High voltage Engineering

Lecture contents

- High voltage DC voltage

HVDC

- Direct current voltages are used for pure scientific research work
- In industry the main application of direct voltage is in tests on cables with a relatively large capacitance which take a very large current if tested with alternating current voltages
- It may be pointed out that although the direct voltage tests are more economical and convenient, the experimentally obtained stress distribution may differ from the normal working conditions where the cable is transmitting power at low-frequency alternating voltages
- With the growing interest in high-voltage direct current transmission, an increasing number of high-voltage laboratories is being equipped with sources producing direct current at high voltages.

Voltage Doubler and Cascade Circuits

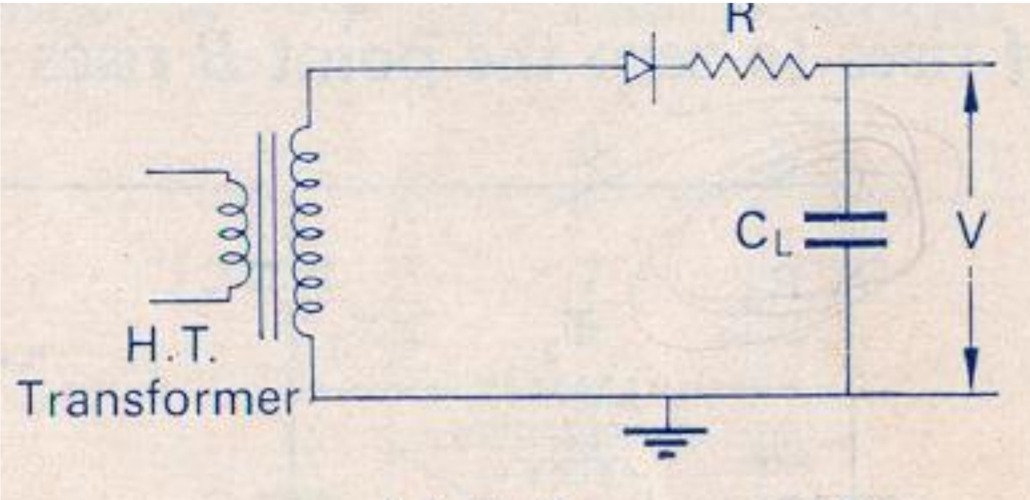
- Direct current supplies for high-voltage testing purposes are generally obtained by rectification of alternating current
- For voltages of up to about 100 kV with a relatively low current output the size of the high-voltage transformer may be considerably reduced by rectifying high-frequency currents of about 30 to 100 kc/s produced by an electronic oscillator
- This arrangement, however, introduces extra complications and most d.c. testing sets are supplied at lower frequency

- In addition to the half-wave and full-wave rectifier circuits, the two most common methods of obtaining d.c. at high voltages are:

- **(a) voltage-doubler circuit, and**
- **(b) cascade-circuit.**

- These circuits are discussed below.

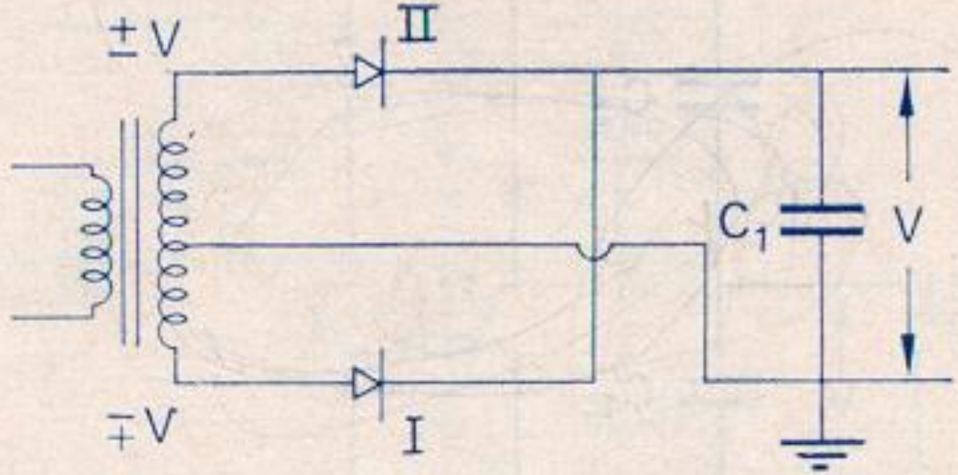
- A simple circuit for half-wave rectification is shown in **Fig (a)**
- When the rectifier conducts, the load capacitance *CL* is charged to the maximum value, *V* max' of the output voltage of the h.t. transformer.



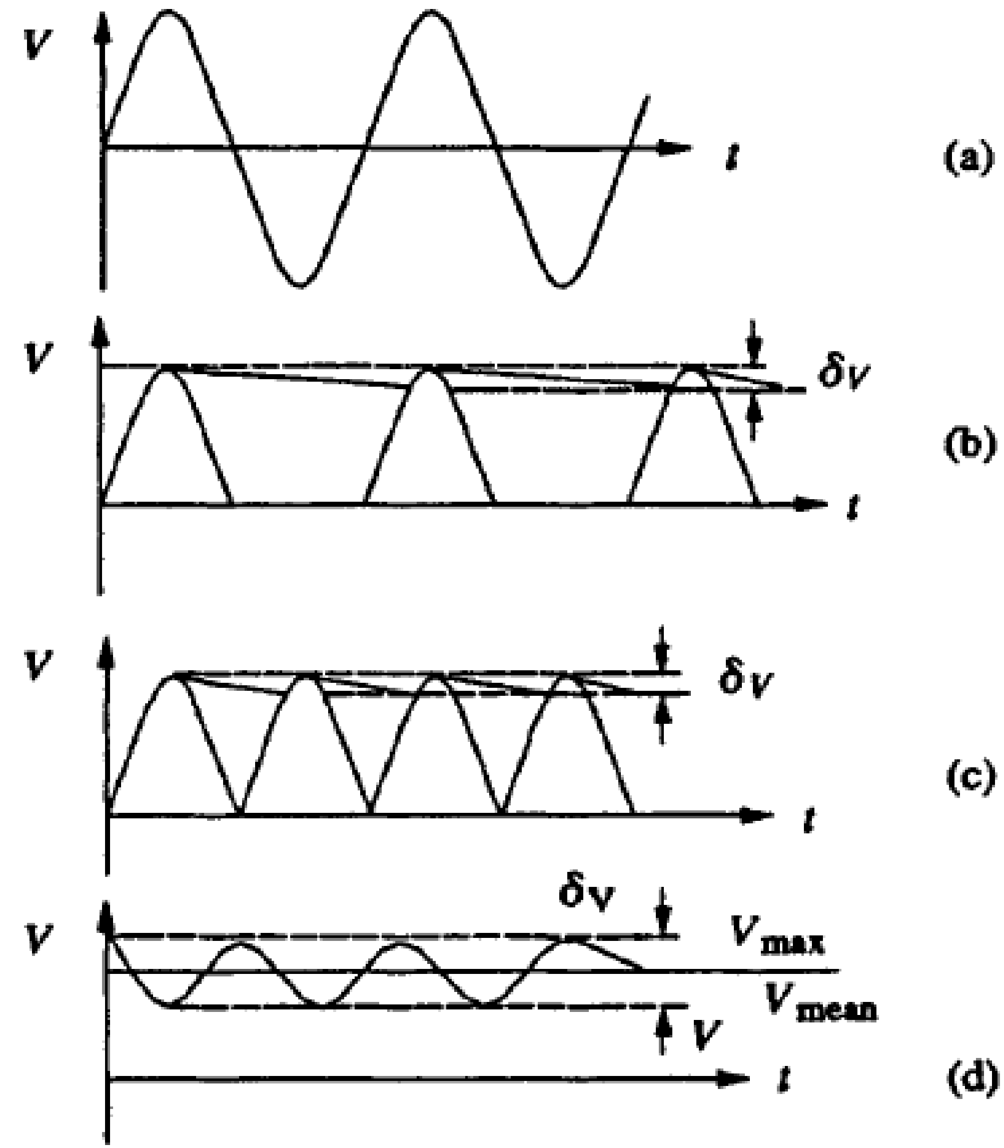
(a) Half-wave rectifier

- In the next half cycle of the alternating voltage, the voltage across C_L remains the same while the voltage of the h.t terminal of the transformer rises to a *V* max'
- The rectifier must be, therefore, designed to withstand a voltage of $2V_{max}$
- The rectifier is protected against excessive currents by the high resistance *R* inserted in the h.t circuit.

- Full-wave rectification can be obtained by using two rectifiers arranged in a manner shown in **Fig. (b)**
- During the half-cycle when the valve II conducts, the auxiliary capacitor C_1 is charged to a voltage *V* max with polarities as marked in the Figure
- During the next half-cycle, current flows through the valve I and the capacitor C_1 is charged to V_{max} with polarities as marked
- The rectifier has to withstand a voltage of 2Vmax.



(b) Full-wave rectifier



Input and output waveforms of half and full wave rectifiers

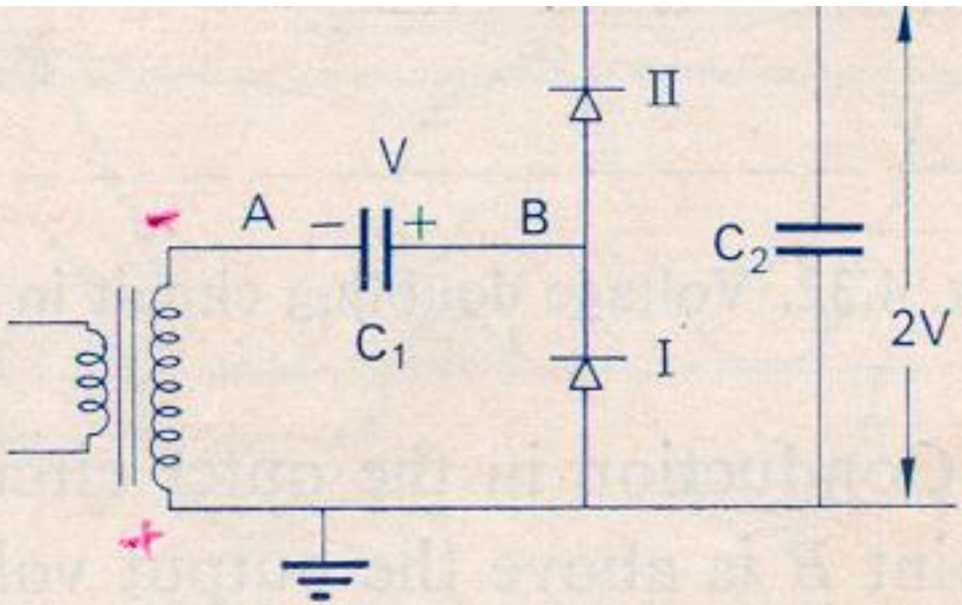
(a) Input sine wave

(b) Output with half wave rectifier and condenser filter

(c) Output with full wave rectifier and condenser filter

(d) Vmax, Vmean and ripple voltage δ *V with condenser* filter of a full wave rectifier

- **Figure 4.31(c)** shows a Cockcroft-Walton type voltage doubler
- When the point *A* is negative the capacitor C_1 charges to a voltage *V*
- As *A* rises to zero the point *B* rises to 2V.



(c) Voltage doubler

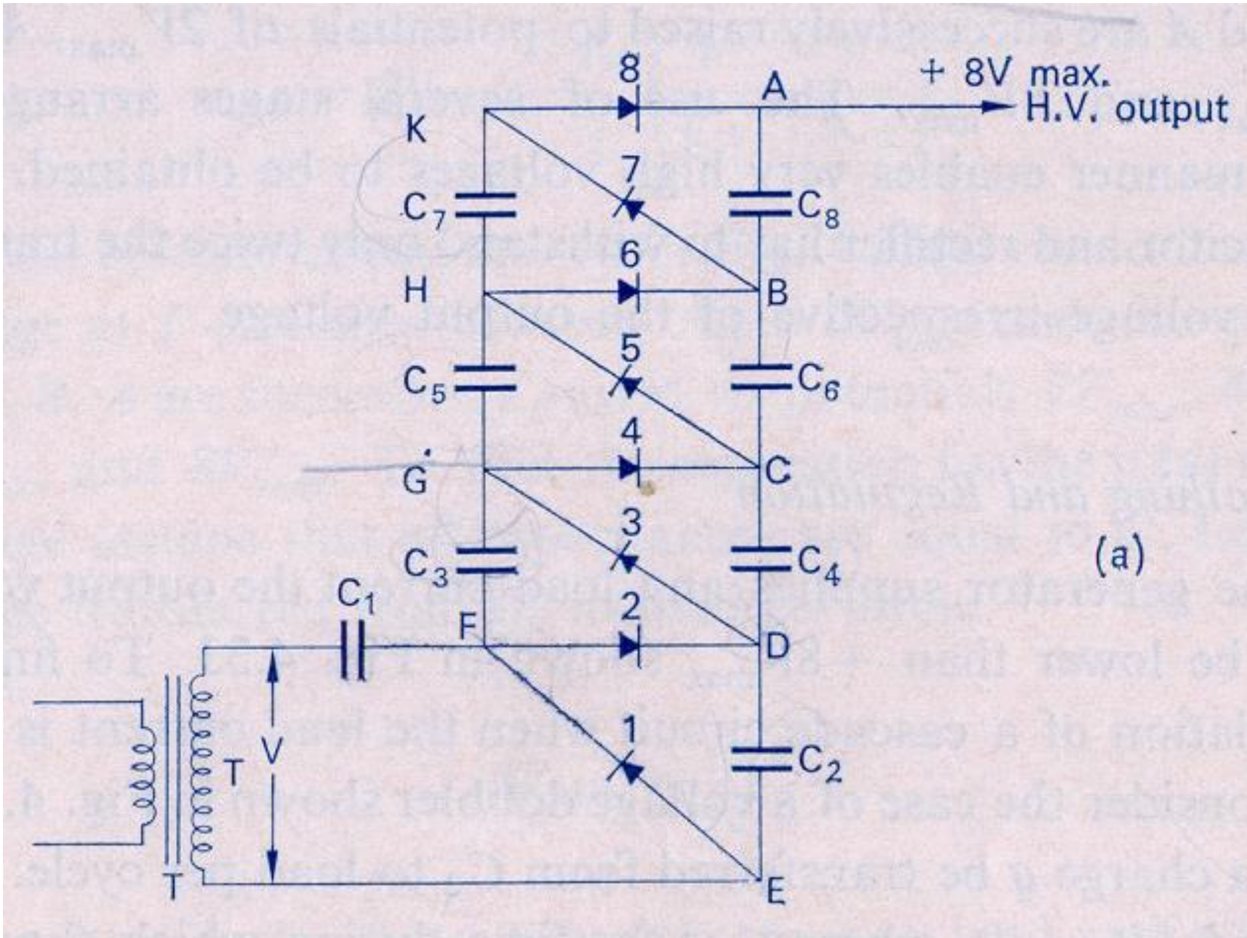
FIG. 4.31. Voltage rectifying and doubling circuits.

- Conduction in the outer circuit takes place as soon as the point *B* is above the output voltage, i.e. when *B* is more positive than *D* and charge from C_1 flows into C_2 making the no load voltage across C_2 equal to 2V
- Such circuit can be connected again in series to produce a further voltage doubling and a practical arrangement presented by Allibone is illustrated in **Fig. 4.32**
- The rectifiers R_1 to R_4 are all in series and the potential distribution across them is uniform since capacitors C_1 to C_4 are all equal
- The second h.t transformer T_2 is supplied through an isolating transformer *T.*

- The potential of G therefore oscillates between + 2V max and +4V rnax and the condenser C_4 is charged through the rectifier 4 to a voltage of +4V max
- The potential of C with respect to earth, therefore, attains a value of +4V max' The whole circuit is a cascade arrangement and the points D, C, B and A are successively raised to potentials of 2V max 4V max 6V max and 8V max
- The use of several stages arranged in this manner enables very high voltages to be obtained. Each capacitor and rectifier has to withstand only twice the transformer voltage irrespective of the output voltage.

- The principle of cascade generator using the Cockcroft Walton circuit is illustrated in **Fig**

- The portion FTE is a single-phase half-wave rectifier circuit and when the rectifier I conducts the condenser C_1 charges up to a voltage of + V max
- The potential of the point F with respect to earth therefore oscillates between zero and +2Vmax and the condenser C_2 is charged to +2V max through the rectifier 2
- The point D then attains a steady potential of + 2V max and the voltage applied to C_3 rectifier 3 therefore varies between +2Vmax and zero
- Thus C_3 is charged up to +2V max



+ 8V max.
H.V. output
A
K
8
7
6
5
4
3
2
1
C7
C8
H
B
C5
C6
G
C
C3
C4
C1
F
D
C2
T
V
T
E
(a)

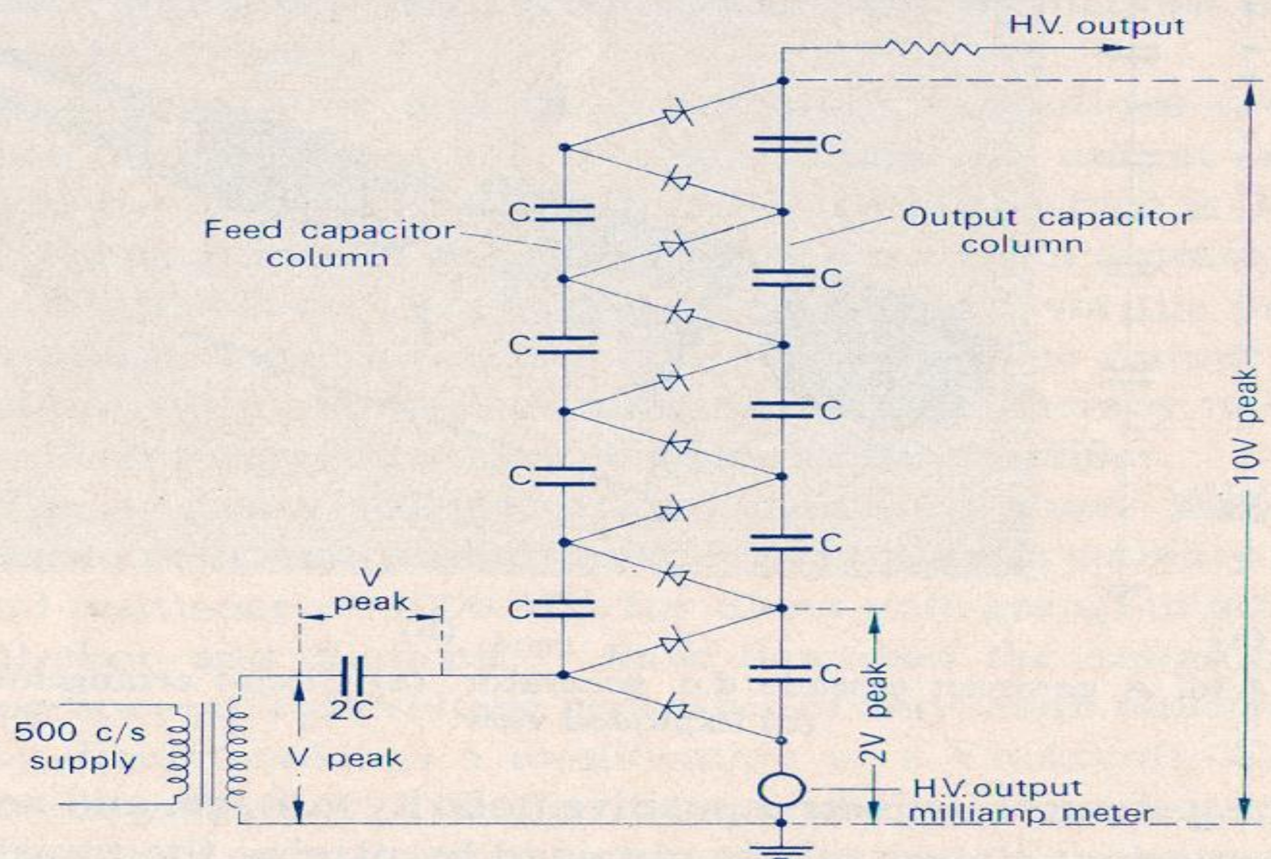


FIG. 4.37. Five-stage Cockcroft–Walton d.c. generator.

(3) Direct Voltages (HVDC)

a) Voltage Doubler and Cascade Circuits

The horizontal rectifier arms are permanently connected to the capacitor junction points on the feed capacitor column and the other ends are supported by insulated columns, so that various series-parallel arrangements of connections can be made by means of links

These insulated columns are also used to direct the flow of oil through the horizontal rectifier arms to form a closed cooling loop of rectifiers, pump and radiator.

- The output voltage of the generator is measured by a moving coil instrument connected in series with an oil-cooled resistance unit
- The output voltage is taken to the load through a protective resistor of sufficient length to withstand the full generator voltage which appears across it when the test object flashes over
- The h.v output current of the generator is measured by means of a moving-coil milli ammeter connected in the earthy end of the generator output

- The 1.2-MV generator gives an output of 900 kV when supplying a continuous load current of 30 mA
- Several types of power rectifiers have been commonly employed in high-voltage rectifier circuits
- These include hot cathode vacuum valves, hot cathode gas-filled valves, mercury pool rectifiers and solid state rectifiers.

- The particular choice depends on many properties which are of importance, such as the ability of the rectifier to withstand overload current and inverse voltage surges; the life and reliability of the rectifier, the cost of the rectifier and the auxiliary equipment, it has summarized that the important secondary properties of the rectifiers and the present trend is to use the silicon type semi-conductor rectifier in the high voltage field

- An analysis of half-wave and full wave rectifier circuit has been made by Mitchell and expressions have been derived for obtaining the circuit data in terms of the known constants of the rectifier
- The treatment was later extended to cover voltage doubler circuits and subsequently Mitchell presented a detailed analysis of the basic circuit of cascade generators from which the performance of such circuits may be obtained

- The electrostatic belt-driven generator developed by Van de Graff is in common use in several nuclear physics research laboratories
- **Fig 4.38** shows the principle of operation of such a generator
- Charge is sprayed on to an insulating moving belt by means of corona discharge points which are at about 10-100 kV *from* earth potential
- The belt (about 20 in wide) is driven at about 3000-6000 ft/min by means of a motor and the charge is conveyed to the upper end where it is removed from the belt by discharging points connected to the inside of an insulated metal electrode through which the belt passes
- The entire equipment is enclosed in an earthed metal tank.

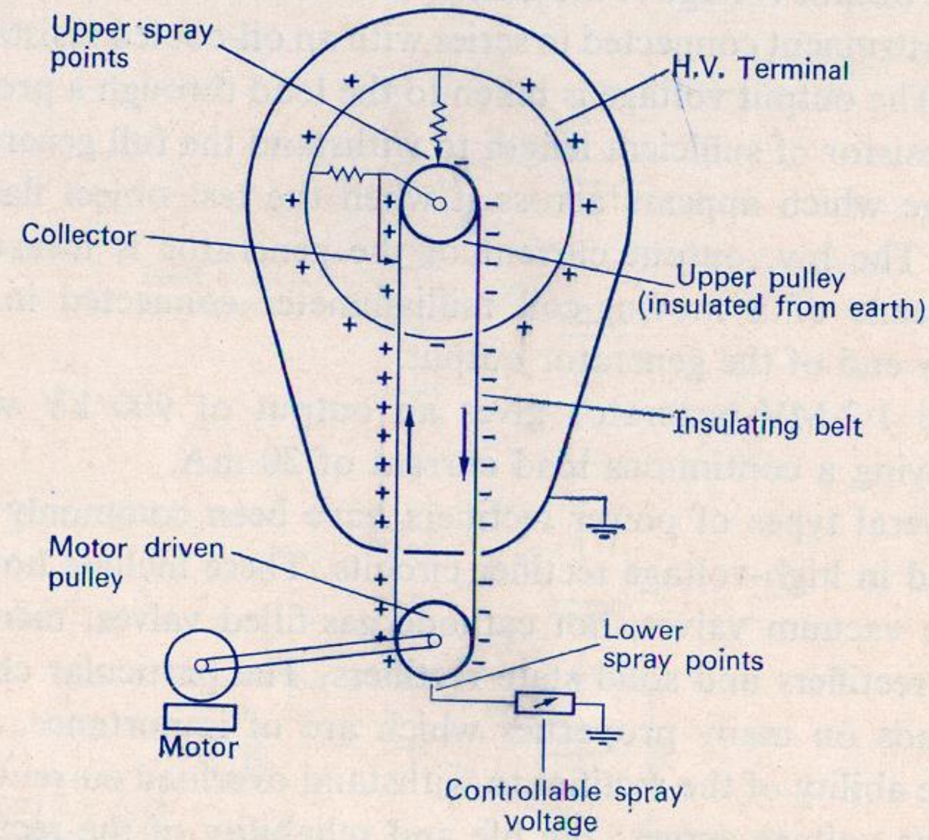


FIG. 4.38. Diagram of electrostatic belt-driven generator.

- The potential of the h.v. terminal at any instant is $V = Q/C$ above earth, where Q is the charge stored and C is the capacitance of the electrode to earth
- The potential of the terminal rises at a rate given by $dv/dt = d/dt(Q/C) = I/C$, where I *is* the net charging current to the terminal
- In *practice dv/dt* may reach a value of 1 MV/*s* and it appears that the final potential of the h.v electrode would be infinite in the absence of any mechanism of charge loss
- Equilibrium is established at a potential such that the charging current equals the discharge current which includes leakage current, corona losses and load currents due to voltage divider, X-ray or ion tubes.

- The shape of the h.v. electrode should be such that local discharges are eliminated from its surface and the field distribution between the electrode and earth is made as uniform as possible by means of suitably placed grading rings.
- The lower spray unit, shown in **Fig. 4.38,** consists of a number of needles connected to a d.c. source so that the discharge between the points and the belt is maintained
- The collector needle system is placed near the point where the belt enters the h.v. terminal.

- A self-inducing arrangement is commonly used *for* spraying on the down-going belt charges of polarity opposite to that of the h.v terminal
- The rate of charging of the terminal, *for* a given speed of the belt, is therefore doubled
- To obtain a selfcharging system, the upper pulley is connected to the collector needle and is therefore maintained at a potential higher than that of the h.v. terminal

Measurement of High Voltages

Types of Voltages to be measured

i. **A.C.H.V**
ii. **D.C.H.V**
iii. **Impulse/Transient H.V**

Measurement of High Voltages

Table: 1 High Voltage Measurement Techniques.

Type of Voltage	Method or technique
(a) d.c voltages	(i) Series resistance microammeter. (ii) Resistance potential divider. (iii) Generating voltmeter. (iv) Sphere and other spark gaps. (v) Electrostatic voltmeters.
(b) a.c voltages (Power frequency)	(i) Series impedance ammeters. (ii) Potential transformers. (iii) Potential dividers. (electromagnetic of CVT). (iv) Electrostatic Voltmeters. (V) Sphere gaps.
(c) a.c high frequency voltage, impulse voltages, and other rapidly changing voltage.	(i) potential dividers with a cathode ray oscillograph (resistive or capacitive dividers). (ii) Peak voltmeters. (iii) sphere gaps.

Measurement of High Voltages

Table: 2 High Current Measurement Techniques.

Type of current	Device or technique
(*a*) Direct currents	(*i*) Resistive shunts with milliammeter
	(*ii*) Hall effect generators
	(*iii*) Magnetic links
(*b*) Alternating currents (Power frequency)	(*i*) Resistive shunts
	(*ii*) Electromagnetic current transformers
(*c*) High frequency a.c., impulse and rapidly changing currents	(*i*) Resistive shunts
	(*ii*) Magnetic potentiometers or Rogowski coils
	(*iii*) Magnetic links
	(*iv*) Hall effect generators

Measurement of High Voltages

Summary.

i) A.C.H.V

a) Electrostatic Voltmeter.
b) Sphere gaps.
c) Uniform field Gaps.
d) Milli ammeter in Series with Resistance.
e) Series Capacitance Voltmeters.
f) Potential Dividers (resistance or Capacitance type).
g) Oscilloscope (CRO)
h) Potential Transformers.

ii) D.C.H.V

a) Electrostatic Voltmeter.
b) Sphere gaps.
c) Uniform field Gaps.
d) Series resistance microammeters
e) Resistance potential Dividers.
f) Generating Voltmeter.
g) Series Impedance Ammeter.
h) Oscilloscope (CRO)

iii) Transient / Impulses High Voltage.

a) Sphere Gaps.

b) Uniform field Gaps.

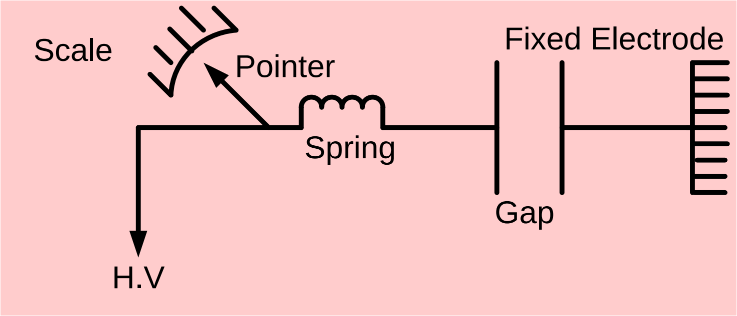
c) Oscilloscope (CRO)

d) With delay Cable

e) Potential dividers.

Measurement of High Voltages

Electrostatic Voltmeters



Voltmeter to measure AC + DC voltage, but not Impulse/Transient voltages.

The mechanical force between two charged electrodes has frequently been used for the measurement of high voltages and the attracted disc electrometer designed by Lord Kelvin is one of the first instruments based on this principle.

Next lecture

- Measurement of High voltage will be continued