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High Voltage

LABORATORY

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High Voltage Engineering

1. Introduction

The need for electrical power is increasing throughout the world and in many countries (both developed and developing) the demand is doubling every five to ten years. So to say, the electricity has come to play an important role in the life of individuals and nations, as the economic prosperity depends upon the use of electricity and fact, the number of units per capita has become the yard stick to measure the prosperity of a nation. The rising demand for electricity has got to be satisfied; but it is presenting unusual problems to the power engineer. In many countries all the promising hydro and thermal sites near load centers have been developed and utilized. Demand for electricity has reaches huge proportions and power systems are becoming more and more complex.

In the world today many AC Extra High Voltage (EHV) lines are in operation.

The network has various voltage levels for generation, transmission, distribution, utilization, control and protection.

1.1 Classification

- Generation is at voltage up to 30 KV AC rms (Line to line). This is due to design limitations of AC generators.
- Long distance high power transmission is by EHV AC lines rated 220 KV, 400 KV, 760 KV, and 1000 KV. For longer and higher powers, higher voltages are economical and essential.
- Backbone transmission network is by EHV AC transmission lines (400 KV AC and 220 KV AC).
- Distribution is at lower AC voltages between 66 KV AC and 30 KV AC.
- Utilization is at low is up to 0.4 KV and medium voltage up to 11 KV.
- The factory sub-stations receive power at distribution voltage such as 11 KV and step it down to 400 Volt AC. Larger factories receive power at 30 KV and have internal distribution at 11 KV, to 400 volt AC.

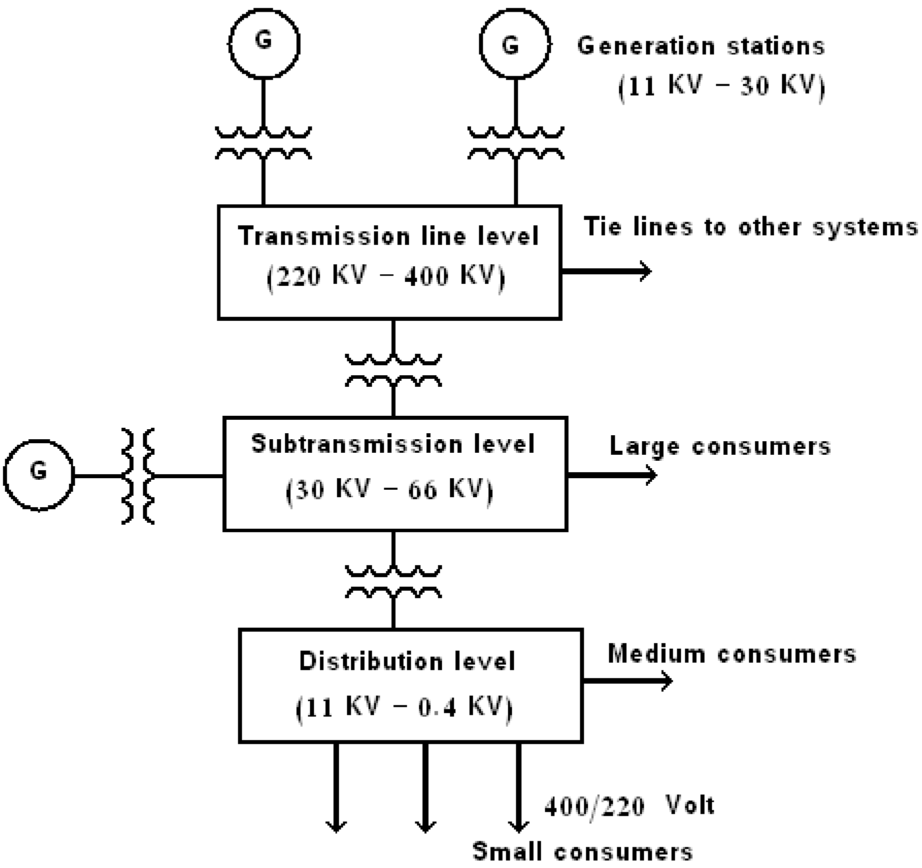

Fig.1 Schematic diagram of power system structure

1.2 Advantages of increasing Voltage

The transmission of electrical energy over greater distances was developed in the beginning of the twentieth century, since then it has made a rapid progress in its design and methods of operation which has resulted into a greater reliability and continuity.

The effect of increase of voltage on: Weight of copper used for transmission, efficiency of the line and the line voltage drop:

1) The line losses are inversely proportional to the square of the voltage and power factor.
2) For line losses remaining constant, the volume of copper used or line weight of copper used is inversely proportional to the square of the line voltage and power factor i.e. say the voltage is doubled, it will decrease the line current to half, as the line losses remaining constant same means the resistance of the line can be made four times by reducing the cross-sectional area to one quarter.

3) For constant current density the increase in voltage causes an increase in efficiency.
4) For constant current density of the conductor, the line voltage drop is independent of the line voltage and remains constant, but the increase of the line voltage decreases the percentage drop.

The increase in voltage causes saving copper losses, and increase in efficiency, but also the improved power factor decreases the copper losses, decreases the volume of copper used and increase the efficiency of the line.

2. Methods of Measuring of High Alternating Voltage (HVAC)

- ***Introduction:***

High alternating voltages can be measured in various ways:

1) by using the resistance divider
2) by using the capacitance divider by using gaps
3) by using gaps

- ***Objectives:***

The students are given the opportunity to extend their theoretical knowledge obtained in the lectures by performing high voltage experiments. Alternating voltages are required for most high-voltage tests. The investigations are performed either directly with this type of voltage, or it is used in circuit for the generation of high direct and impulse voltages. Various methods of measuring high alternating voltages are encountered in a high voltage laboratory capable of sustaining voltages up to 1.5 MV.

Caution:

High voltages are very dangerous. You should follow the instructor's directions. You should resist at all-time temptation to wander off in the laboratory to locations outside your experiment.

2.1 Gaps Measurement of High Alternating Voltage (Peak Value Measurement)

Measurement with gaps method has the advantages that:

- Very simple arrangement.
- Used for high D.C, A.C, and impulse voltage measurements (peak value).
- There are two gap types:
    1. Rod Gaps.
    2. Sphere Gaps.

The students have been studied the experiments of measuring High Alternating Voltage using sphere gaps. In this lab they will study both measurement of High Direct Voltage and Impulse Voltage as follows:

2.2 Measurement of High Direct Voltage (HVDC)

2.2.1 Objectives:

High direct voltages are necessary for testing insulation systems, for charging capacitive storage devices and many other applications in physics and technology. The topics covered in this experiment fall under the following headings:

- Rectifier characteristics
- Ripple factor
- Polarity effect
- Insulating screens

Caution:

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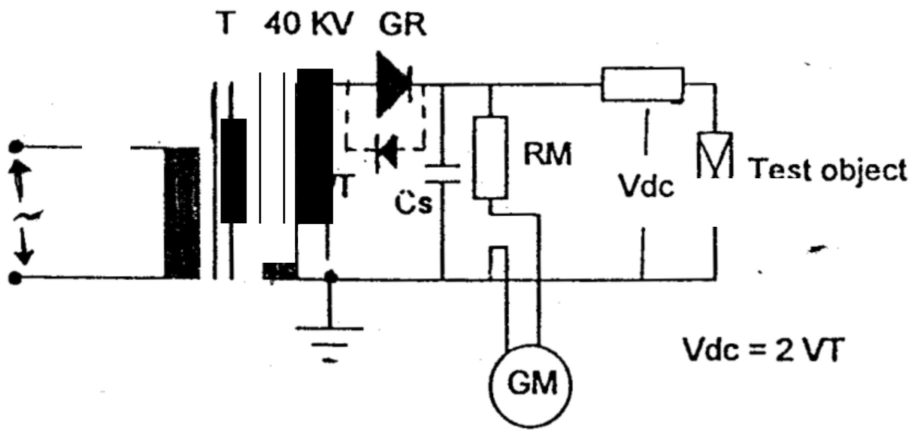
Experiment:

The following circuit elements are used repeatedly during this experiment:



T: Testing transformer, rated transformation ratio 220 V/80 kV, rated power 8 kVA.

RM: High voltage resistors.

ESV: Electrostatic voltmeters for H.V.

F: Sphere gap D = 150 mm.

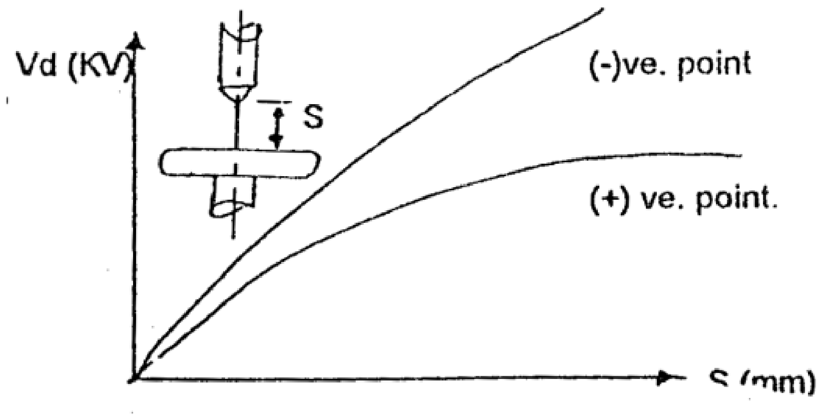
GR: Selenium rectifier, peak inverse voltage $2\times80\sqrt{2}$ kV, rated current 5 mA.

CS: Smoothing capacitor

Polarity Effect

- A point plane gap, in series with a 10 kΩ protective resistance, is connected in parallel to the measuring resistance RM.. The breakdown voltage of this spark gap should be measured for both polarities (+ve and –ve polarity) at spacing S = 10, 20, 40, 60 and 70 mm. The transformer voltage may not be measured beyond 40 kV in this experiment to avoid overloading of the rectifiers and capacitors.
- Fill results in the shown table of measurements and plot the relationship between breakdown voltage and spacing for this experiment
- Comment on results

S(mm)	*10*	*20*	*40*	*60*	*80*
D.C. Voltage (+) ve.					
Mean value					
D.C. Voltage (-) ve.					
Mean value					



2.3 Breakdown Tests of Transformer oil

2.3.1 Introduction

Of the insulating liquids petroleum mineral oils are the most common and are by far the cheapest. Of these oils, transformer oil enjoys the most extensive use and we shall discuss its chemical and electrical properties briefly. Capacitor oil is similar to transformer oil but it's subjected to a very high degree of purification. It's used to impregnate paper and polymer film for capacitors, thereby raising their permittivities and dielectric strengths and reducing their size, mass and cost. Cable oils of various kinds are used as impregnants for paper insulation and also to improve its heat-transfer ability. Transformer oil can be almost colorless to yellow liquid depending on its geographical origin. Chemically it consists of a mixture of hydrocarbons which include parafins, isoparaffins, naphthenes and aromatics. When in service the liquid in a transformer is exposed to prolonged heating at elevated temperature up to a limit of about 95°C and consequently it undergoes a gradual ageing process. The oil gets darker with time, the change in color being accompanied by the formation of acids and resins or sludge in the liquid. Some of the acids may attack the insulating material and may corrode the metal parts of the transformer. Breakdown tests are normally conducted using test cells such as oil tester. The electrodes used are usually spheres 0.5 to 1 cm in diameter & 100-200 μm. 50-100 kV.

The breakdown depends on the field, gap separation, cathode work function, temperature of the cathode, viscosity, liquid temperature and density, etc.

When breakdown occurs, the electrode surface becomes rough, and at times explosive sounds are heard due to the generation of impulsive pressure through the liquid.

Three theories explain the breakdown and they are classified as follows.

1. Suspended Particle Mechanism.
2. Cavitation and Bubble Mechanism.
3. Stressed Oil Volume Mechanism.

1) Suspended Particle Mechanism

$$F = \frac{1}{2} r^3 \frac{(\varepsilon_2 - \varepsilon_1)}{2\varepsilon_1 + \varepsilon_2} gradE^2$$

ε1: Liquid Permitivity

ε2: Permitivity of impurities

r : radius of particles (Assume spherical particles).

This force is directed towards areas of maximum stress if ε2 > ε1, and vise versa in case when ε2 < ε1. These particles become aligned due to these forces, and thus form a stable chain bridging the electrode gap causing a breakdown between the electrodes.

2) Cavitation and the Bubble Theory

This theory means that a kind of vapour bubble formed is responsible for breakdown. The following processes have been suggested to be responsible for the formation of the vapour bubbles:

a). Gas pockets at the surfaces of the electrodes.

b). Electrostatic repulsive forces between space charges which may be sufficient to overcome the surface tension.

c). Gaseous products due to the dissociation of liquid molecules by electron collisions

d). Vaporization of the liquid by corona type discharge from sharp points and irregularities on the electrode surfaces.

$$E_o = \frac{1}{\varepsilon_1 - \varepsilon_2}\left[\frac{2\pi\sigma(2\varepsilon_1 + \varepsilon_2)}{r}\left\{\frac{\pi}{4}\sqrt{\left(\frac{V_b}{2rE_o}\right)} - 1\right\}\right]^{\frac{1}{2}}$$

where

σ: Surface tension of the liquid

ε_1: Liquid Permitivity

ε_2: Permittivity of gas bubbles

r: radius of bubbles (Assume spherical bubbles).

V_b: Voltage drops in the bubble

Breakdown occurs when V_b = minimum of Paschen's curve.

3) Stressed Oil Volume Theory

Namely, the breakdown strength is determined by the "largest possible impurity". It was proposed that the electrical breakdown strength of the oil is the region, which is stressed to the maximum and by the volume of oil included in that region.

According to this theory the breakdown strength is inversely proportional to the stressed oil volume.

Evaluation of the test

All theories discussed above don't consider the dependence of breakdown strength on the gap length. They all tried to account for the maximum breakdown strength only. However, experiments showed that

$$V_b = k.d^n$$

d: gap length

k: constant

n: constant, always less than 1.

Breakdown depends on the voltage, the mode in which the voltage is applied, time of application. It may be summarized that the breakdown of oil is determined only by experimental investigations.

Test procedure:

- Put a transformer oil sample in the oil tester
- Observe for different gap spacing the oil breakdown voltage

- Determine the power law dependence between the gap spacing and the applied voltage for the oil as shown in the following tutorial example.

Tutorial Example on liquid breakdown

In an experiment for determining the breakdown strength of transformer oil, the following observations were made. Determine the power law dependence between the gap spacing and the applied voltage for the oil.

Gap Spacing (mm)	*4*	*6*	*10*	*12*
Voltage at breakdown (kV)	*90*	*140*	*210*	*255*

$$V_b = k.d^n$$

or, $$ln\ V = ln\ k + n\ ln\ d$$

$$n = \frac{\ln V - \ln k}{\ln d}$$

= Slope of the straight line as shown in Fig. E.1

= 0.947

From Fig. 2 , k = 24.5

$\therefore$ Relationship between the breakdown voltage and the gap spacing for the transformer oil studied is

$$V_b = 24.5 \times d^{0.947}$$

Where V is in kV and d is in mm.

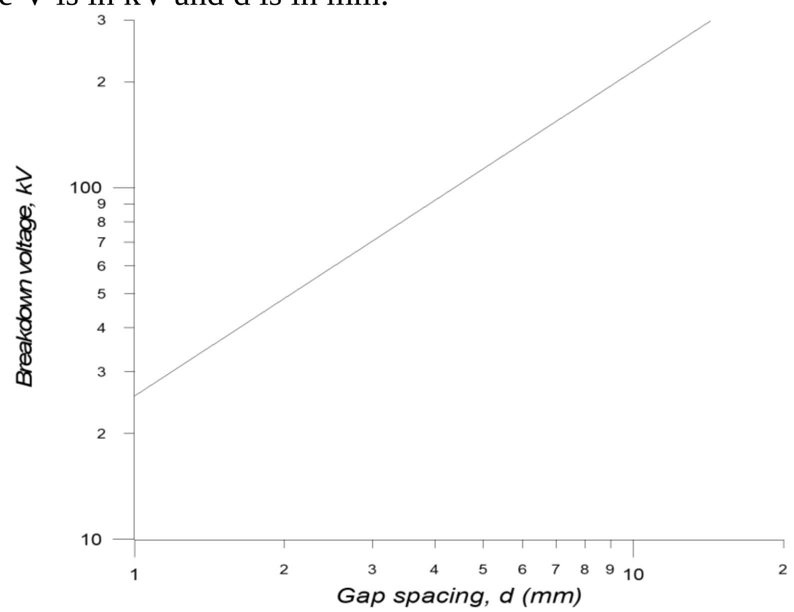


Fig.2 Breakdown voltage as a function of gap spacing.

4. Generation of Impulse Voltage

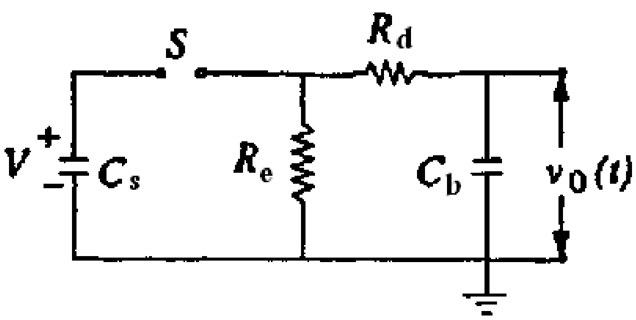
4.1 Testing with lightning impulse voltages

Lightning strokes terminating on transmission lines will induce steep rising voltages in the line and setup traveling waves along the line and may damage the system's insulation. The magnitude of these overvoltages may reach several thousand kilovolts, depending upon the insulation. Exhausts measurements and long experience have shown that lightning over voltages are characterized by short front duration, ranging from a fraction a microsecond to several tens of microseconds and then slowly decreasing to zero. The standard impulse voltage have been accepted as a periodic impulse that reaches its peak value in 1.2 µsec and then decrease (in about 50 µsec) to half its peak value.

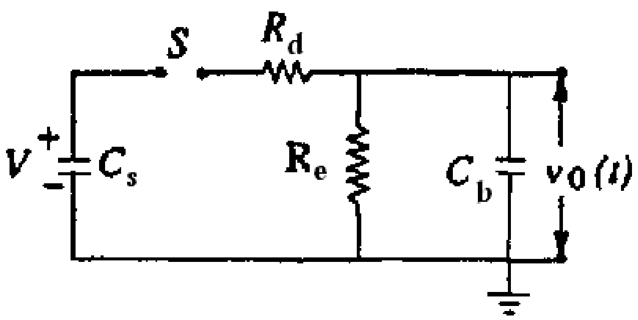
Impulse voltages are required in high-voltage tests to simulate the stresses due to external and internal over-voltages, and also for fundamental investigations of the breakdown mechanisms.

4.2 Calculation of Single-Stage Impulse Voltage Circuits:

The student must be familiar with the operation of the circuits which are required for impulse voltage generator. The most important basic circuits used for the generation of impulse voltages, denoted "circuit a" and "circuit b", are shown in Fig. 3. With the assumption that $R_e C_s >> R_d C_b$, then $\eta_{circuit\ b} >> \eta_{circuit\ a}$



Circuit a



Circuit b

The time constants T1 and T2 are linked with the characteristics of lightning impulse voltages by factors which depend upon the ratio Ts / Tr as follows:

$$T_s = k_2 \, T_2 \,, \qquad T_r = k_1 \, T_1$$

T_s / T_r	1.2/5	1.2/50	1.2/200
k_1	1.44	0.73	0.70
k_2	1.49	2.96	3.15

Test procedure:

- Prepare the impulse voltage generator to generator an impulse waveform.
- Record the output wave using the digitizing oscilloscope which is connected to the capacitance divider to measure the output wave.
- Calculate the front time and tail time of the resulting wave.
- Calculate the peak value of the output wave.
- Calculate the waveform efficiency.
- Compare the calculated and measured results
- Comment on the results.

HIPOTRONICS Impulse Generator

Components and Setting up

HIPOTRONICS Impulse Generator

Controls and Indicators

Tektronix Digitizing Oscilloscope

Connections and Operation