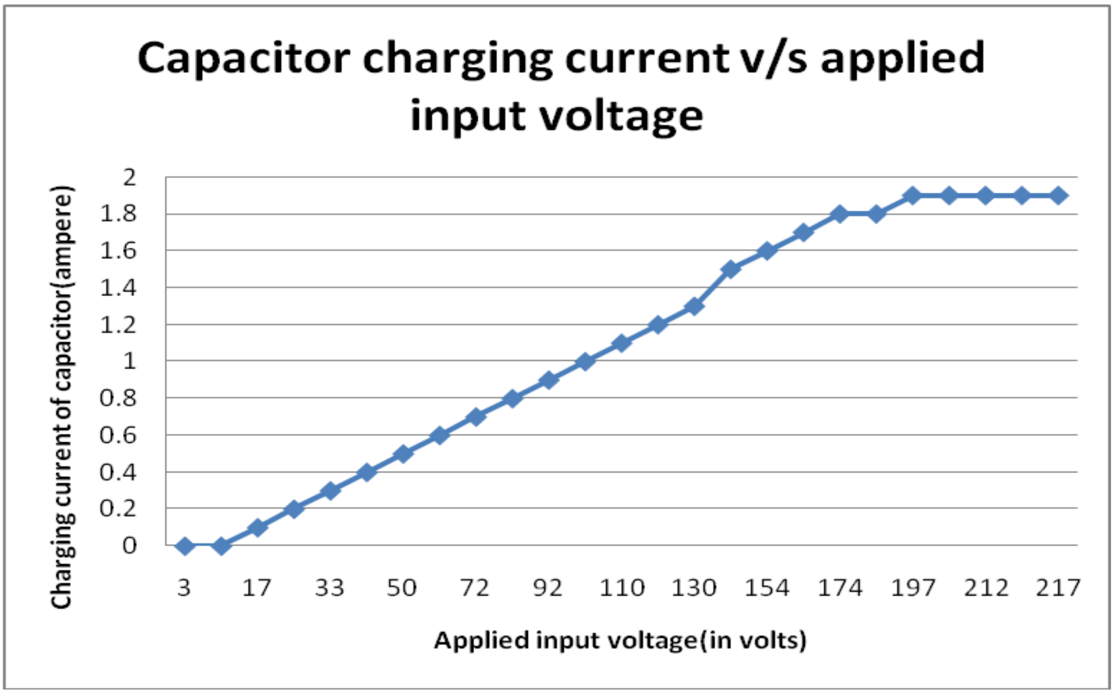
During Discharging:

Sr. No	Capacitor Voltage(kV)	Input applied(V)	Charging current of capacitor(A)
1	137.58	212	1.9
2	135	208	1.9
3	131.43	202	1.9
4	126.80	195	1.9
5	124.50	190	1.9
6	120.50	184	1.8
7	116.88	178	1.7
8	111.34	169	1.6
9	105	160	1.5
10	98.81	150	1.4
11	91.91	140	1.3
12	85.57	130	1.2
13	78.60	119	1.1
14	65.46	100	1.0
15	58.64	90	0.9
16	52.15	80	0.8
17	45.52	70	0.7
18	39.19	60	0.6
19	32.52	50	0.5
20	25.68	40	0.4
21	19.24	30	0.2
22	12.63	19	0.1
23	6.15	10	0

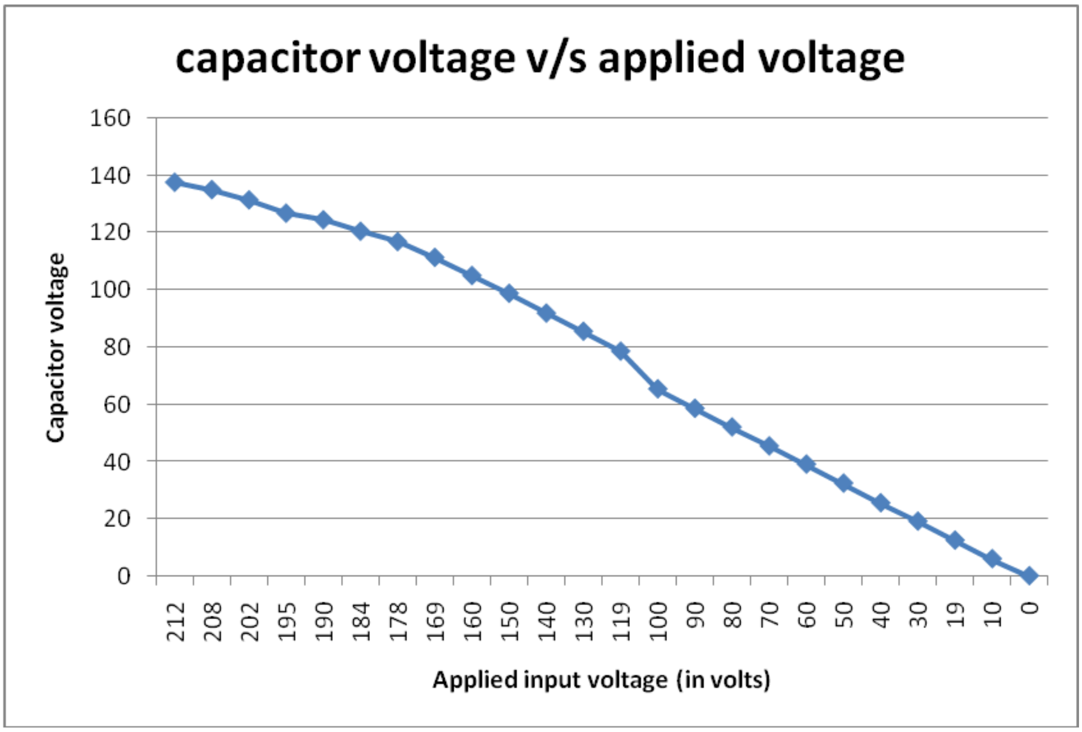
8. GRAPHS:

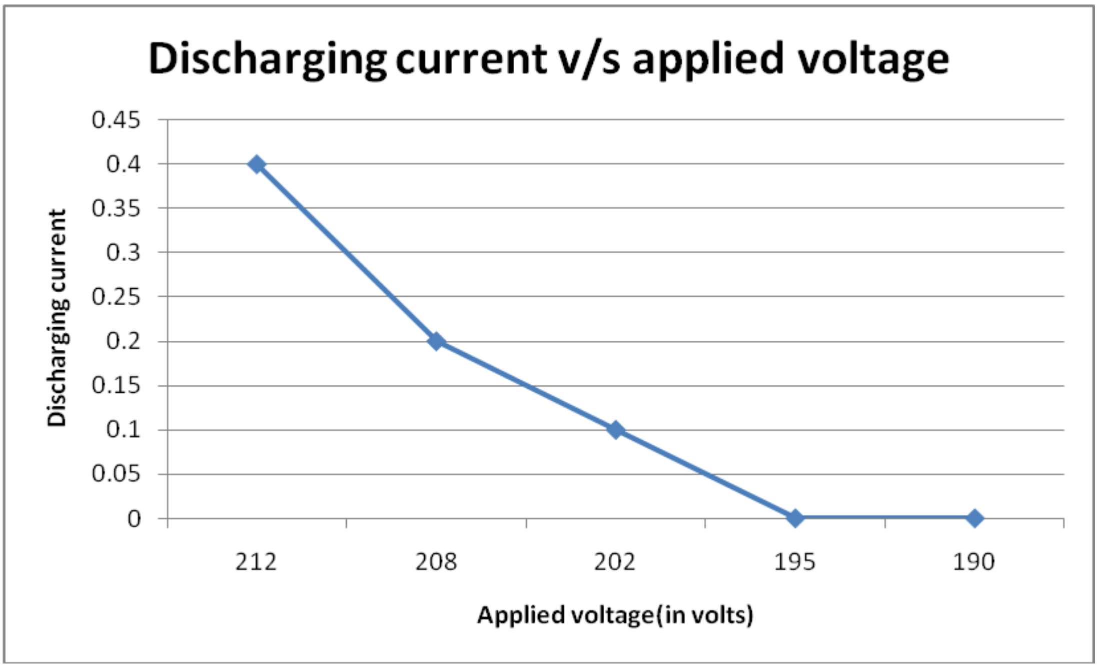


Voltage across capacitor v/s applied input voltage
Capacitor Voltage (KV)
160
140
120
100
80
60
40
20
0
3 9 17 23 33 42 50 60 72 82 92 102 110 122 130 145 154 166 174 186 197 204 212 216 217
Applied input voltage(in volts)



Capacitor charging current v/s applied input voltage
Charging current of capacitor(ampere)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
3 17 33 50 72 92 110 130 154 174 197 212 217
Applied input voltage(in volts)


capacitor voltage v/s applied voltage
Capacitor voltage
160
140
120
100
80
60
40
20
0
212
208
202
195
190
184
178
169
160
150
140
130
119
100
90
80
70
60
50
40
30
19
10
0
Applied input voltage (in volts)


Discharging current v/s applied voltage
Discharging current
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
212
208
202
195
190
Applied voltage(in volts)

9. MATLAB SIMULATIONS:

MODEL:

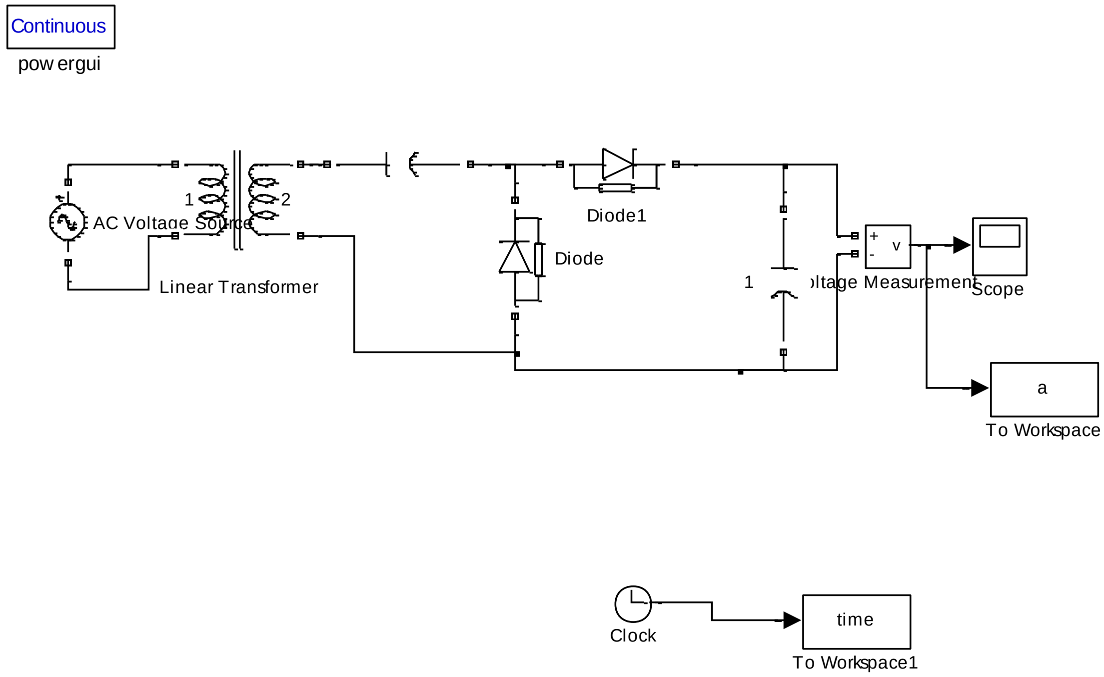


Fig: 4.3 Equivalent Circuit of HVDC Generation and its Measurement

10. RESULT:

Various graphs between voltage across capacitor and current through it with applied input voltage has been drawn for both charging and discharging. Simulation of the circuit in matlab is done.

****

EXPERIMENT NO – 05 (a)

TO GENERATE AND MEASURE POSITIVE IMPULSE VOLTAGE WAVEFORMS USING 280 KV, 2 STAGE, AND 1.96 KJ IMPULSE TEST SET

CONTENTS:

1. Objectives: 33
2. Equipment required: 33
3. Expected outcome of experiment: 33
4. Theory: 34
5. Circuit diagram: 35
6. Methodology for measurements: 35
7. Measurements: 36
8. Results and discussion: 38

1. OBJECTIVE:

- To generate and measure positive impulse voltage waveforms using **280 kV, 2-stages, and 1.96 kJ** impulse test set.

2. EQUIPMENT REQUIRED

Sr. No.	Unit	Description/Rating	Quantity
1.	High Voltage AC Transformer	100 kVA, 0.23/100 kV	1
2.	Motor Set	230 V AC, 23 rpm, 1.76 HP, B Class Insulation, Continuous Duty	1
3.	Motor driven Sphere Gap.	220 Volt, 50 Hz	1
4.	Wave Tail Resistance and Wave Front Controlling Resistance in both Upper and Lower Stage of Impulse Generator.	140 kV, 43 k Ω and 140 kV, 35 k Ω	1
5.	Modular Charging Set in both Upper and Lower Stage	140 kV, 2.5 M Ω and Charging Capacitance 140 kV, 100000 pF	1
6.	Tektronix Digital Phosphor Oscilloscope	Four Channel, 5GS/sec, 1 GHz	1
7.	DSTM Impulse Voltmeter	280 kV DGM DC Voltmeter.	1

3. EXPECTED OUTCOME OF EXPERIMENT:

After completion of experiment the student will able to know

- The generation of positive impulse voltage using Marx circuit.
- The measurement of impulse voltage using capacitive potential divider.

4. THEORY:

For producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series. The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by Marx. Now-a-days modified Marx circuits are used for the multistage impulse generators

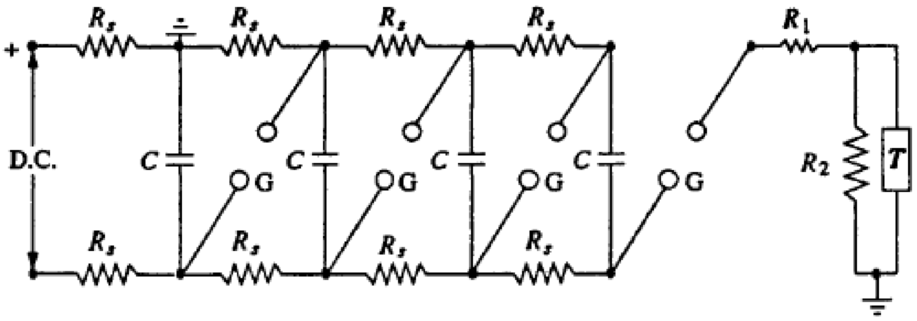


Fig: 5a.1 Schematic Diagram of Marx Circuit Arrangement for Multi-Stage Impulse Generator

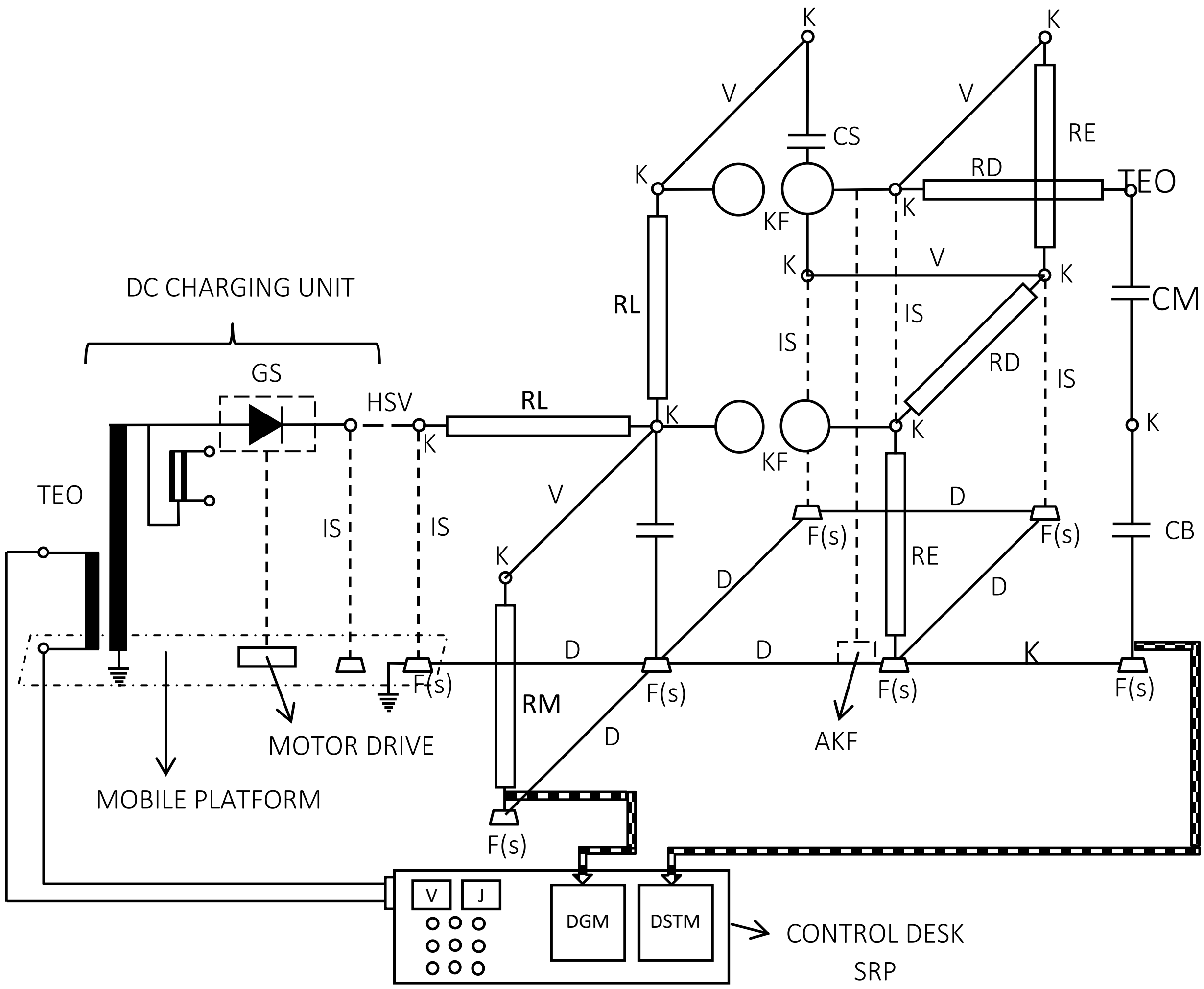
In order that equipment designed to be used on high voltage lines, and others, be able to withstand surges caused in them during operation, it is necessary to test these equipment with voltages of the form likely to be met in service. The apparatus which produces the required voltages is the impulse generator. In high voltage engineering, an impulse voltage is normally a unidirectional voltage which rises quickly without appreciable oscillations, to a peak value and then falls less rapidly to zero.

One Motor set is used to change the polarity of rectifier. Both the rectifier and cascaded generator with motor set are based on a roller base support which is properly earthed. The DC input is obtained from the rectifier and though a flexible connector it is given to a charging set which is having cup type connections. The sphere of both first and second stage of impulse generator is having 5cm diameter. Both these spheres are connected to 220 volts, 50 Hz motor. This motor is used to adjust the sphere gap 0 to 9cm.

The two charging capacitors of upper and lower stage are in series through the sphere gap rise to 280 kV across the wave front controlling resistor. Charging capacitor is connected to a measuring unit through a conducting rod.

Measuring capacitor through control cable is connected to DSTM impulse voltmeter. The measuring unit has a voltage divider unit having 140 kV, 280 mega Ω resistors. The DC voltage measured across the resistor is given to DGM DC voltmeter through a control cable. Measuring unit is connected to earth rod to dissipate energy to earth. By selecting the polarity of rectifier we can produce either positive or negative pulse. The control switch, main switch, primary and secondary switches on transformer, switch for motor control, switch for rectifier, and switch to increase the voltage regulation in steps. Tektronix digital phosphor oscilloscope is used to observe the impulse wave produced.

5. CIRCUIT DIAGRAM:



SRP = 1
TEO = 1
GS = 1
CS = 2
CB = 2

RM = 1
RL = 2
RD = 2
RE = 2
KF = 2

V, I – LV INSTRUMENT

EL = 1
ES = 1
IS = 5
V = 4

HSV = 1
K = 12
F(S) = 7
D = 7

AKF = 1
EST = 1
DGM = 1
DSTM = 1

NTZ = 2

Fig 5b.2: V, I-LV Instrument

6. METHODOLOGY FOR EXPERIMENT:

Procedure:

6.1 Before the start of the experiment, ensure that the earth rod is removed from the test set.
6.2 Ensure that the door of lab is properly latched.
6.3 Switch on the panel control switch, then the main switch.
6.4 Switch on primary switch, the earth switch will come down.
6.5 Then switch on the secondary switch. Set voltage to zero if it is not.
6.6 Switch on the DSTM, DGM and switch on the oscilloscope.

6.7 Adjust the distance between the sphere gaps to 1 cm. Raise the potential in steps.
6.8 When the voltage is near to the voltage as given in the BIL chart, switch the trigger device to obtain the triggering of both the spheres simultaneously.
6.9 Note down the DGM reading DSTM reading, input voltage, charging current and discharging current.
6.10 Repeat the above steps for various settings of sphere gap distance i.e. for 2 to 9 cm at a step of 1 cm increase and increase and increase the voltage in steps to bring the voltage near to spark over voltage of spheres.
6.11 Read and measure the voltage waveforms on the oscilloscope. Also note down the readings on the meters.
6.12 Repeat the experiment for different settings of sphere gaps.
6.13 Prepare the table and plot the graph for breakdown voltages. Also take the print of the wave shape captured on oscilloscope.

7. MEASUREMENTS:

Table 1: Recording of measurements.

Sr. No	**Gap Spacing** (In cm)	**Input Voltage** (In kV)	**DSTM Reading** (In kV)	**DGM Reading** (In kV)	**Charging Current** (in A)	**Discharging Current** (in A)
1.	1	40	57	30.45	0.9	9.0
2.	1	42	58.6	30.5	1.1	9.1
3.	1	45	58.9	30.82	1.6	8.9
4.	2	73	99	52.6	3.8	8.0
5.	2	89	103.2	54.3	3.4	7.8
6.	2	90	103	54.4	3.2	7.9
7.	3	100	143	75.4	4.6	6.6
8.	3	110	145.4	76.2	5.0	6.7
9.	3	110	144.8	76	5.0	6.6
10.	4	120	179	94.9	6.3	5.1
11.	4	122	183	97	6.0	5.2
12.	4	130	182.9	86	6.6	5.0
13.	5	204	207	111	7.2	4.8
14.	5	205	207	110	7.7	4.6
15.	5	200	208	111	8.0	4.7
16.	6	203	205	123	7.7	1.8
17.	6	204	210	120	8.2	1.6

Table 2 Observation of average DSTM voltage with gap spacing are shown

Sr. No	**Spacing** (in cm)	**Average DSTM**(in kV)
1	1	58.17
2	2	101.73
3	3	144.4
4	4	181.63
5	5	207.33
6	6	208.66

Graphs:

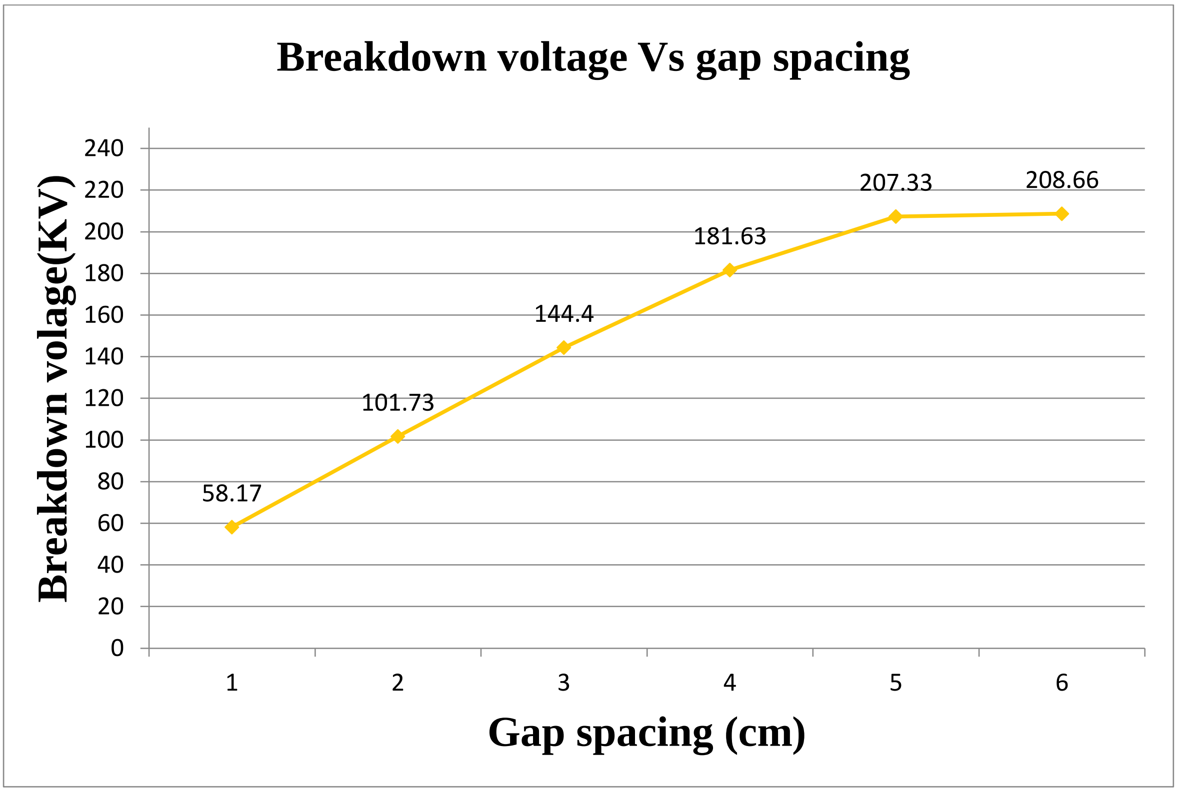


Fig 5a.3: Graph between Breakdown Voltage and Gap Spacing

MATLAB Simulation:

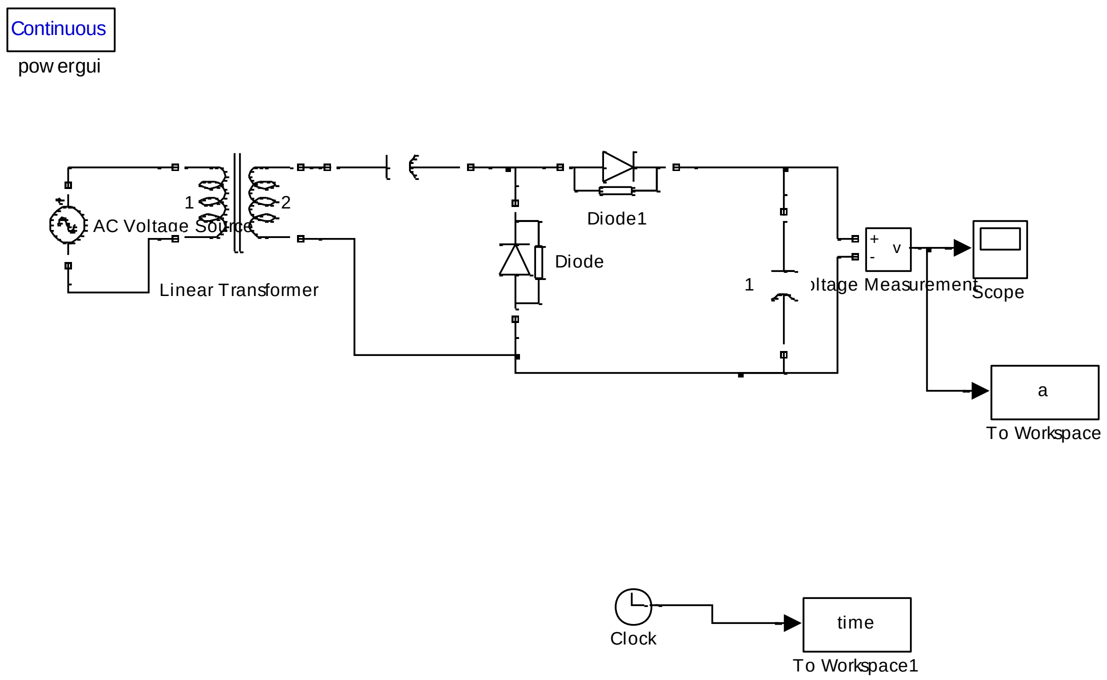


Fig 5a.4: MATLAB Simulation Model for This Experiment

8. RESULTS AND DISCUSSION:

- Waveforms of positive switching wave are obtained at different gap spacing. Graph between breakdown voltage v/s gap spacing shows that with the increase in gap spacing the breakdown voltage increases.

****

EXPERIMENT NO – 05 (b)

TO GENERATE AND MEASURE NEGATIVE IMPULSE VOLTAGE WAVEFORMS USING 280 KV, 2 STAGE, 1.96 KJ IMPULSE TEST SET

CONTENTS:

1. Objectives: 39
2. Equipment's required: 39
3. Expected outcome of experiment: 40
4. Theory: 40
5. Circuit diagram: 41
6. Methodology for measurements: 42
7. Measurements: 42
8. Results and discussion: 43

1. OBJECTIVES:

- To generate and measure negative impulse voltage waveforms using **280 kV, 2stages, and 1.96kJ** impulse test set.

2. EQUIPMENT REQUIRED:

Sr. No.	Unit	Description/Rating	Quantity
1	AC Transformer	100 kVA , 0.23/100 kV	1
2	Motor Set	230VAC, 23 rpm,1.76 hp, B Class Insulation Continuous Duty	1
3	Motor driven Sphere Gap	220 Volt, 50 Hz	1
4	Wave Tail Resistance and Wave Front Controlling Resistance in both Upper and Lower Stage of Impulse Generator	140 kV, 677 Ω 140 kV, 350 Ω	1
5	Modular Charging Set	Charging Resistance 140 kV, 2.5 M Ω and Charging Capacitance 140kV, 100000pF in both Upper and Lower Stage	1
6	Tektronix Digital Phosphor Oscilloscope	Four Channel, 5GS/sec, 1 GHz	1
7	DSTM Impulse Voltmeter	280 kV DGM Voltmeter	

3. EXPECTED OUTCOME OF EXPERIMENT:

After completion of experiment the student will able to know

- The generation of negative impulse voltage using Marx circuit.
- The measurement of impulse voltage using capacitive potential divider.

4. THEORY:

For producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series. The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by Marx. Now-a-days modified Marx circuits are used for the multistage impulse generators

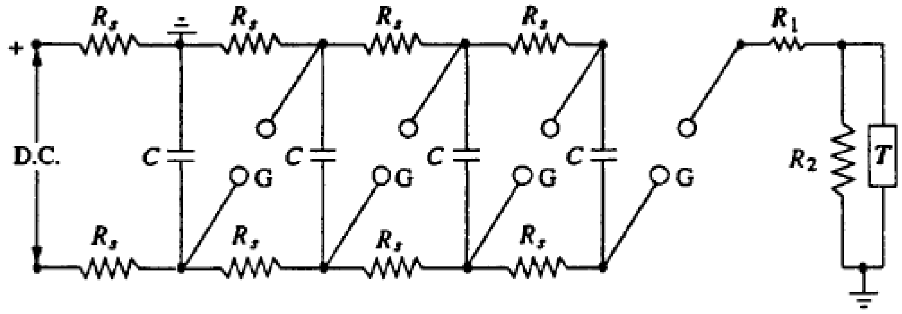


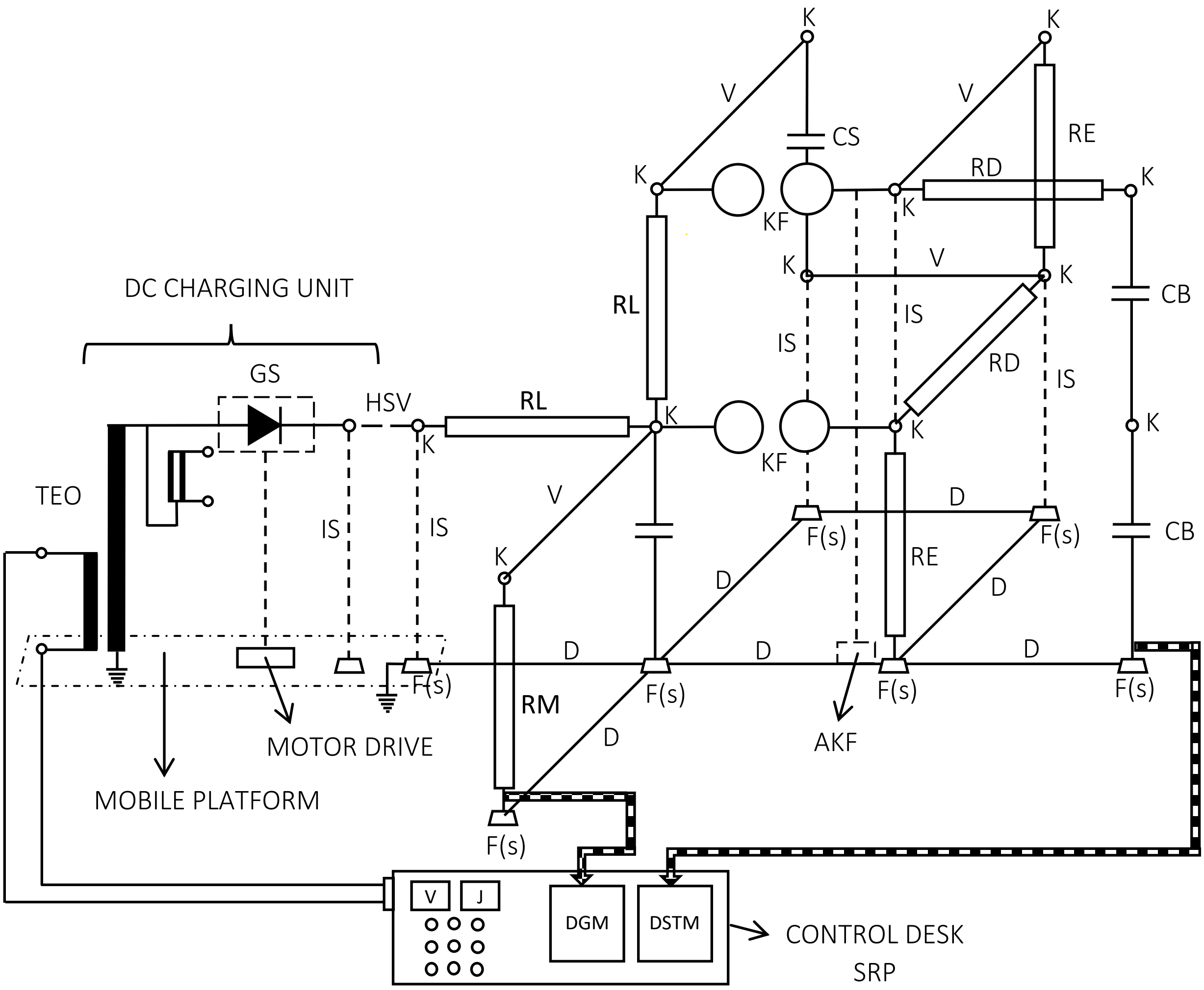
Fig: 5b.1 Schematic Diagram of Marx Circuit Arrangement for Multi-Stage Impulse Generator

In order that equipment designed to be used on high voltage lines, and others, be able to withstand surges caused in then during operation, it is necessary to test these equipment with voltages of the form likely to be met in service. The apparatus which produces the required voltages is the impulse generator. In high voltage engineering, an impulse voltage is normally a unidirectional voltage which rises quickly without appreciable oscillations, to a peak value and then falls less rapidly to zero.

Transmission and distribution of electrical energy involves the application of high voltage apparatus like power transformers, switchgear, overvoltage arrestors, insulators, power cables, transformers, etc., which are exposed to high transient voltages and currents due to internal and external over voltages. Before commissioning, they are therefore tested for reliability with standard impulse voltages or impulse currents. Depending on the apparatus and the type of their proposed application, one differentiates between various types of waveforms of test voltages and test currents.

One Motor set is used to change the polarity of rectifier. Both the rectifier and ac cascaded generator with motor set are based on roller base support which is properly earthed. The dc input is obtained from the rectifier and through a flexible connector it is given to the charging set which is having cup type connections. The sphere of both first and second stage of impulse generator is having 5 cm diameter. Both these spheres are connected to a 220 volt, 50 Hz motor. This motor is used to adjust the sphere gap from 0 to 9 cm. The two charging capacitors of upper and lower stage are in series through the sphere gap rise to 280 kV across the wave front controlling resistor. Charging capacitor is connected to a measuring unit through a conducting rod. Measuring capacitor through control cable is connected to DSTM impulse voltmeter. The measuring unit has a voltage divider unit having 140 kV, 280 MΩ resistor. The dc voltage measured across this resistor is given to DGM dc voltmeter through a control cable. Measuring unit is connected to earth rod to dissipate energy to earth. By selecting the polarity of rectifier we can produce either positive of negative pulse. The control panel consists of control switch, main switch, primary and secondary switch on transformer, switch for motor control, switch for rectifier, switch to increase the voltage regulation in steps. Tektronix Digital Phosphor Oscilloscope is used to observe the impulse wave produced.

5. <u>CIRCUIT DIAGRAM:</u>



V, I – LV INSTRUMENT

SRP = 1	RM = 1				
TEO = 1	RL = 2	EL = 1	HSV = 1	AKF = 1	NTZ = 2
GS = 1	RD = 2	ES = 1	K = 12	EST = 1	
CS = 2	RE = 2	IS = 5	F(S) = 7	DGM = 1	
CB = 2	KF = 2	V = 4	D = 7	DSTM = 1	

Fig 5b.2 Impulse Voltage Generator

6. METHODOLOGY OF MEASUREMENTS:

6.1 Before the start of the experiment, ensure that the earth rod is removed from the test set.
6.2 Ensure that the door of lab is properly latched
6.3 Switch on the panel control switch, then the main switch.
6.4 Switch on primary switch, the earth switch will come down.
6.5 Then switch on the secondary switch. Set voltage to zero if it is not.
6.6 Switch on the DSTM and DGM. And switch on the oscilloscope.
6.7 Adjust the distance between the sphere gaps to 1 cm. Raise the potential in steps.
6.8 When the voltage is near to the voltage as given in the BIL chart, switch the trigger device to obtain the triggering of both the spheres simultaneously.
6.9 Note down the DGM reading DSTM reading, input voltage and charging current and discharging current.
6.10 Repeat the above steps for various settings of sphere gap distance i.e. for 2 to 9 cm at a step of 1 cm increase and increase the voltage in steps to bring the voltage near to spark over voltage of spheres.
6.11 Read and measure the voltage waveforms on the oscilloscope. Also note down the readings on the meters.
6.12 Repeat the experiment for different settings of sphere gaps.
6.13 Prepare the table and plot the graph for breakdown voltages. Also take the print of the wave shape captured on oscilloscope.

7. MEASUREMENTS:

Table 1: Table to be used for recording the measurements.

Sr. No	**Gap Spacing** (In cm)	**Input Voltage** (In kV)	**DSTM Reading** (In kV)	**DGM Reading** (In kV)	**Charging Current** (In A)
1.	1				
2.	2				
3.	2				
4.					
5.					
6.					
7.					

Table 2: Table to be used for observation of average DSTM voltage with gap spacing

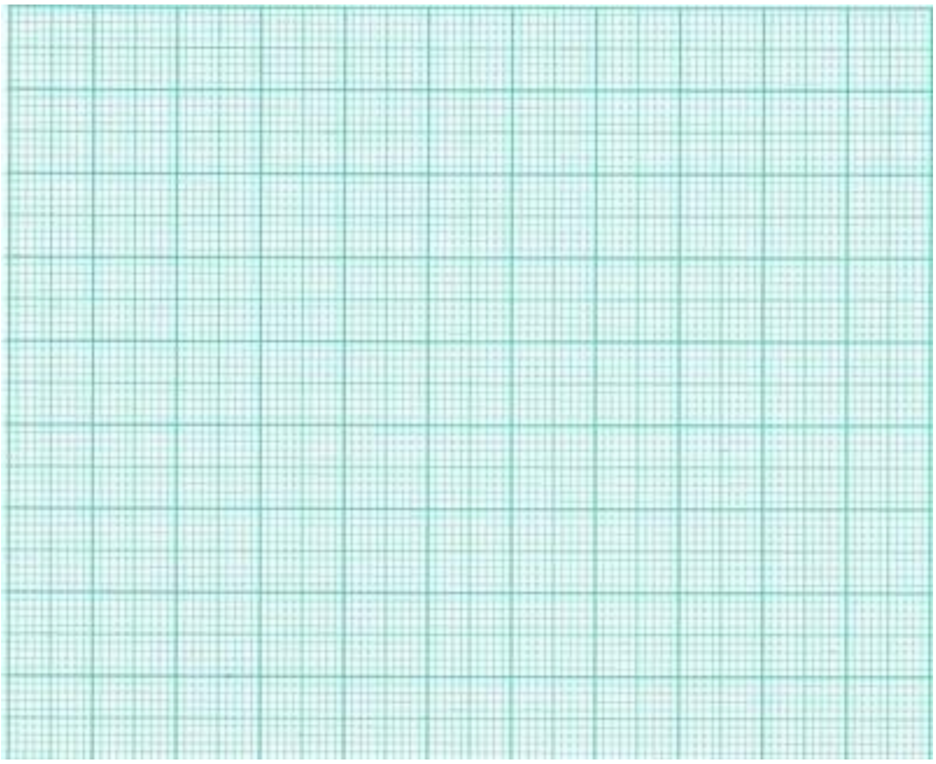
Sr. No	**Spacing** (in cm)	**Average DSTM** (in kV)
1		
2		

8. <u>RESULT AND DISCUSSION:</u>

Based on your measurements, let us now discuss the results that you obtained. Please provide responses to following points:

- How does the breakdown voltage vary with gap spacing?
- Plot the graph of breakdown voltage vs gap spacing.

Breakdown voltage –gap spacing (V-cm) graph:



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EXPERIMENT NO – 06 (a)

GENERATION OF SWITCHING WAVE (POSITIVE) WITH THE HELP OF TWO STAGE, 280 KV IMPULSE GENERATOR

CONTENTS:

1. Objectives: 44
2. Equipment's required: 44
3. Expected outcome of experiment: 45
4. Theory: 45
5. Circuit diagram: 46
6. Methodology for measurements: 46
7. Measurements: 47
8. Results and discussion: 48

1. OBJECTIVES:

- The Generation of Switching Wave (Positive) with the Help of Two Stage, 280 kV Impulse Generator

2. EQUIPMENT REQUIRED:

Sr. No.	Unit	Description/Rating	Quantity
1	AC Transformer	100 kVA ,0.23/100 kV	1
2	Motor Set	230 VAC, 23 rpm,1.76 hp, B class Insulation Continuous Duty	1
3	Motor driven Sphere Gap	220 Volt, 50 Hz	1
4	Wave Tail Resistance and Wave Front Controlling Resistance in both Upper and Lower Stage of Impulse Generator	140 kV, 43k Ω 140 kV, 35k Ω	1
5	Modular Charging Set	Charging Resistance 140 kV, 2.5 M Ω and Charging Capacitance 140KV, 100000 pF in both Upper and Lower Stage	1
6	Tektronix Digital Phosphor Oscilloscope	Four Channel, 5GS/sec, 1 GHz	1
7	DSTM Impulse Voltmeter	280 KV DGM Voltmeter	

3. EXPECTED OUTCOME OF EXPERIMENT:

After completion of experiment the student will able to know

- The generation of positive switching voltage wave using Marx circuit.
- The measurement of impulse voltage using capacitive potential divider.

4. THEORY:

For producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series. The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by Marx. Now-a-days modified Marx circuits are used for the multistage impulse generators

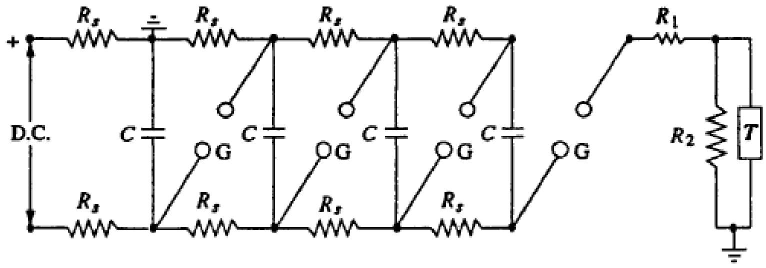
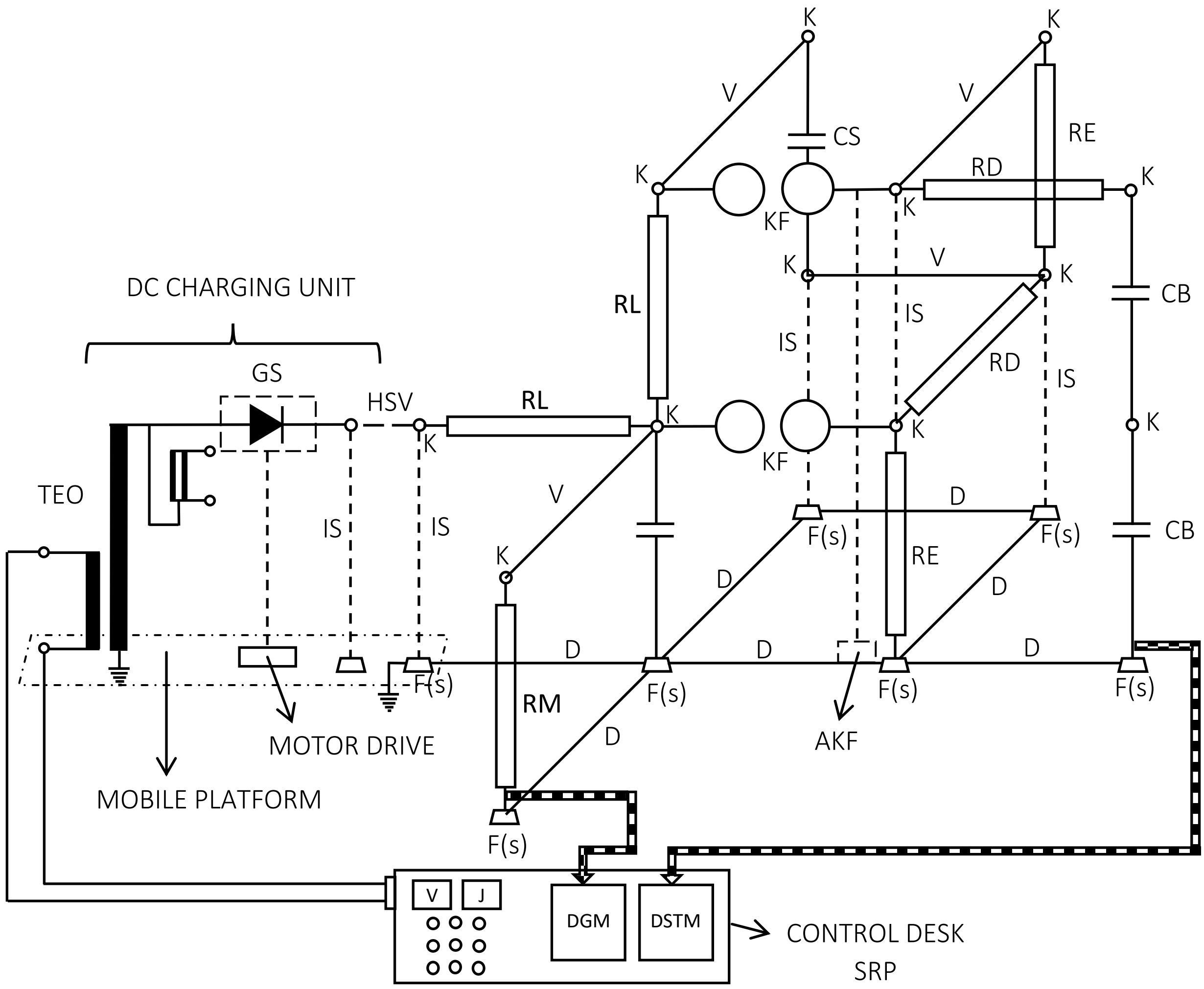


Fig: 6a.1 Schematic Diagram of Marx Circuit Arrangement for Multi-Stage Impulse Generator

Motor set is used to change the polarity of rectifier. Both the set rectifier and ac cascaded generator with motor set are based on a roller base support which is properly earthed. The dc input is obtained from the rectifier and through a flexible connector it is given to the charging set which is having cup type connections. The sphere of both first and second stage of impulse generator is having 5 cm diameter. Both these spheres are connected to a 220 volt, 50 Hz motor. This motor is used to adjust the sphere gap from 0 to 9 cm. The two charging capacitors of upper and lower stage are in series through the sphere gap rise to 280 kV across the wave front controlling resistor. Charging capacitor is connected to a measuring unit through a conducting rod. Measuring capacitor through control cable is connected to DSTM impulse voltmeter. The measuring unit has a voltage divider unit having 140 kV, 280 mega Ω resistor. The dc voltage measured across this resistor is given to DGM dc voltmeter through a control cable. Measuring unit is connected to earth rod to dissipate energy to earth. By selecting the polarity of rectifier we can produce either positive or negative pulse. The control panel consists of control switch, main switch, primary and secondary switch on transformer, switch for motor control, switch for rectifier, switch to increase the voltage regulation in steps. Tektronix Digital

Phosphor Oscilloscope is used to observe the impulse wave produced. Input voltage, impulse voltage produced, charging and discharging current can be measure

5. <u>CIRCUIT DIAGRAM:</u>



V, I – LV INSTRUMENT

SRP = 1	RM = 1				
TEO = 1	RL = 2	EL = 1	HSV = 1	AKF = 1	NTZ = 2
GS = 1	RD = 2	ES = 1	K = 12	EST = 1	
CS = 2	RE = 2	IS = 5	F(S) = 7	DGM = 1	
CB = 2	KF = 2	V = 4	D = 7	DSTM = 1	

Fig 6a.2 Switching Voltage Generator

6. <u>METHODOLOGY OF MEASUREMENTS:</u>

6.1 Before the start of the experiment, ensure that the earth rod is removed from the test set.
6.2 Ensure that the door of lab is properly latched
6.3 Switch on the panel control switch, then the main switch.
6.4 Switch on primary switch, the earth switch will come down.
6.5 Then switch on the secondary switch. Set voltage to zero if it is not.

6.6 Switch on the DSTM and DGM. And switch on the oscilloscope.
6.7 Adjust the distance between the sphere gaps to 1 cm. Raise the potential in steps.
6.8 When the voltage is near to the voltage as given in the BIL chart, switch the trigger device to obtain the triggering of both the spheres simultaneously.
6.9 Note down the DGM reading DSTM reading, input voltage and charging current and discharging current.
6.10 Repeat the above steps for various settings of sphere gap distance i.e. for 2 to 9 cm at a step of 1 cm increase and increase the voltage in steps to bring the voltage near to spark over voltage of spheres.
6.11 Read and measure the voltage waveforms on the oscilloscope. Also note down the readings on the meters.
6.12 Repeat the experiment for different settings of sphere gaps.
6.13 Prepare the table and plot the graph for breakdown voltages. Also take the print of the wave shape captured on oscilloscope.

7. MEASUREMENTS:

Table 1: Table to be used for recording the measurements

Sr. No	**Gap Spacing** (in cm)	**Input Voltage** (in kV)	**DSTM Reading** (in kV)	**DGM Reading** (in kV)	**Charging Current** (in kV)	**Discharging Current** (in kV)
1.	1	56	42	28	0.8	
2.	1	55	43.8	29.53	0.5	
3.	1	55	40.6	25	0.3	
4.	3	119	114	56	1.5	0.4
5.	3	120	115	63	2.1	
6.	5	179	207	97	2.2	
7	5	181	206	99	1.6	
8.	5	182	207	105	1.6	
9.	5	193	206	100	4.0	
10.	7	223	227	105	8.0	2.0
11.	7	220	234	100	8.4	1.9
12.	7	222	233	122	8.8	1.8
13.	7	221	227	106	9	1.6
14.	7	221	227	127	8.4	

Table 2: In this table the observation of average DSTM voltage with gap spacing are shown

Sr. No	Spacing	Average DSTM
1	1	42.133
2	3	114
3	5	206.5
4	7	229.6

8. RESULT AND DISCUSSION:

Based on your measurements, let us now discuss the results that you obtained. Please provide responses to following points:

- Plot the graph between breakdown voltage vs gap spacing.

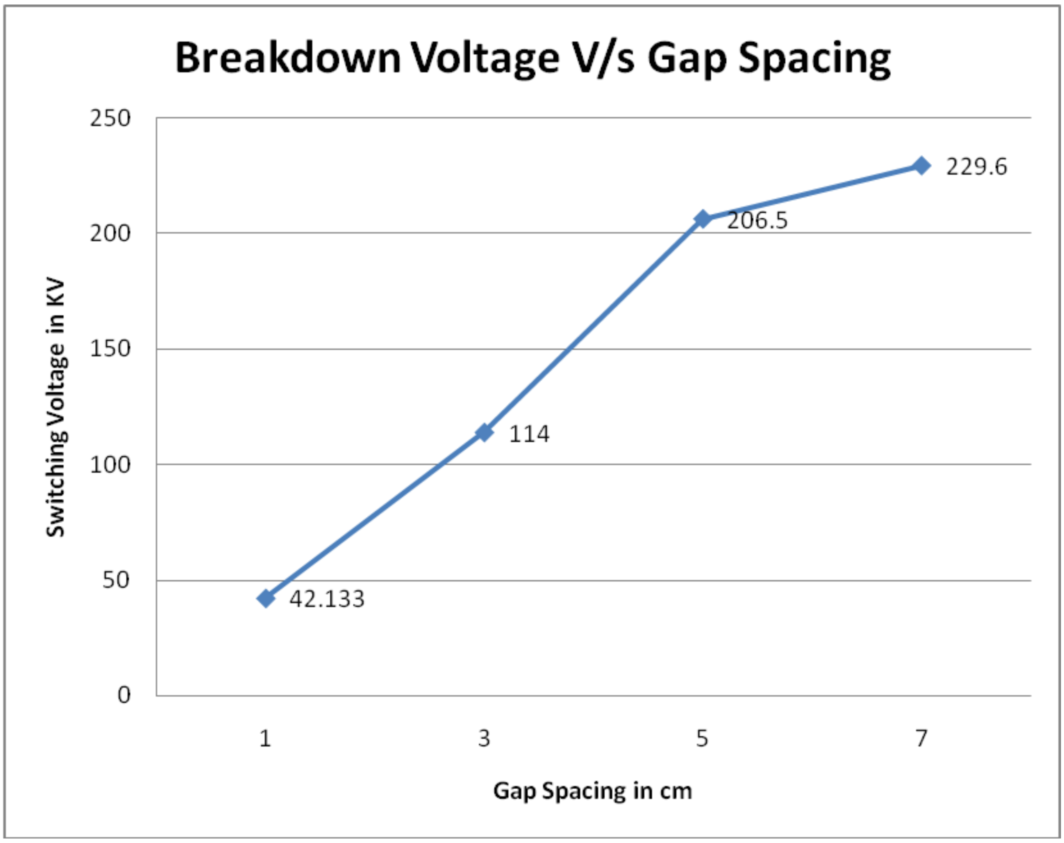
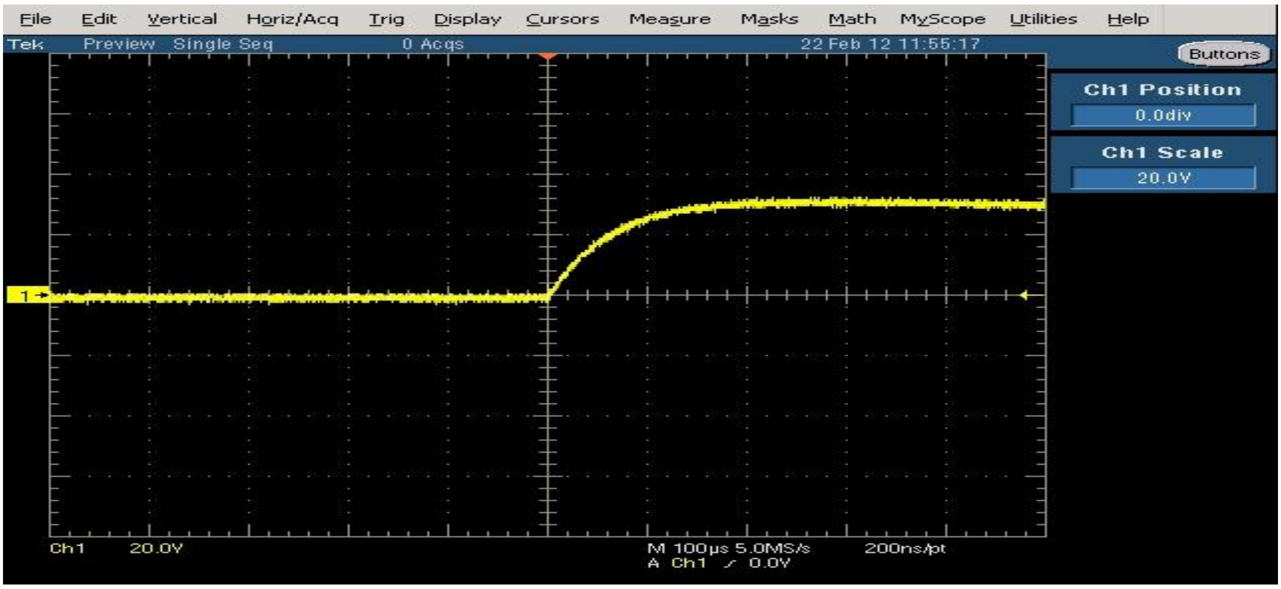
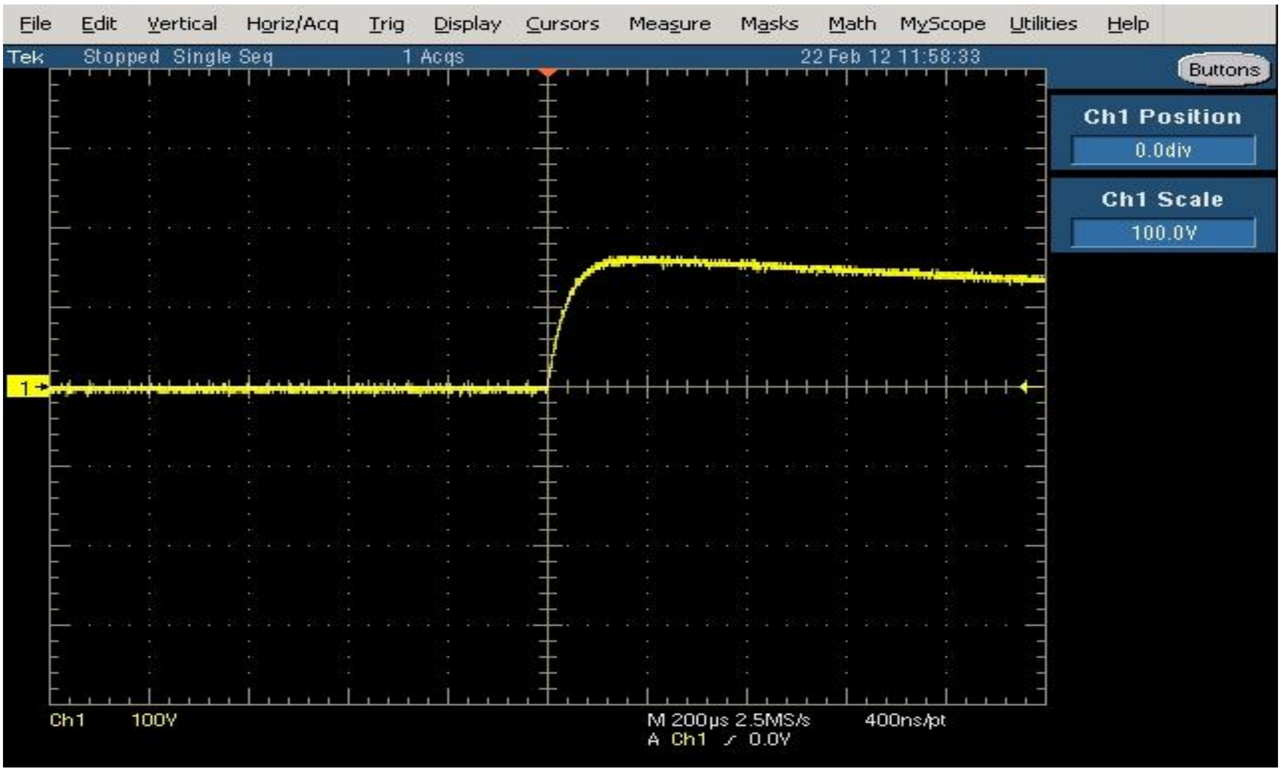


Fig 6a.3: Graph between Breakdown Voltage Vs Gap Spacing

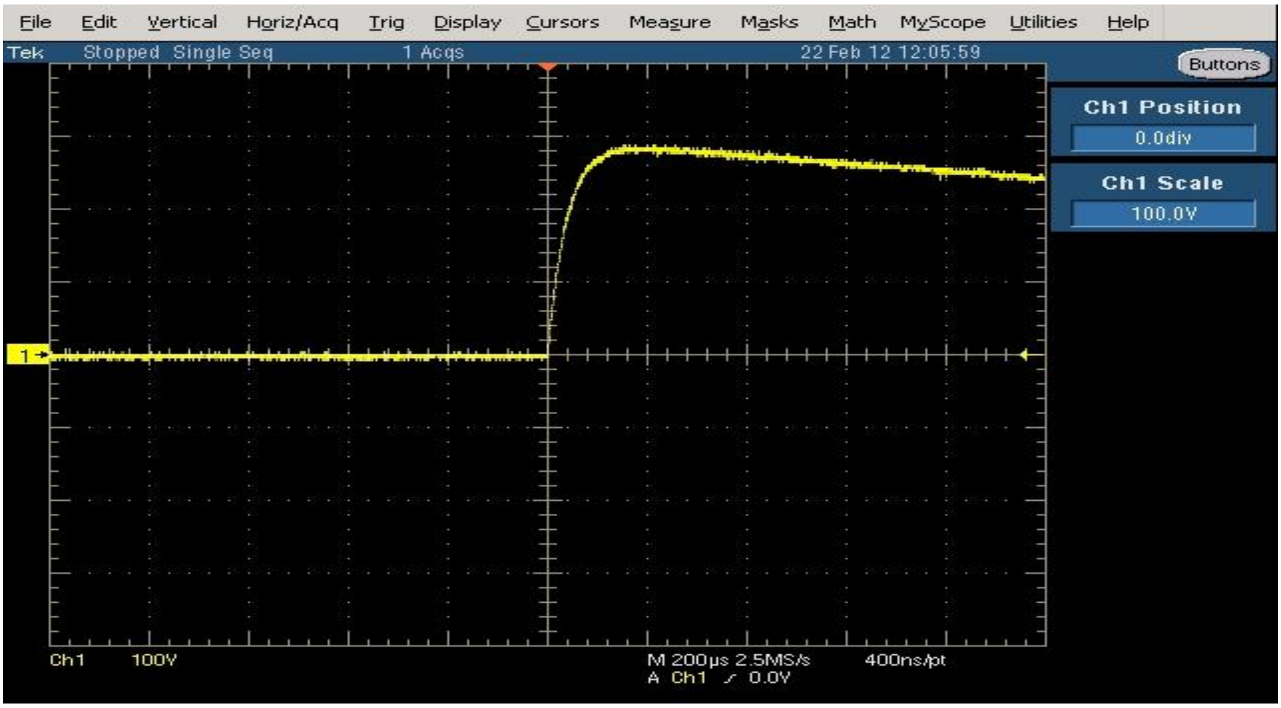
➢ Waveform Obtained at 1 cm



➢ Waveform Obtained at 3 cm



➢ Waveform Obtained at 7 cm



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EXPERIMENT NO – 06 (b)

GENERATION OF SWITCHING WAVE (NEGATIVE) WITH THE HELP OF TWO STAGE, 280 KV IMPULSE GENERATOR

CONTENTS:

1. Objectives: 51
2. Equipment required: 51
3. Expected outcome of experiment: 52
4. Theory: 52
5. Circuit diagram: 53
6. Methodology for measurements: 53
7. Waveform: 54
8. Results: 54

1. OBJECTIVE:

- Generation of Switching Wave (Negative) With the Help of Two Stage, 280 kV Impulse Generator

2. EQUIPMENT REQUIRED:

Sr. No	Unit	Description/Rating	Quantity
1	AC Transformer	100 kVA, 0.23/100 kV	1
2	Motor Set	230 V AC, 23 rpm, 1.76 HP, B Class Insulation, Continuous Duty	1
3	Motor driven Sphere Gap	220 Volt, 50 Hz	1
4	Wave Tail Resistance and Wave Front Controlling Resistance in both Upper and Lower Stage of Impulse Generator	140 kV, 43 k Ω and 140 kV, 35 k Ω	1
5	Modular Charging Set	140 kV, 2.5 M Ω and Charging Capacitance 140 kV, 100000 pF	1
6	Tektronix Digital Phosphor Oscilloscope	Four Channel, 5 GS/sec, 1 GHz	1
7	DSTM Impulse Voltmeter	280 kV DGM DC Voltmeter.	1

3. EXPECTED OUTCOME OF EXPERIMENT:

After completion of experiment the student will able to know

- The generation of positive impulse voltage using Marx circuit.
- The measurement of impulse voltage using capacitive potential divider.

4. THEORY:

For producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series. The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by Marx. Now-a-days modified Marx circuits are used for the multistage impulse generators

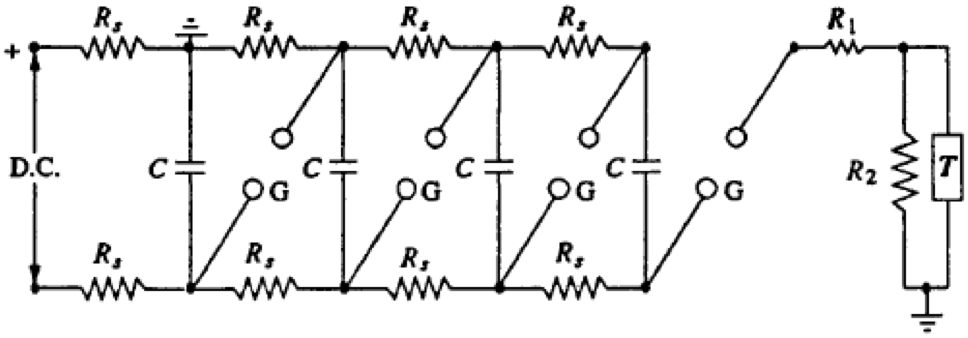
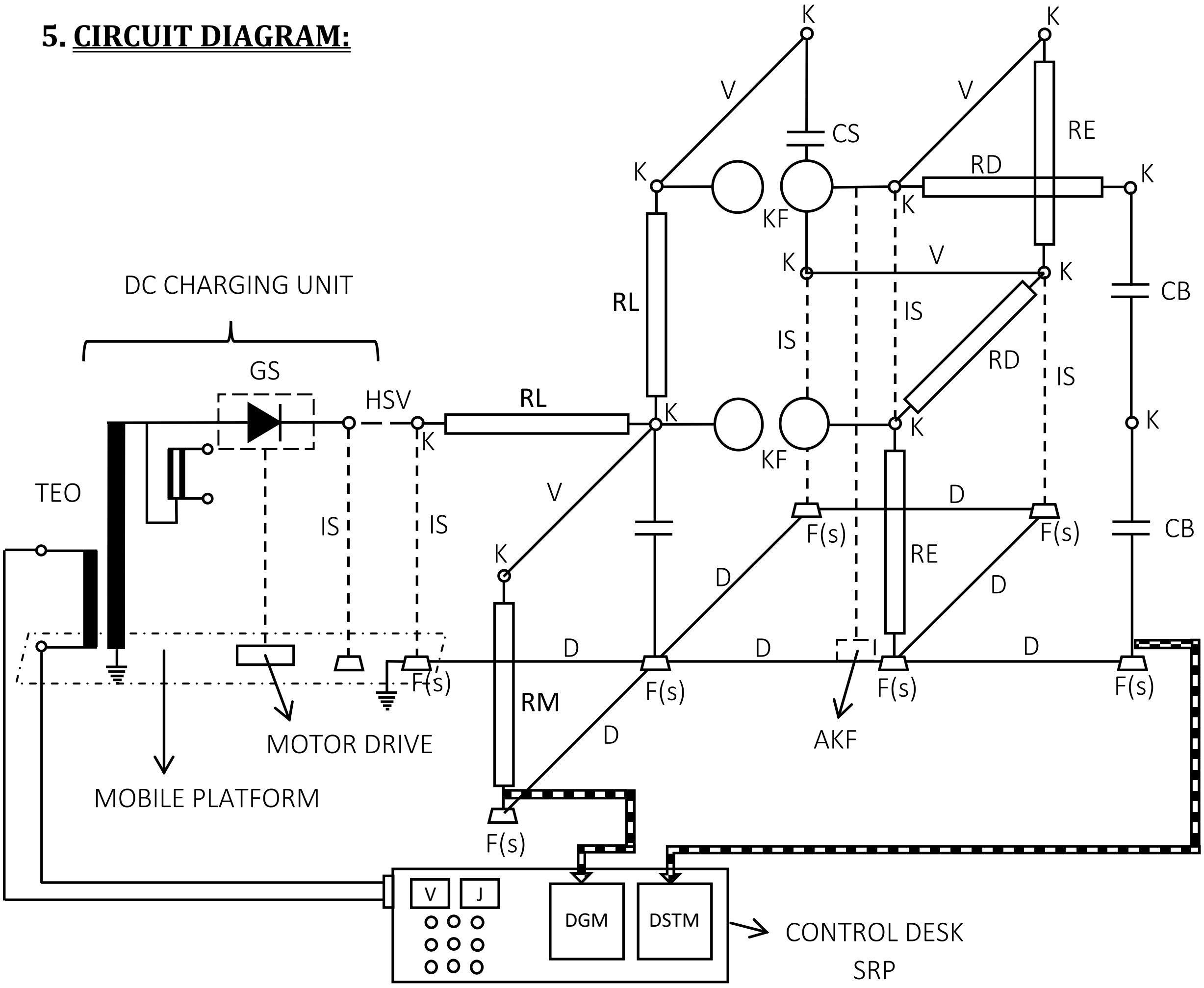


Fig: 6b.1 Schematic Diagram of Marx Circuit Arrangement for Multi-Stage Impulse Generator

Motor set is used to change the polarity of rectifier. Both the set rectifier and ac cascaded generator with motor set are based on a roller base support which is properly earthed. The dc input is obtained from the rectifier and through a flexible connector it is given to the charging set which is having cup type connections. The sphere of both first and second stage of impulse generator is having 5 cm diameter. Both these spheres are connected to a 220 volt, 50 Hz motor. This motor is used to adjust the sphere gap from 0 to 9 cm. The two charging capacitors of upper and lower stage are in series through the sphere gap rise to 280 kV across the wave front controlling resistor. Charging capacitor is connected to a measuring unit through a conducting rod. Measuring capacitor through control cable is connected to DSTM impulse voltmeter. The measuring unit has a voltage divider unit having 140 kV, 280 M Ω resistor. The dc voltage measured across this resistor is given to DGM DC voltmeter through a control cable. Measuring unit is connected to earth rod to dissipate energy to earth. By selecting the polarity of rectifier we can produce either positive or negative pulse. The control panel consists of control switch, main switch, primary and secondary switch on transformer, switch for motor control, switch for rectifier, switch to increase the voltage regulation in steps. Tektronix Digital Phosphor Oscilloscope is used to observe the impulse wave produced. Input voltage, impulse voltage produced, charging and discharging current can be measure

5. CIRCUIT DIAGRAM:



V, I – LV INSTRUMENT

SRP = 1	RM = 1				
TEO = 1	RL = 2	EL = 1	HSV = 1	AKF = 1	NTZ = 2
GS = 1	RD = 2	ES = 1	K = 12	EST = 1	
CS = 2	RE = 2	IS = 5	F(S) = 7	DGM = 1	
CB = 2	KF = 2	V = 4	D = 7	DSTM = 1	

Fig: 6b.2 Circuit Diagram of Two Stage 280 KV Impulse Generator

6. METHODOLOGY FOR MEASUREMENTS:

6.1 Switch on the panel control switch, then main switch.
6.2 After that switch on the primary switch. The earth switch will come down.
6.3 Then switch on the secondary switch. Set voltage to zero if it is not zero. Switch on oscilloscope.
6.4 Adjust the distance between sphere gaps 1 cm. Raise the potential in steps. On giving supply to trigger circuit it produces spark.
6.5 Note down the DGM reading, DSTM reading, input voltage and charging current and discharging current.

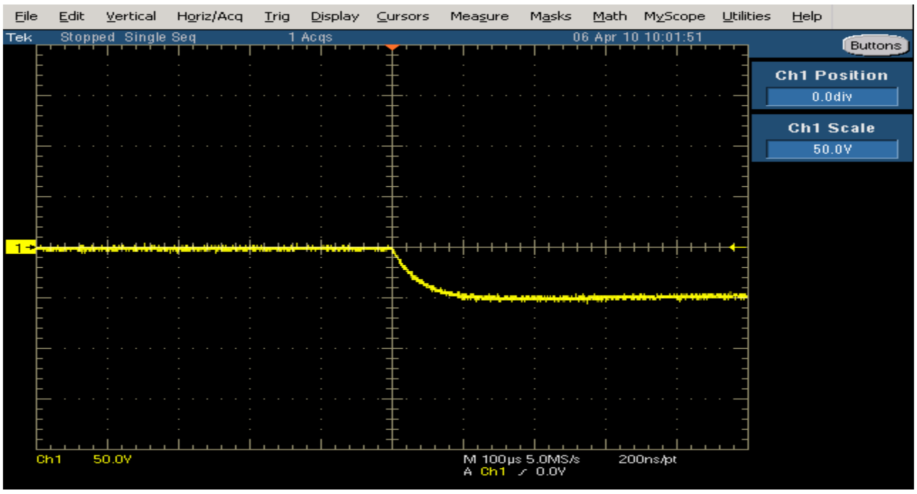
6.6 Repeat the above steps for various settings of sphere gap distance i.e. for 3, 5 and 7 cm. Observe the impulse voltage pulse produced on the oscilloscope.

6.7 Now reduce the voltage fast. Wait for the discharge voltage to become zero. Once it comes to zero switch off the secondary switch, primary switch and after that switch off the control switch and then panel main switch.

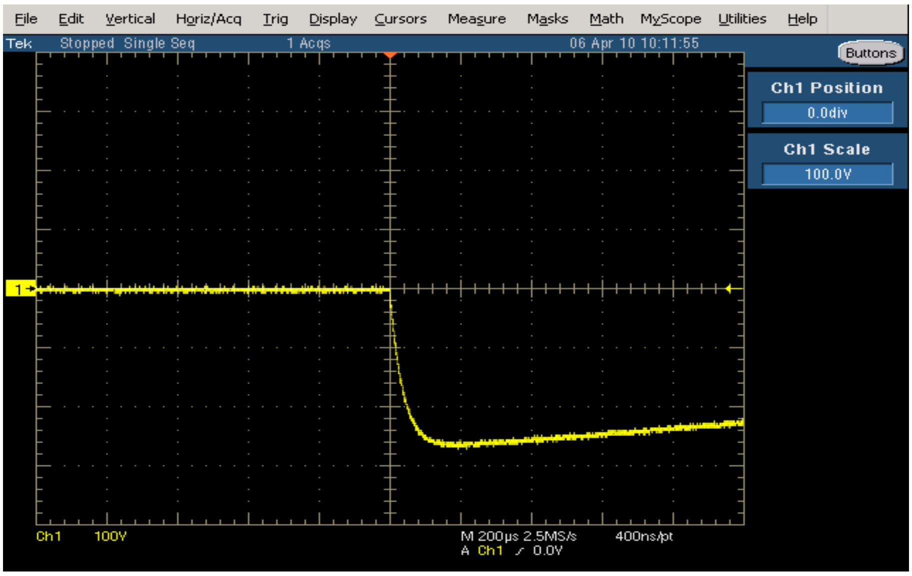
6.8 Plot the graph between breakdown voltage and sphere gap spacing

7. WAVEFORMS:

- Waveform Obtained at 1 cm



- Waveform Obtained at 5 cm



8. RESULT:

- Waveforms of negative switching wave are obtained at different gap spacings.

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EXPERIMENT NO - 07

100 KVA Motorized Fully Automatic Insulating Oil Testing Machine

CONTENTS:

1. Objectives: 55
2. Equipment's required: 55
3. Expected outcome of experiment: 55
4. Theory: 55
5. Methodology for measurements: 56
6. Measurements: 57
7. Result & Conclusion: 57

1. OBJECTIVE:

- Study of 100 KVA Motorized Fully Automatic Insulting Oil Testing Machine.

2. EQUIPMENT REQUIRED:

- Insulating Oil Testing Machine (100 KVA Motorized Fully Automatic)
- Test Cell
- AC Cord
- Paper Roll
- Insulting Oil

3. EXPECTED OUTCOME OF EXPERIMENT:

After completing the experiment student will know about:

- How to measure Breakdown Voltage (BDV) or dielectric strength of oil.
- Also be able to verify that increasing gap leads to increase in BDV.

4. THEORY:

Introduction:

AT-100, is a fully automatic insulating oil tester designed for testing dielectric strength of insulating oil with voltage range from 0 to 100 KV rms. The rate of voltage rise is 2 KV/sec.

AT-100 comprises of a High Voltage step-up transformer & control circuit. The HV transformer driven by variable voltage auto-transformer (variac). A motor drives the variac arm. The variable voltage value is input to HV transformer & monitored. When breakdown occurs in oil, a high current spike is generated in HV transformer secondary. Voltage at which breakdown occurs is displayed & logged into processor memory. The system steps down HV voltage to zero & starts to take another test, by completing stirring waiting process for requisite duration. A buzzer sounds a beep to signal completion of that cycle. Statistical data on the set of tests performed is stored in memory. At the end of the test cycle report printout is obtained.

Note:

The test parameters selected in advanced using the switched are of the two types:

4.1 IEC 156
4.2 User Defined

4.1 IEC 156: (Automatic Programmed)

- No. of Tests : 06
- Settling Time : 180 sec
- Stirring Time : 60 sec
- Waiting Time : 60 sec

4.2 User Defined Setting:

- No. of Tests : 1 to 9
- Settling Time : 0-999 sec
- Stirring Time : 0-999 sec
- Waiting Time : 0-999 sec

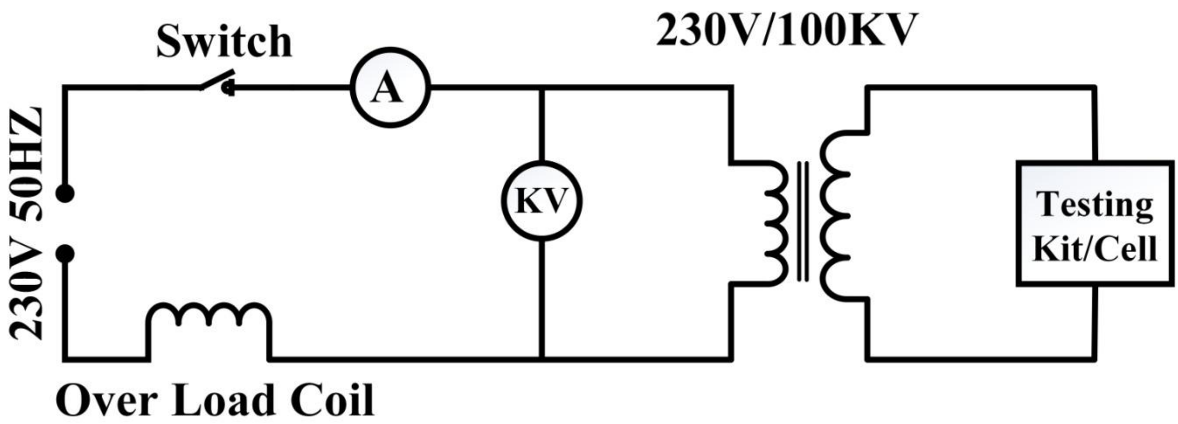

Fig: 7.1. Circuit Diagram of Insulating Oil Testing Machine

5. <u>METHODOLOGY OF MEASUREMENTS:</u>

5.1 Open the cover of the tester softly.
5.2 Put the oil cup, filled with oil sample on the cradle of HV terminals. Then put the acrylic cover to close the sensitive switch, otherwise it will not show the display.
5.3 Connect an additional earth to the ground terminal.

5.4 Connect the tester to AC 220 V mains supply and put mains switch ON.
5.5 Press (Menu) button then enter into main menu. There are three choices;
   a. Set Time
   b. Set Parameter
   c. Inquire Data
5.6 Move the cursor to "Set parameter" & then press Enter Key.
5.7 Choose IEC-156 Mode & Press Enter Key
5.8 Now, press (Test) button & tester starts running as per the mode of parameter data.
5.9 As per IEC-156, after kit performs the test 6 times, the tester shows the results and then prints the result.

Note: During any stage of testing, if (Menu) key is pressed, the testing will be cancelled.

6. MEASUREMENTS AND RESULTS:

Mode : IEC-156 **Times : 06**

Test 1 : ____________________KV

Test 2 : ____________________KV

Test 3 : ____________________KV

Test 4 : ____________________KV

Test 5 : ____________________KV

Test 6 : ____________________KV

Average: ________________KV

8. RESULT & CONCLUSIONS:

- Dielectric breakdown voltage is a measurement of electrical strength that insulation oil can with stand without failure.

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EXPERIMENT NO - 08

MEASUREMENT OF PARTIAL DISCHARGE USING PD TEST SET

CONTENTS:

1. Objectives: 58
2. Equipment's required: 58
3. Expected outcome of experiment: 58
4. Theory: 58
5. Methodology for measurements: 60
6. Measurements and results: 61

1. OBJECTIVE:

- Measurement of Partial Discharge Using PD Test Set

2. EQUIPMENT REQUIRED:

PD test set have the following components:

- Amplifier Unit
- Gating Unit
- Discharge Magnitude Meter
- Calibrator 700 CRL
- Display Unit
- Time Base Generator
- Voltmeter
- Input Units
- Step Wave Generator

3. EXPECTED OUTCOME OF EXPERIMENT:

After completing the experiment student will know about:

- The partial discharge measurement
- The dielectric condition of high voltage equipment can be evaluated.

4. THEORY:

Introduction:

Partial discharge (PD) usually begins within voids, cracks, or inclusions within a solid dielectric, at conductor-dielectric interfaces within solid or liquid dielectrics, or in bubbles within liquid dielectrics. Since PDs are limited to only a portion of the insulation, the discharges only partially bridge the distance between electrodes. PD can also occur along the boundary between different insulating materials. Partial discharges within an insulating material are usually initiated within gas-filled voids within the dielectric. Because the dielectric constant of the void is considerably less than the surrounding dielectric, the electric field across the void is significantly higher than that across an equivalent distance of dielectric. If the voltage stress across the void is increased above the Corona Inception Voltage (CIV) for the gas within the void, PD activity will start within the void.

PD can also occur along the surface of solid insulating materials if the surface tangential electric field is high enough to cause a breakdown along the insulator surface. This phenomenon commonly manifests itself on overhead line insulators, particularly on contaminated insulators during days of high humidity. Overhead lines use air as their insulation medium.

The discharge detector is designed for use on both routine discharge testing and diagnostic testing. A discharge magnitude meter which gives a reading of the peak magnitude of the discharge. A gating unit which allows meaning full discharge magnitudes meter reading is to be taken in the presence of persistent electrical interference. A visual display is provided to show the clarity of discharge patterns. This instrument is modular in construction.

Note:

4.3 If voltmeter is not available then we cannot connect input to voltmeter measurement. For marker only 1 to 2 V AC input to voltmeter must be connected.

4.4 Mains interference normally excluded from the test circuit by connecting AC filter at the input of the control input.

4.5 System earth: all the earth connections internally of the instrument are connected to this terminal. When it is required to separate the high voltage test system earth from the mains supply earth. The link between two terminals removed and connects system earth and high voltage earth separately.

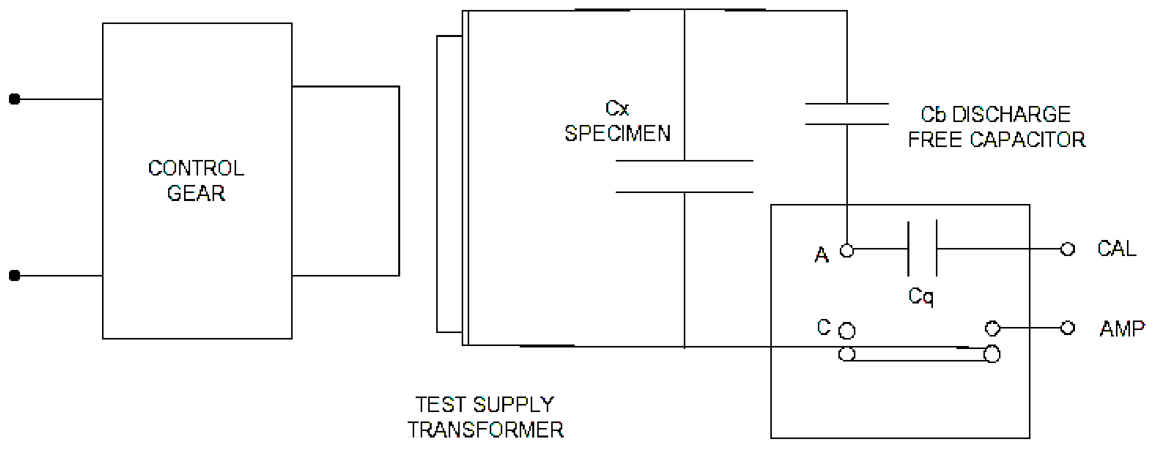

Fig: 8.1. Block Diagram of Typical Test Installation as a Standard Test Circuit

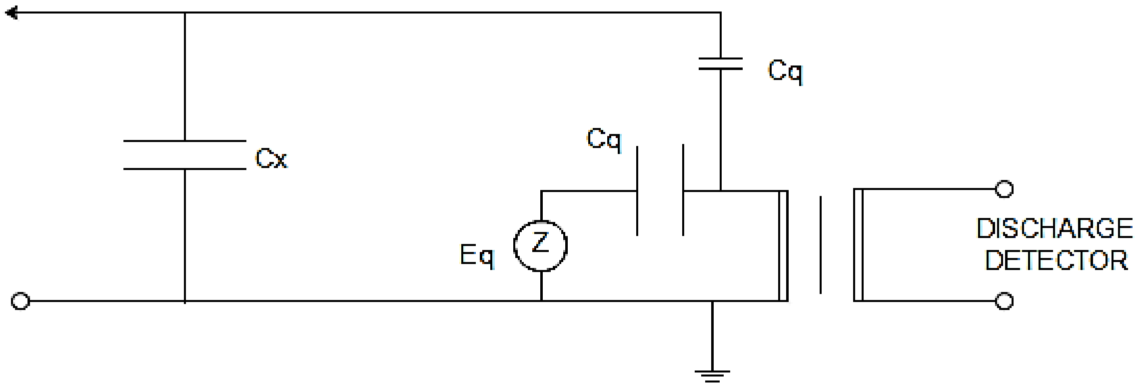

Fig.8.2 Standard Test Circuit Equivalent Circuit Diagram Given Value

5. METHODOLOGY OF MEASUREMENTS:

5.10 Set up the circuit and detector according the diagram.
5.11 Switch on discharge detector and allow 30 seconds to warm-up.
5.12 Set the amplifier gain to maximum, adjust brilliance and focus as required. Check the circuit noise is visible and pulses seen at about 0.5cm magnitude on the trace.
5.13 Switch on step-wave generator and note the pulses appear on the trace.
5.14 Switch on marker wave supply.
5.15 Select the voltmeter range.
5.16 Ensure minimum voltage of the regulator at initial stage, than start increasing, when test voltage reaches the ionization inception level of the specimen, pulses will appear on the trace. A check should be made to ensure that, these pulses are due to discharge occurring in the specimen and not in the termination.
5.17 The type of discharge should be identified as:
  a) The ellipse always written in clockwise direction.
  b) The marker always occurs at the zeros of the test voltage waveform.
  c) The negative marker pulse indicates when the test voltage is changing from positive to negative polarity.
  d) The positive marker pulse indicates when the test voltage is changing from negative to positive polarity.
5.18 Adjust the gain of discharge detector amplifier to read the pulses height not more than 15mm. the collapse ellipse switch may be operated to facilitate this comparison.
5.19 Measure the magnitude of discharges by the help of calculator. The calculator gives the accuracy of about ±10%.
  a) Take attenuator reading for which the amplitude of the calibration of the step wave corresponding to the amplitude of the discharge pulse.

b) Using the calculator, set the input unit number (or the value of the calibrator capacitance) against the attenuation of the calibration of the step wave in db.

c) Calculate the value of the ratio of specimen capacitance (C_x) to the blocking capacitance (C_b).

d) Read the discharge magnitude on the inner scale against the value of $\frac{C_b}{C_x}$.

Note: a more accurate value can be obtained by using the formula, appropriate to the test circuit being used and then calculate the discharge magnitude from the step wave voltage and circuit parameter.

Test circuit load = $C_x + C_b$

Discharge magnitude, $Q_z = E_q C_q \left(1+\frac{C_x}{C_b}\right)$

For maximum sensitivity: $C_b >> C_x$

6. MEASUREMENTS AND RESULTS:

Sr. No	Type of Equipment	Rating of Equipment	PD Values

****