High Voltage & Power System Protection– 21EE71
Module-2

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Course Module Details

Module-2a

Generation of High Voltages and Currents: Generation of High Direct Current Voltages, Generation of High Alternating Voltages, Generation of Impulse Voltages, Generation of Impulse Currents, Tripping and Control of Impulse Generators.

Introduction

- Need for HV DC Generation
- High voltage dc require for industry, medical sciences, HVDC transmission etc.

Applications of high voltage DC: Electrostatic precipitator (ESP) in thermal power plant for the ash handling unit, electrostatic paint, cement industry etc.

Applications of high voltage AC: Power transmission

Generation of High voltage DC

1. Rectifier circuits

2. Van de Graff generators

3. Cock croft- Walton type high voltage DC set

1. Rectifier circuits

- Rectifiers are the devices to convert AC to DC
- Rectifier circuits for producing high DC voltages from AC sources.

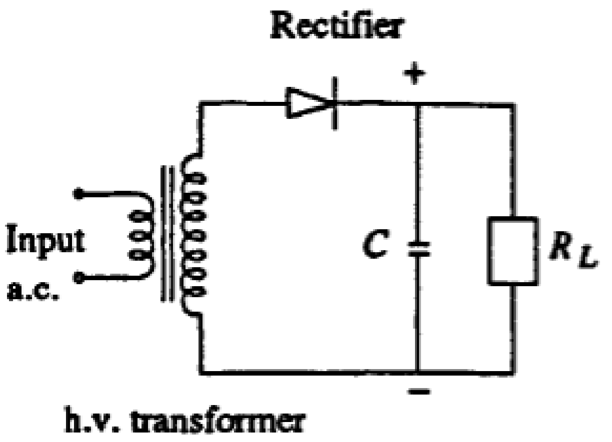
(a) Half wave rectifiers.

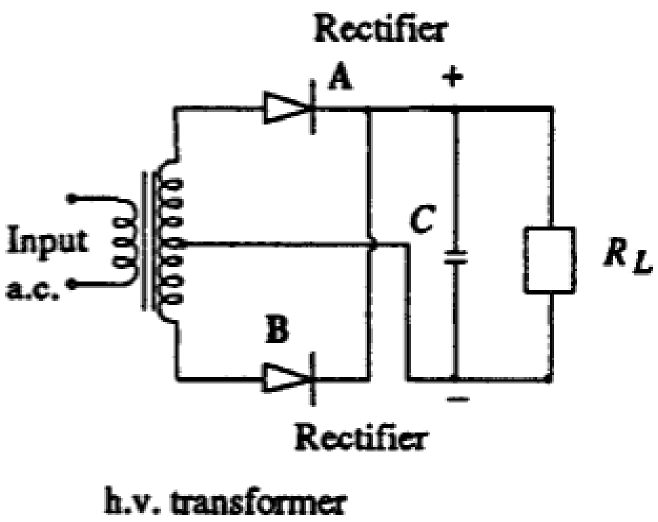
(b) Full wave rectifiers.

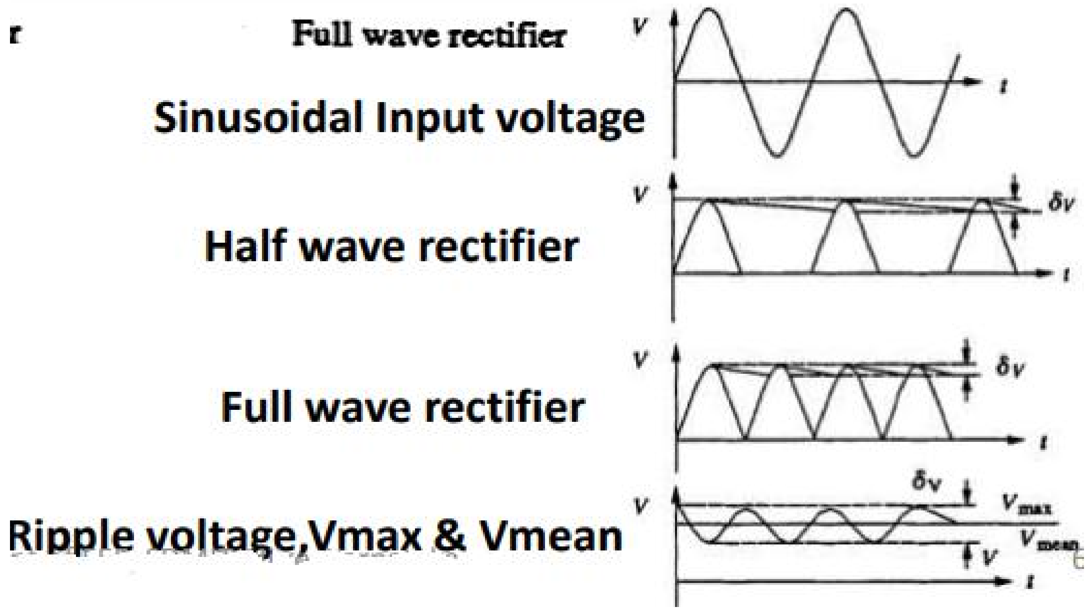
(c) Voltage doubler type rectifiers

1. Rectifier circuits

(a) Half wave rectifiers & b) Full wave rectifiers



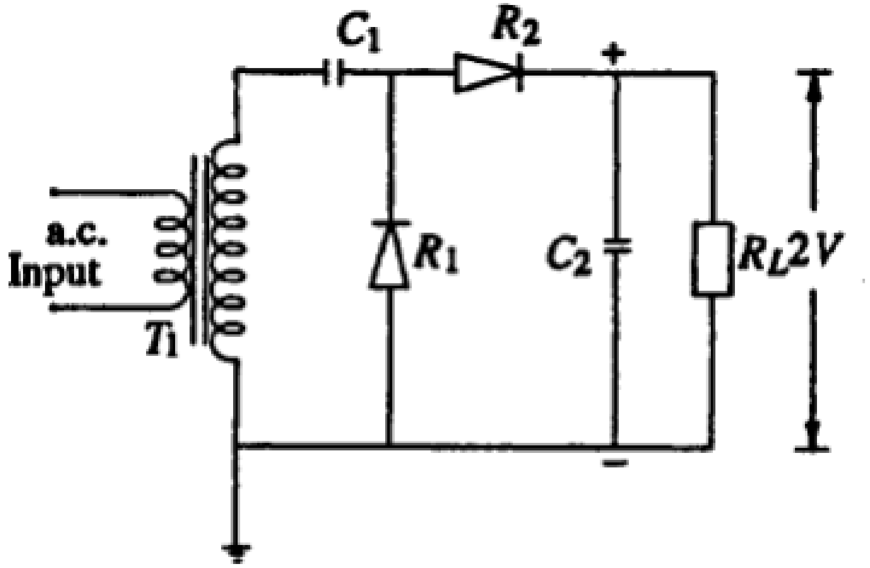




1. Rectifier circuits

c) Voltage doubler type rectifiers

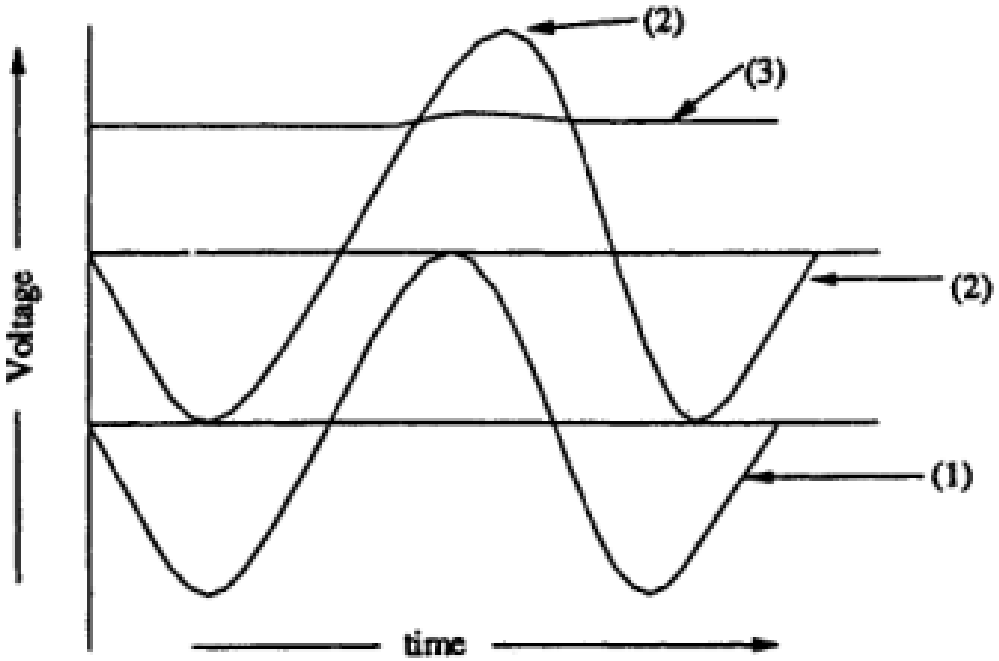
- Both half and Full wave rectifier circuits produce DC voltage less than AC Maximum voltage
- Voltage doubler is used to achieve higher DC voltages



Simple voltage doubler

1. Rectifier circuits

c) Voltage doubler type rectifiers



Waveforms of a.c. voltage and the d.c. output voltage on no-load of the voltage doubler shown in Fig

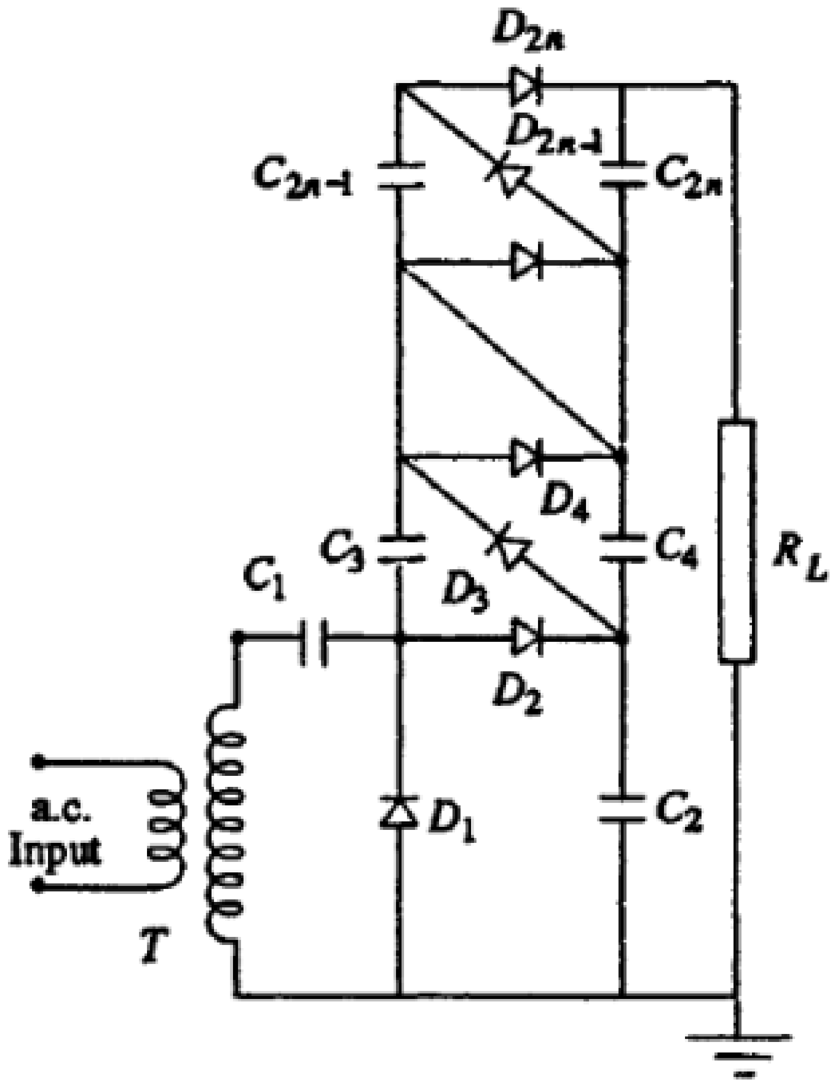
Note:

1. *AC input voltage waveform*

2.AC output voltage waveform without condenser filter

3.AC Output voltage waveform with condenser filter

Cock croft- Walton type high voltage DC set



Numerical

Q.2

An 8 stage Walton Circuit has a capacitance of 0.05μF. The secondary voltage of supply transformer is 125kV at a frequency of 150Hz.If the load current is 5mA, Solve for:

i) % Voltage Regulation

ii) % Ripple

iii) Optimum number of stages for maximum output

iv) Maximum output voltage

Numerical

Q.3

A 10 Stage Cock croft Walton circuit has all capacitors of 0.06μF. The secondary voltage of the supply transformer is 100kV at a frequency of 150Hz. If the load current is 1mA. Solve i) Percentage of Voltage regulation ii) Percentage Ripple iii) Optimum Number of Stages for maximum output voltage iv) The Maximum output voltage

Generation of HV AC Voltage

Need for Cascade transformer

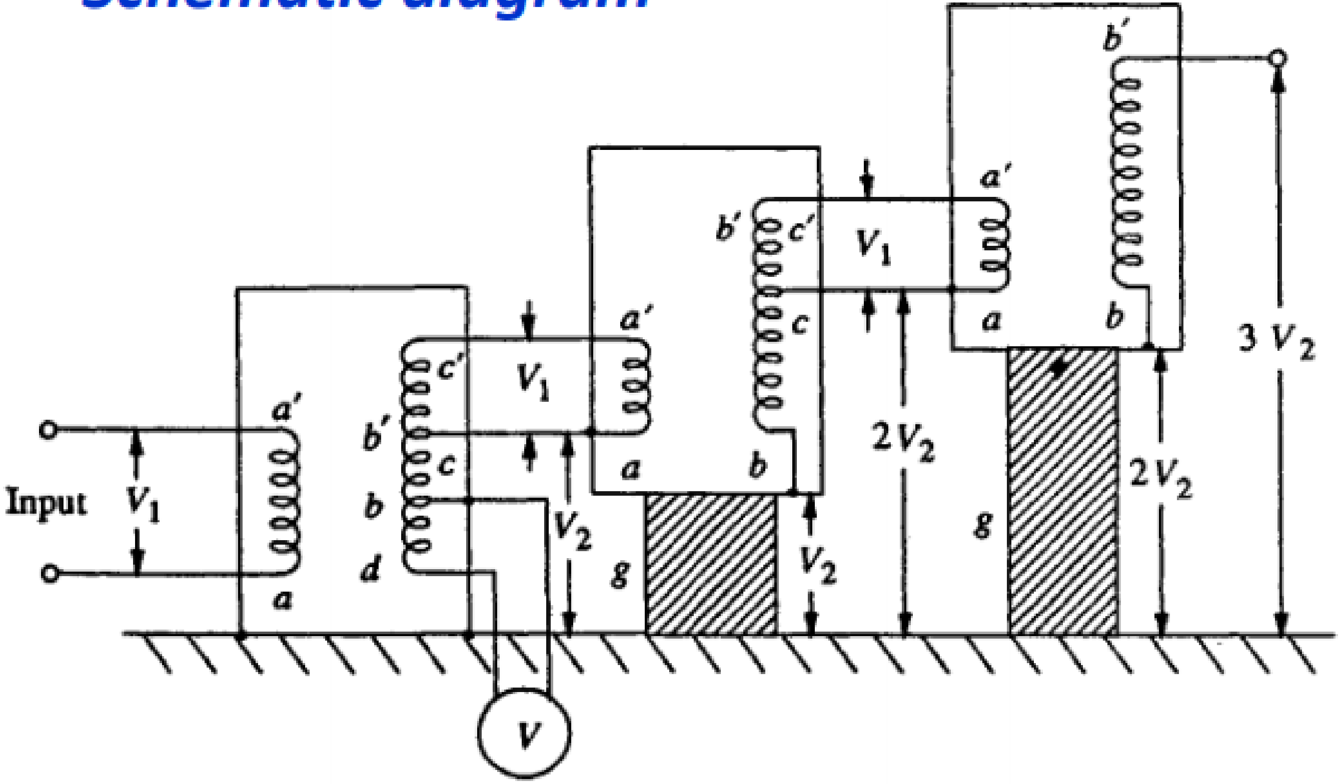
1. Single transformer can be used for the voltage requirement < 500 kV
2. For Higher voltage requirements, Single Unit construction will be difficult
3. May result in Insulation, Transportation and Errection problem and not economical

To Overcome:

1. Several Identical Transformers can be connected in series to Generate HV-AC

Cascade Transformer for HVAC Generation

Schematic diagram



V_1 — Input voltage
V_2 — Output voltage
aa' — L.V. primary winding
bb' — H.V. secondary winding
cc' — Excitation winding
bd — Meter winding (200 to 500 V)

Cascade transformer connection (schematic)

Cascade Transformer for HVAC Generation

1. The first transformer is at the ground potential along with its tank.
2. The second transformer is kept on insulators and maintained at a potential of V2, the output voltage of the first unit above the ground.
3. The high voltage winding of the first unit is connected to the tank of the second unit.
4. The low voltage winding of this unit is supplied from the excitation winding of the first transformer, which is in series with the high voltage winding of the first transformer at its high voltage end.
5. The rating of the excitation winding is almost identical to that of the primary or the low voltage winding

Cascade Transformer for HVAC Generation

- Supply to the units can be obtained from a motor-generator set or through an induction regulator for variation of the output voltage.
- Isolating transformers IS1,IS2 and IS3 & are 1:1 ratio transformers
- They are insulated to their respective tank potentials and are meant for supplying the excitation for the second and the third stages at their tank potentials
- Power supply to the isolating transformers is also fed from the same AC input

Cascade Transformer for HVAC Generation

Advantages of cascade connection

1. Natural cooling is sufficient
2. Transformers are light and compact
3. Ease of transportation & assembly
4. Either star or delta connection are possible

Draw backs

1. More space requirement and expensive

Resonant Transformers

1. Resonant transformer, an electrical component which consists of two coils with high Q factor wound on the same core with capacitors connected across the windings to make two coupled LC circuits.
2. Resonant transformer is one of the best choice for high voltage generation which operates on resonance phenomenon ($X_L = X_c$).
3. In resonance condition, the current through test object is very large and that is limited only by the resistance of the circuit.
4. The waveform of the voltage across the test object will be purely sinusoidal

Applications of Resonant Transformer:

This principle is utilized in testing at very high voltages and on occasions requiring large current outputs such as cable testing , dielectric loss measurements, partial discharge measurements, etc

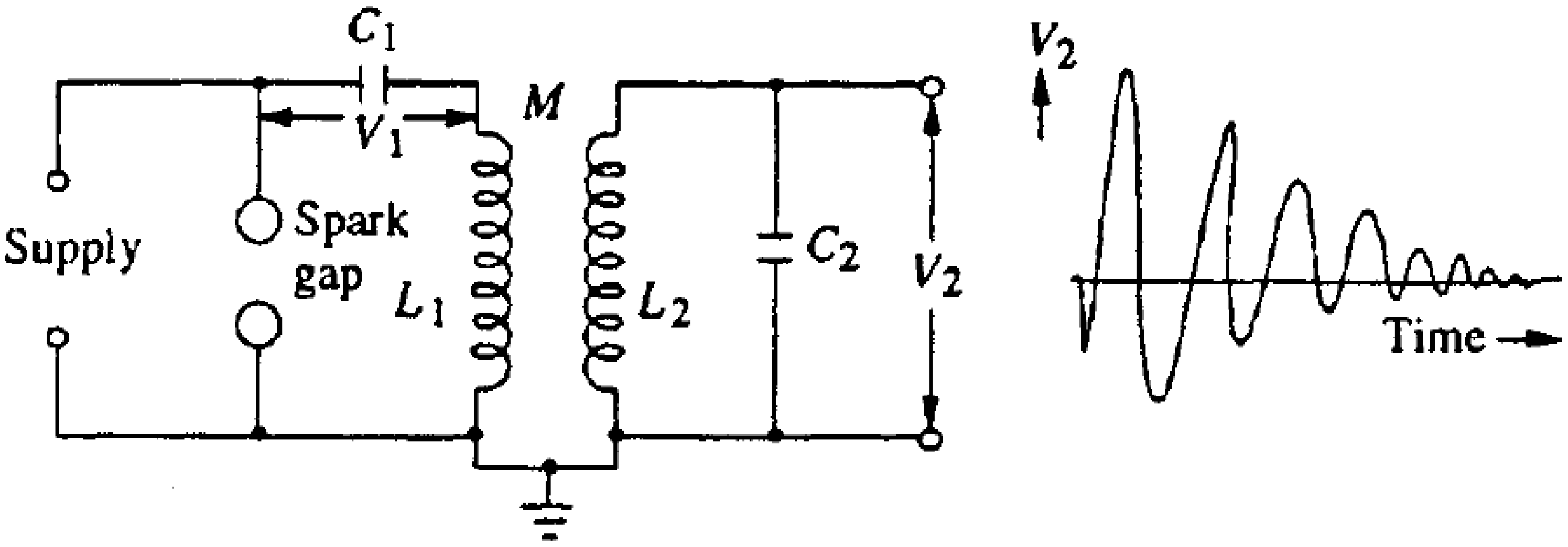
Tesla coil

1. Tesla coil is an electrical resonant transformer circuit designed by inventor Nikola Tesla.
2. It is Used to generate or produce high voltage, low current & high frequency AC power
3. High frequency transformer is required.
4. The commonly used high frequency resonant transformer is the Tesla coil.
5. Tesla coil is a doubly tuned resonant circuit.
6. The primary voltage rating is 10 kV and the secondary may be rated to as high as 500 to 1000 kV.
7. Output frequency range: 50kHz to 1 MHz.
8. Damped oscillations can be obtained by using Tesla Coil.

Applications:

1. X-ray generation, experiment in electrical Lighting etc

Tesla coil



(a) Equivalent circuit (b) Output waveform

Tesla coil

1. The primary is fed from an AC supply through the condenser C1.
2. A spark gap G connected across the primary is triggered at the desired voltage V, which induces high self excitation in the secondary.
3. Spark gap G act as a switch of the circuit.
4. The primary and the secondary windings (L1 and L2) are wound on an insulated former with no core (air-cored) and are immersed in oil. The windings are tuned to a frequency of 10 to 100 kHz by means of the condensers C1 and C2.
5. The output voltage V is a function of the parameters LI, L2, C1, C2 and the mutual inductance M.
6. Usually, the winding resistances will be small and contribute only for damping of the oscillations.

Tesla coil

1. If W1 is the energy stored in C1 and W2 is the energy transferred to C2 and if the efficiency of the transformer is η, then

$$W_1 = \frac{1}{2}\eta C_1 V_1^2 = \left(\tfrac{1}{2} C_2 V_2^2\right)$$

$$V_2 = V_1 \sqrt{\eta \frac{C_1}{C_2}}$$

Advantages of Tesla coil

•The absence of iron core in transformers and hence saving in cost and size.

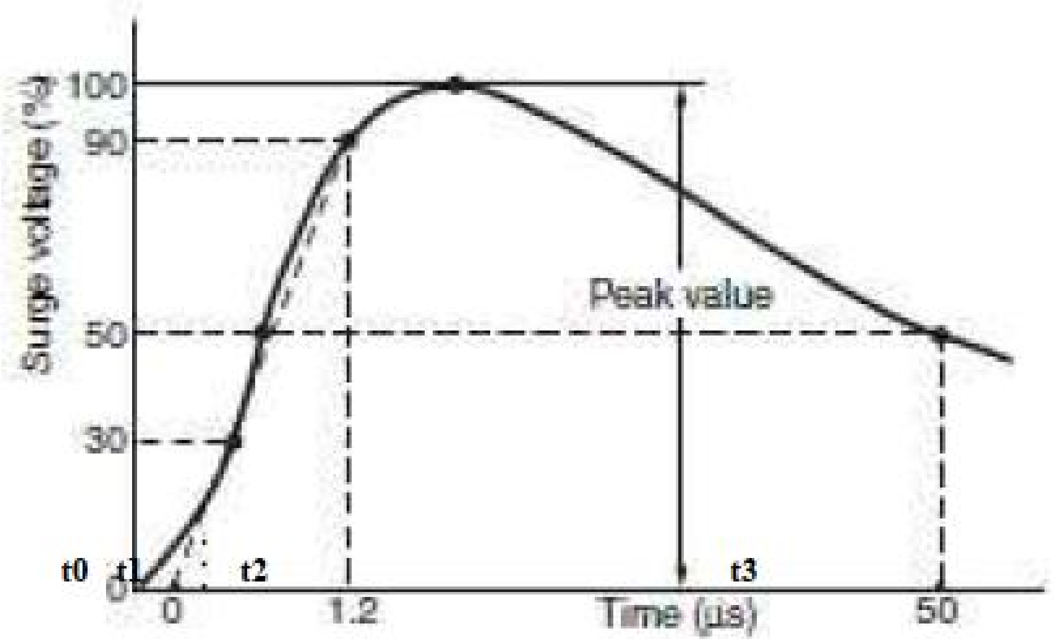
•pure sine wave output (Less wave form distortion).

• Slow build-up of voltage over a few cycles and hence no damage due to switching surges

•Uniform distribution of voltage across the winding coils due to subdivision of coil stack into a number of units.

Generation of Impulse Voltages

Standard Impulse Wave



Generation of Impulse Voltages

Impulse Generator

“An impulse generator is an electrical apparatus which produces very short high-voltage or high-current surges”

It can be classified into two types

a) Impulse voltage generators

b) Impulse current generators.

Generation of Impulse Voltages

Basic Circuit of Impulse Generator

1. Impulse generator produces high impulse voltage.
2. High impulse voltages are used to test the strength of electric power equipment against lightning and switching surges.
3. Steep-front impulse voltages are sometimes used in nuclear physics experiments.
4. High impulse currents are needed for tests on equipment such as lightning arresters.
5. Fuse testing
6. Technical applications such as lasers, thermonuclear fusion, and plasma devices.

Generation of Impulse Voltages

Impulse Generator

Classification of Impulse Voltage Generator

1. Single Stage Impulse Generator

2. Multi Stage Impulse Generator

Generation of Impulse Voltages

Basic Circuit of Impulse Generator

- Tripping and Control of Impulse Generators

- Generation of Impulse Currents

Triggering and Synchronization of the impulse Generator

Why triggering & synchronization?

- Used to Control for charging process of impulse generator
- To integrate the measuring devices.
- CRO is used for measuring and studying the effect of impulse wave on the performance of the insulation of the equipment
- Impulse waves are of shorter duration
- It is necessary that operation of the generator and the oscillograph should be synchronized accurately
- Time sweep circuit is main part of oscillograph
- The time sweep circuit of the oscillograph should be initiated at the time slightly before the impulse wave reaches the deflecting plates
- The impulse generator drives both sweep and triggering circuits

Methods of Triggering and Synchronization of Impulse Generator

1. **Three electrode gap arrangement**
2. **Trigatron gap**

1. Three electrode gap arrangement

1. This is one of the method for triggering and synchronization of impulse generator.

2. The spacing between 2 spheres is adjusted so that two series gap are able to withstand charging voltage of impulse generator.

3. Central sphere is called control sphere.

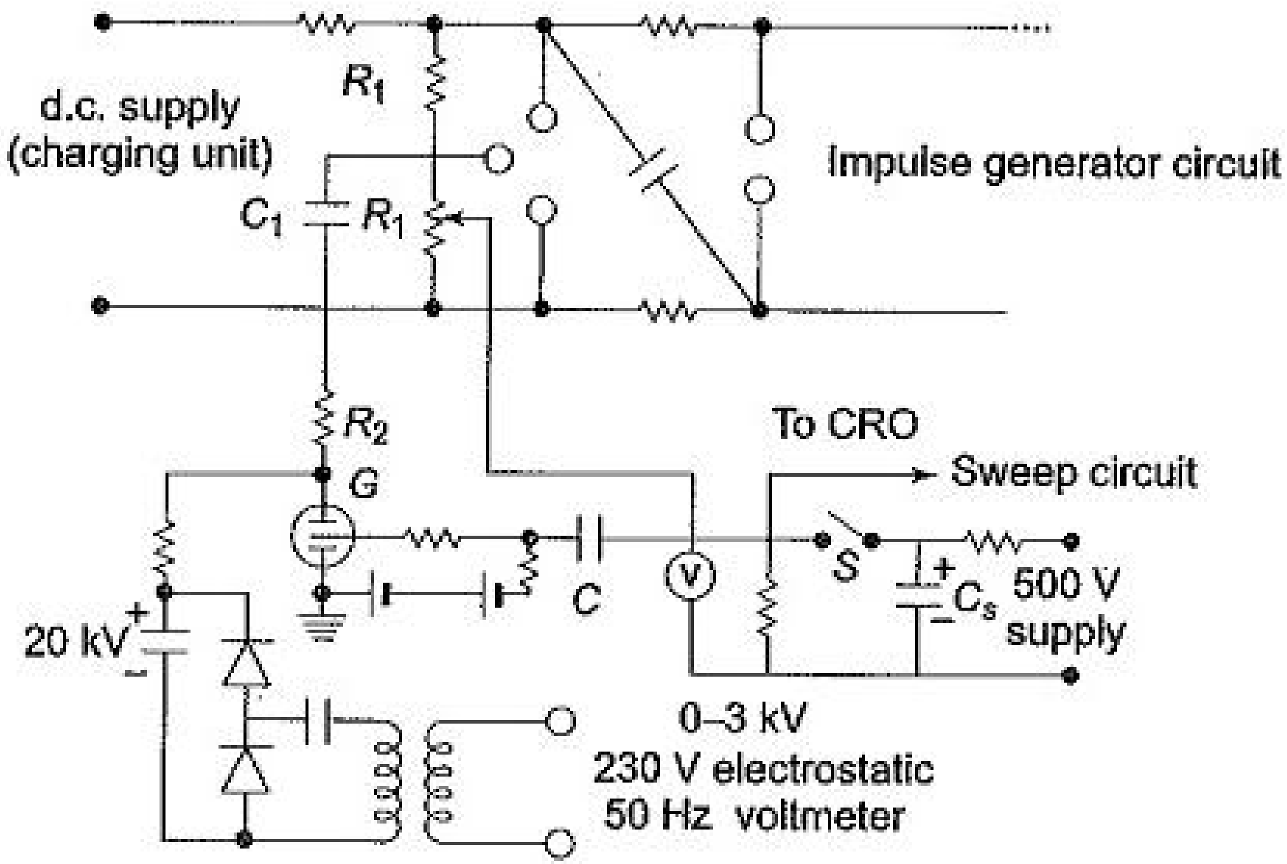
4. A high resistance is connected between the outer sphere and its junction point is connected to control sphere.

5. The voltage between outer sphere is equally divided between two sphere gap

Circuit Diagram of Three electrode gap Arrangement

Operation:

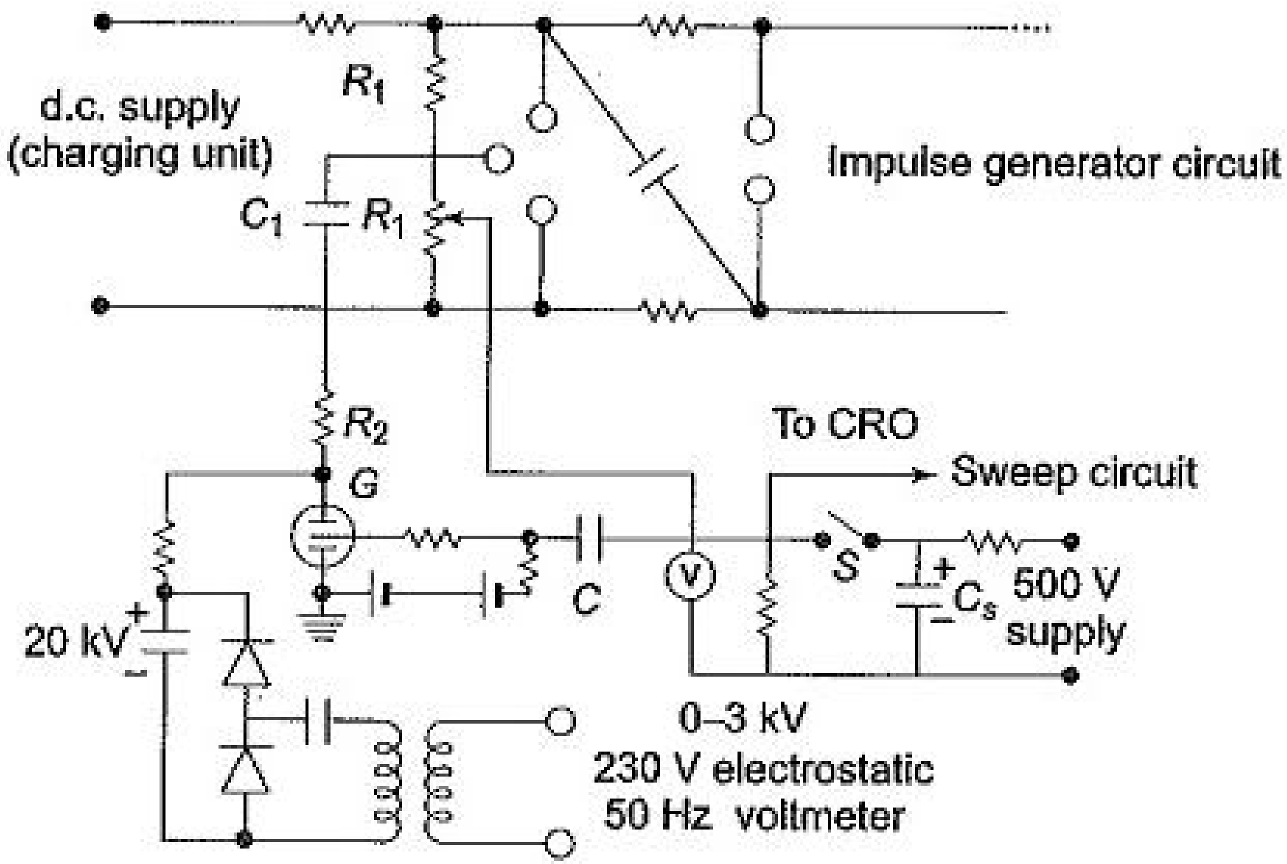
- Charging Unit (DC Supply): Provides high-voltage DC supply (20 kV in this case) for charging.
- Capacitors (C and C1): Used to store charge at high voltages.
- Resistors (R1, R2): These resistors control the rate of charging and discharge. R1 helps in the charging process, and R2 limits the current during discharge.
- Three-Electrode Gap (G): Acts as a switch that gets triggered when the voltage across it exceeds its breakdown voltage.



Circuit Diagram of Three electrode gap Arrangement

Operation:

- Impulse Generator Circuit: Generates high-voltage impulse waves, typically for testing insulation and other high-voltage components.
- CRO (Cathode Ray Oscilloscope): Used to observe the generated impulse waveform.Sweep Circuit: Synchronizes the CRO sweep with the impulse signal.
- Electrostatic Voltmeter: Measures the output voltage, typically in the range of 0-3 kV



Circuit Diagram of Three electrode gap arrangement

Operation:

1.The switch‘s’ is closed which initiate the sweep circuit of the oscillograph.

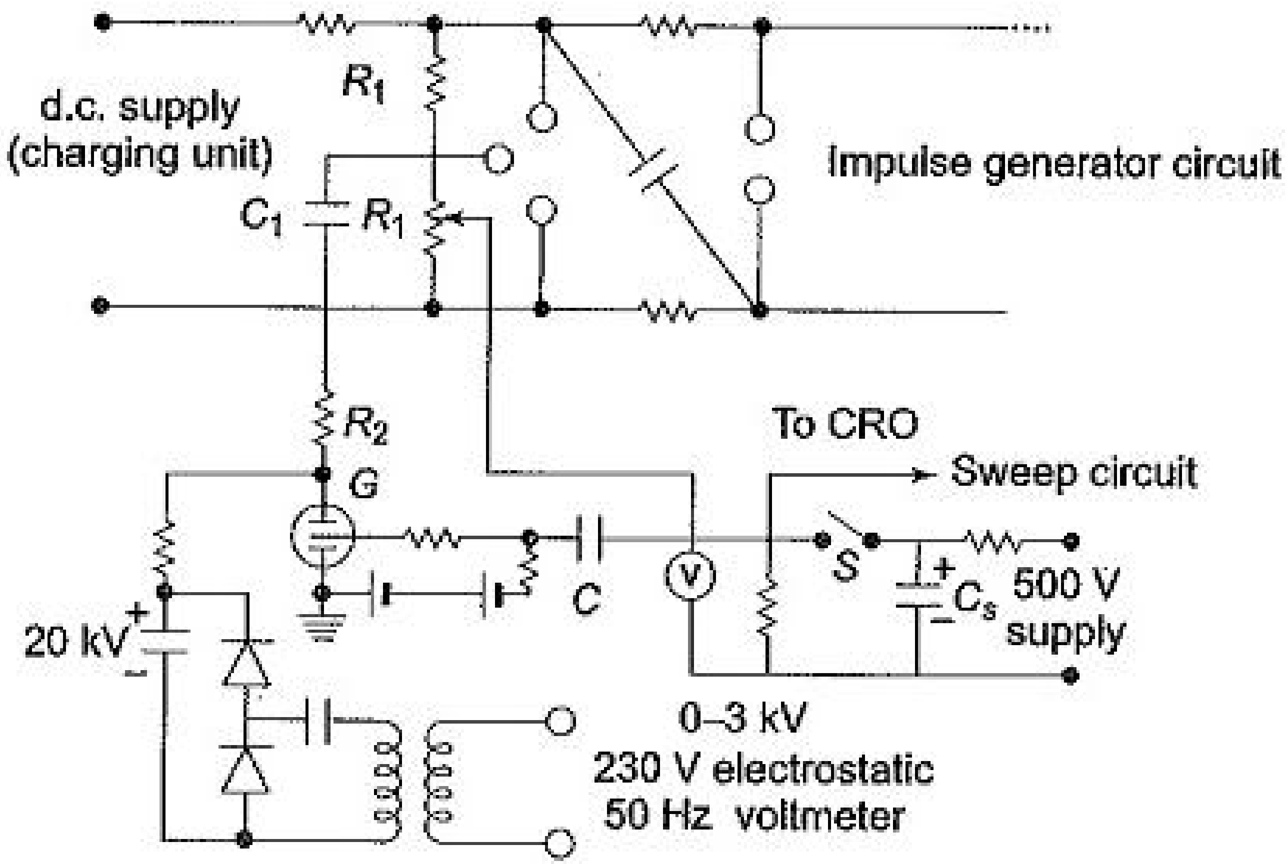
2.The same impulse is applied to the thyratron tube.

3.The inherent time delay of thyratron ensure sweep circuit operate first before the starting of high impulse wave.

4. Further delay can be created by using Capacitance-Resistance (R1C1) circuit.

5.The tripping impulse is applied through capacitor C2.

6. During charging period the voltage across thyratron is about +20kV.



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Trigatron gap

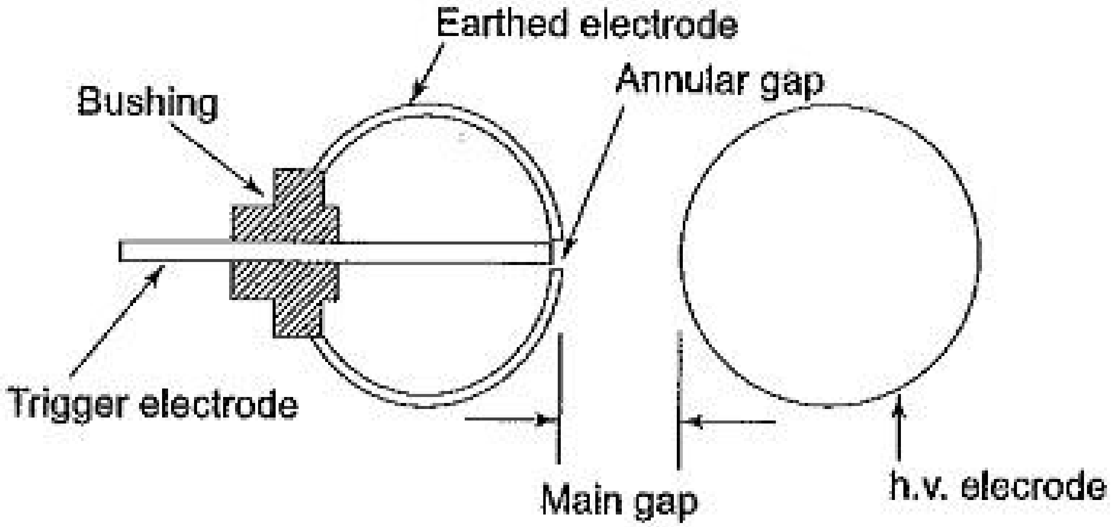
"Trigatron", is used to control the flash over at the spark gaps in order to get a desired magnitude of the output voltage repeatedly.

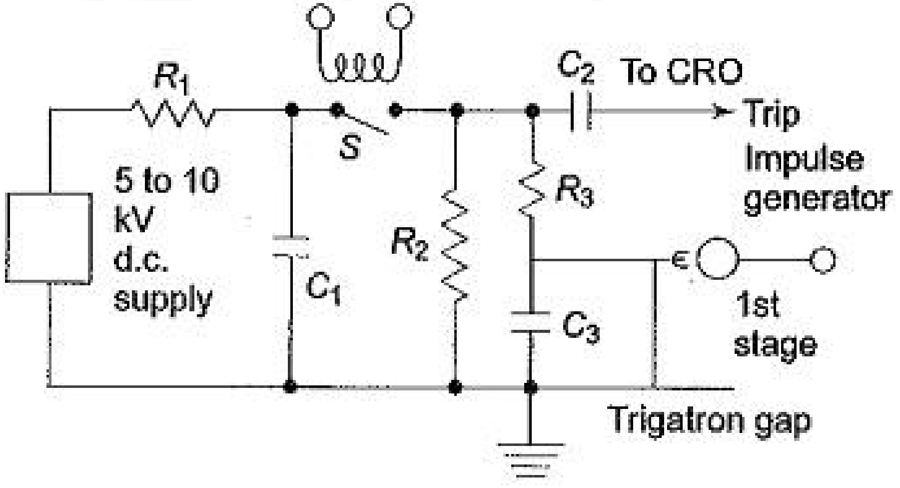
2. Used as ‘First gap of impulse generator’

3. "Trigatron", consists essentially of Earthed Electrode and Trigger Electrode

Trigatron gap

1. A small hole is drilled into earth electrode into which metal rod projects (trigger rod).
2. The annular gap between the rod and the surrounding hemisphere is 1 mm.
3. A glass tube is fitted over rod electrode.
4. The potential of metal electrode and earth electrodes are same.
5. Tripping pulse or control pulse applied between metal and earth electrodes.
6. When the tripping pulse is applied, main field is distorted results in Break down.

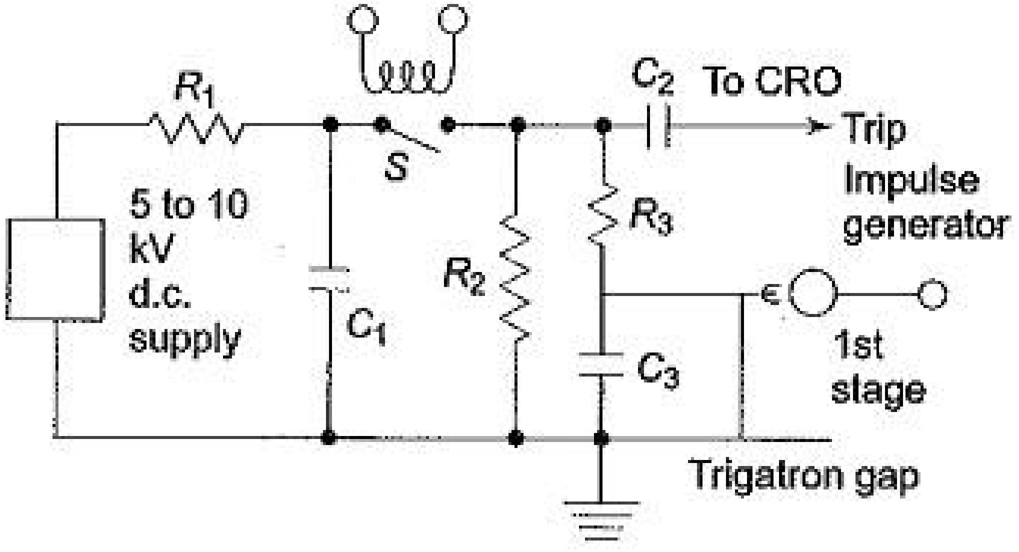




(b) Tripping circuit using a trigatron

Operation of Trigatron gap

- The *capacitor C1* is charged through *high resistance R1*
- Switch S is closed
- *A pulse is applied to a sweep circuit* of the oscillograph through the *capacitor C2*
- Same time capacitor *C3 is charged*
- Triggering pulse is applied through *trigger electrode* (metal rod electrode)
- The *requisite delay* in triggering the generator can be provide by *R3 and C3*



(b) Tripping circuit using a trigatron

THANK YOU

High Voltage Engineering – 21EE71

Module-2b

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Course Module Details

Module-2b

Measurement of High Voltages and Currents:

Measurement of High Direct Current Voltages, Measurement of High AC and Impulse Voltages, Measurement of High Currents – Direct, Alternating and Impulse, Cathode Ray Oscillographs for Impulse Voltage and Current Measurements

Objectives of Today’s Session

Measurement of High Voltages and Current

1. Generating Voltmeters

2. Measurement of High AC and Impulse Voltages

1. Series Impedance Voltmeter
2. Series Capacitance Voltmeter
3. Potential Transformer
4. Electrostatic Voltmeter

Generating Voltmeters

1. High voltage measuring device employs Generating principle

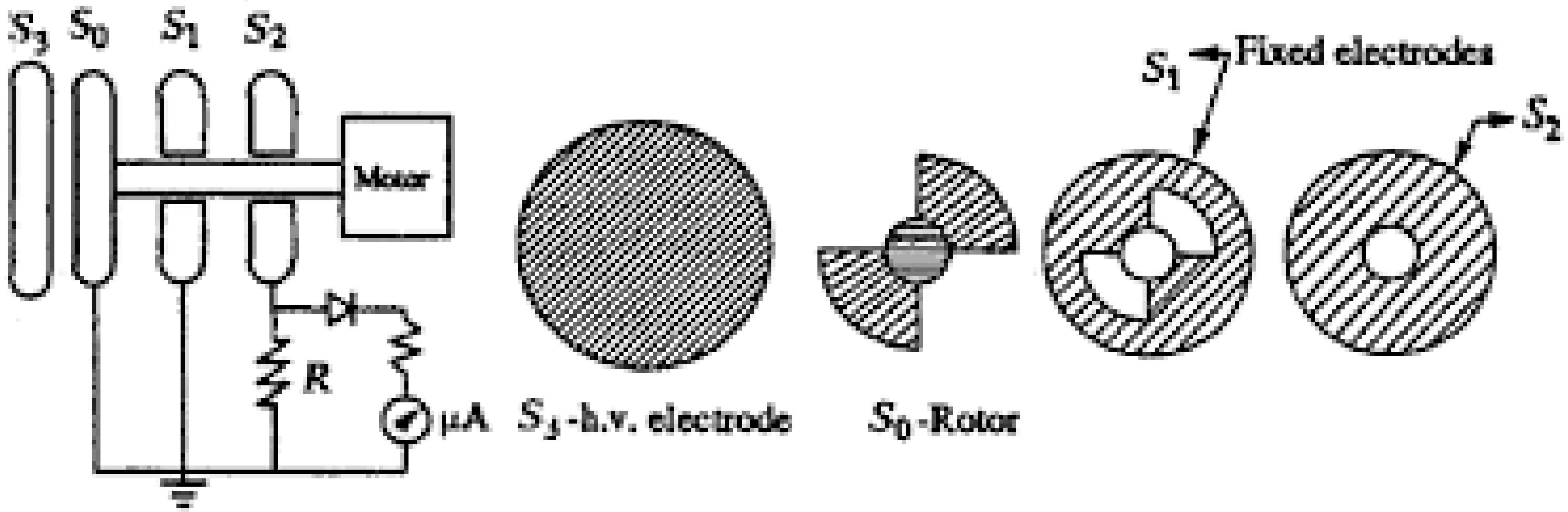
- When source loading is prohibited
- When direct connection to the HV source is to be avoided

2. Generating Voltmeter is a variable capacitor electrostatic voltage generator that generates current proportional to the applied external voltage

3. It is driven by a synchronous or constant speed motor

Generating Voltmeters: Principle of Operation

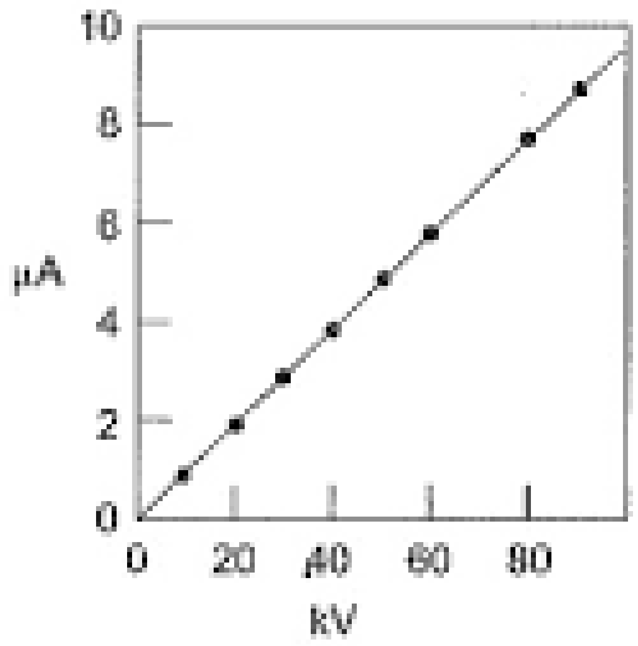
- It has a rotating cylinder consists of two exciting field electrodes S_1 and S_2 and a rotating two pole armature driven by a synchronous motor at a constant speed 'n".



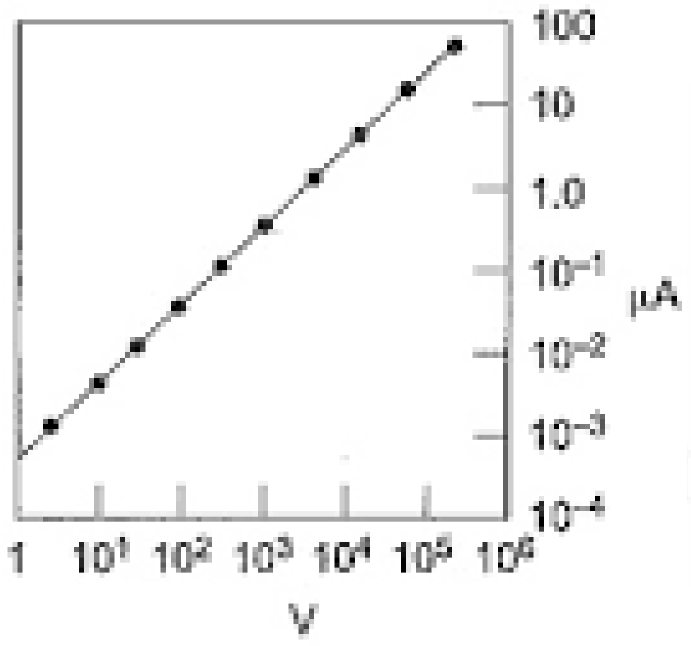
Generating Voltmeters: Principle of Operation

- High voltage source is connected to a disc electrode S_3
- S_3 is placed at fixed distance on the axis of the low voltage electrodes S_0, S_1 and S_2
- S_0 is driven at a constant speed by a synchronous motor at suitable speed i.e 1500, 3000 or 3600 rpm
- S_0, S_1 are designed to produce sinusoidal variations in the Capacitance
- Generated AC current through resistance "R" is rectified and measured through moving coil meter.
- The meter scale is linear and can be extended by extrapolation

Generating Voltmeters: Calibration Curves



(a) Rotating cylinder type



(b) Rotating vane type

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Generating Voltmeters: Principle of Operation

- Charge stored in a capacitor of Capacitance "C" is given by

$Q= CV$ ----(1)

If the Capacitance 'C' varies with time when connected to source voltage 'V' then,

$i = dq/dt$

$i = V\, dC/dt$ ---- (2)

If the 'C' varies within the limit C_0 and $C_0 + C_m$

- For a constant frequency **'ω'**, the current is proportional to the applied voltage
- The generated current is rectified and measured using moving coil meter.
- Generating Voltmeters can be used for a measurement of a.c voltage measurements

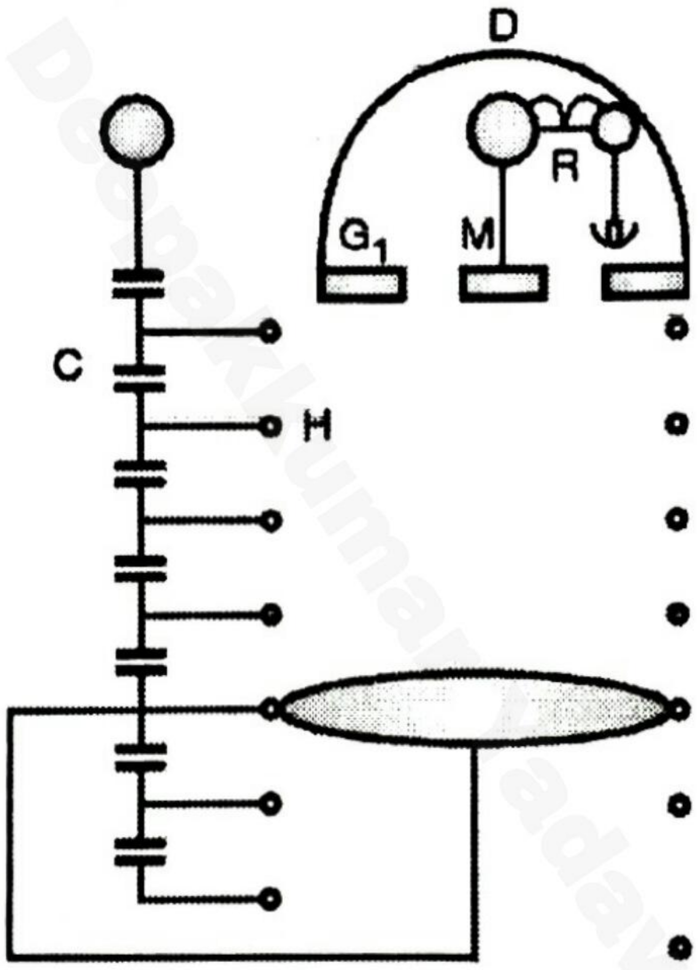
Generating Voltmeters: Advantages

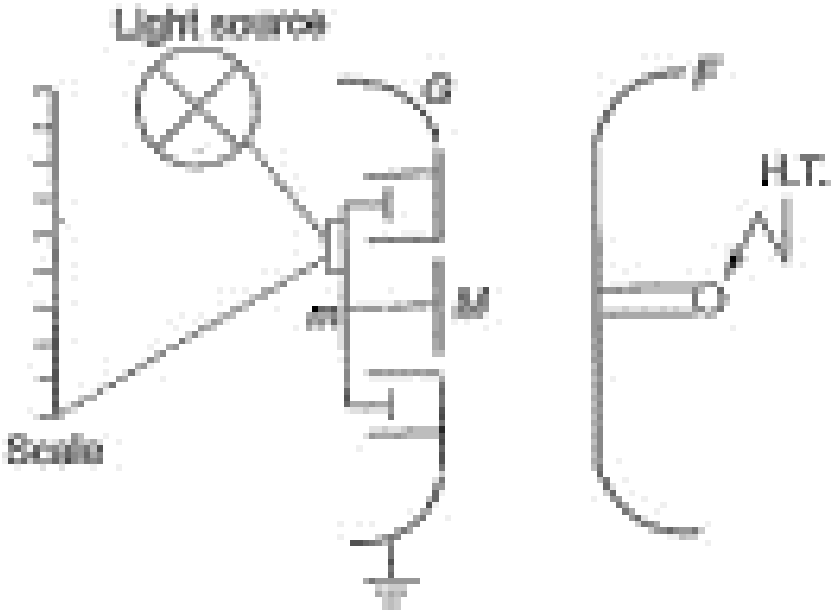
- No source loading by the meter
- No direct connection with the HV Electrode
- Linear Scale and Extension of Range is easy

Disadvantages

- Complexity in construction
- Size is large, Requires additional auxiliary drive motor
- Complexity in Calibration due to disturbance in position and mounting of electrodes

Electrostatic Voltmeter

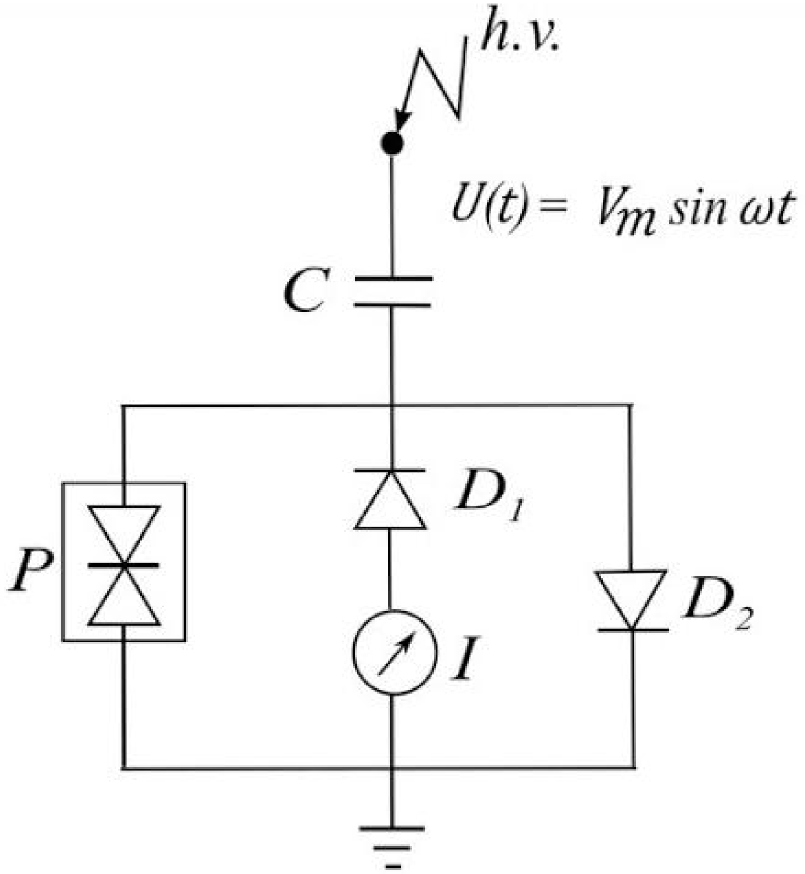


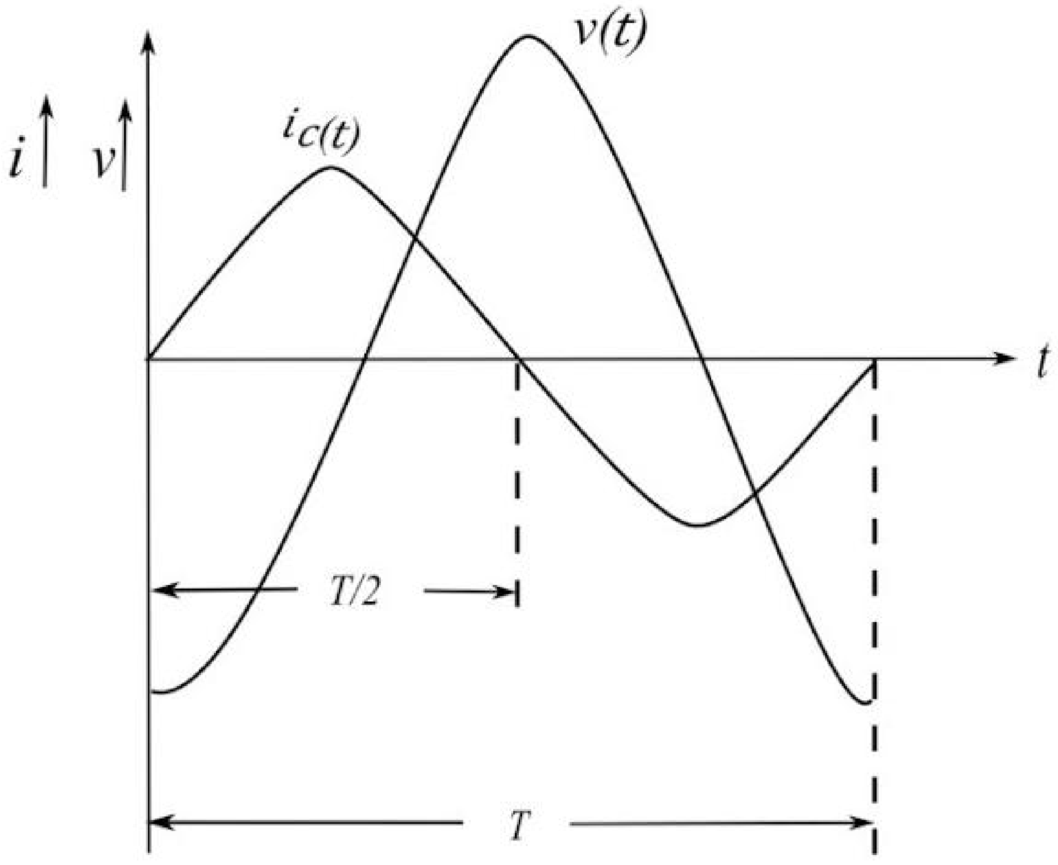


Working

- C – 5 to 50 pF and R is in 10^13 Ohms
- Control torque is provided by a balancing weight
- Moving disc ‘M’ forms central core
- Due to large space Gap, Uniformity of the electric field is maintained by Guard rings H
- H are maintained at constant potential in space by a capacitance divider.
- Safe Working stress in air : 5 kV/cm or less
- Safe Working stress in vacuum: 100 kV/cm

Peak Reading ac Voltmeter: Chubb- Fortscue Method





Peak Reading ac Voltmeter: **Digital Peak Voltmeter**

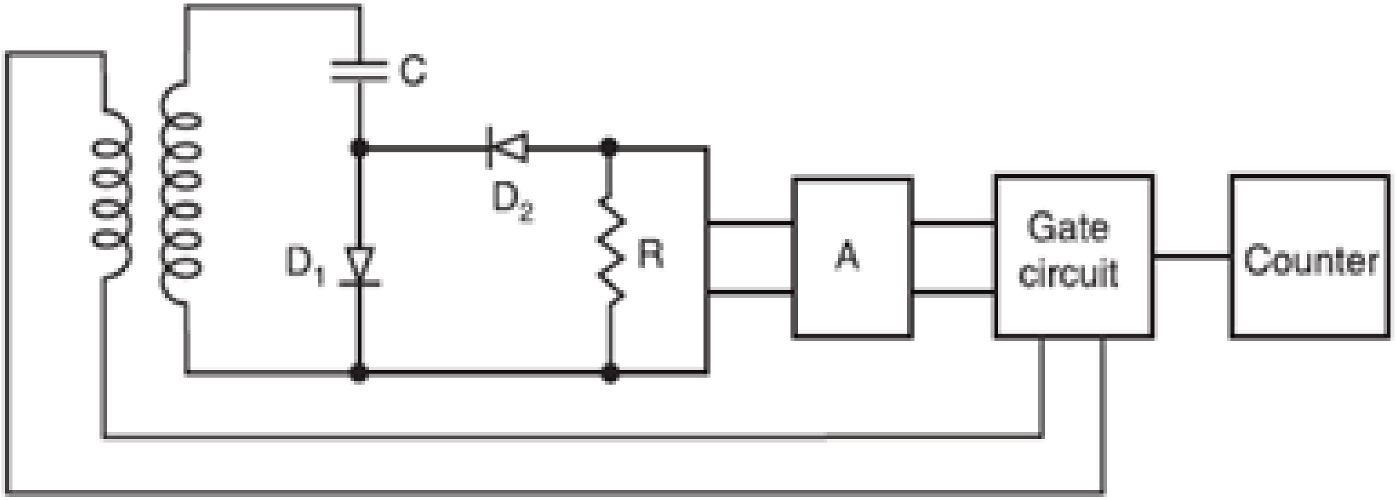


Fig: Digital Peak voltmeter

Factors influencing the Spark over voltage of Sphere Gap

1. Nearby Earthed Objects
2. Atmospheric conditions and Humidity
3. Irradiation
4. Polarity and Rise Time of voltage waveforms

Factors influencing the Spark over voltage of Sphere Gap

1. Nearby Earthed Objects

- Investigated by Kuffel
- By enclosing the earthed sphere inside an earthed cylinder
- Observations:
- Spark Over Voltage is been reduced
- Reduction found to be $\Delta V = m \log\left(\frac{B}{D}\right) + C$
- ΔV – Percentage Reduction
- B – Diameter of the earthed enclosing cylinder
- D – Diameter of the Spheres
- m, C are constants

Factors influencing the Spark over voltage of Sphere Gap

1. Nearby Earthed Objects

- $\Delta V = m \log\left(\frac{B}{D}\right) + C$
- Reduction of less than 2% for S/D ≤ 0.5 and B/D ≥ 0.8
- Reduction of up to 3% for S/D ≈1.0 and B/D ≥ 1.0
- It is observed, The reduction in voltage is within the limits if S/D is ≤ 0.6 A.
- A – Spacing b/w Sparking point to horizontal ground plane

Factors influencing the Spark over voltage of Sphere Gap

2. Effects of Atmospheric conditions

- Spark over voltages of a spark gap depends on the air density
- Varies with the changes in the Temperature and Pressure

$$V = kV_0 \text{ ----- } (1)$$

V – Spark Over voltage under test condition of temp 'T' and pressure 'P' torr

V_0 – Spark Over voltage under Standard conditions of temp T = 20^0C p = 760 torr

Where k is a function of the air density factor d, given by

$$d = \frac{p}{760}\left(\frac{293}{273+T}\right) \text{ ----- } (2)$$

- Spark over voltages increase with humidity.
- 2% to 3% increase with humidity range of 8 g/m^3 to 15 g/m^3

Factors influencing the Spark over voltage of Sphere Gap

3. Effect of Irradiation

- Illumination with UV rays and X-rays helps for easy Ionization in gaps
- Reduction of 20% in spark over voltage is observed for spacings of 0.1D to 0.3 D for a 1.3 cm sphere gap
- Irradiation is necessary for smaller gaps of Gap space < 1 cm to obtain consistent values

4. Effect of Polarity and Waveform:

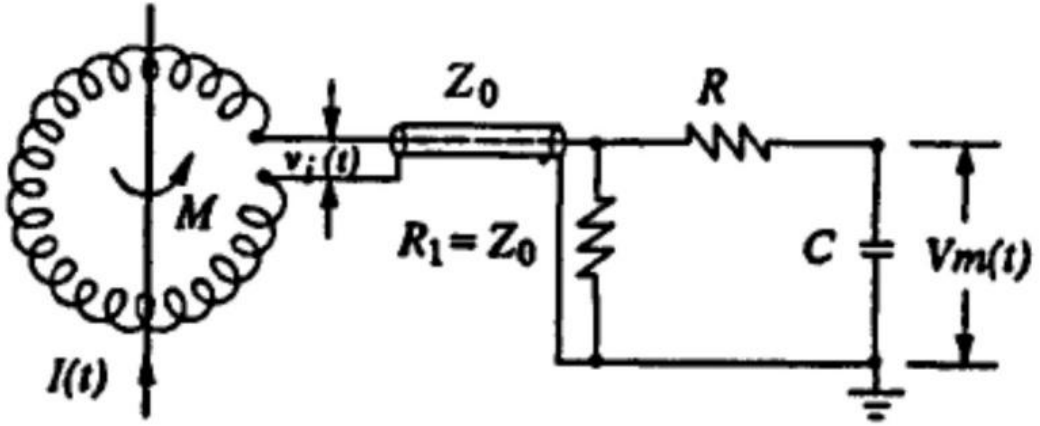
- Spark over voltages for Positive and –Ve polarity impulses are different
- The wave front and wave tail durations also influence the breakdown voltage

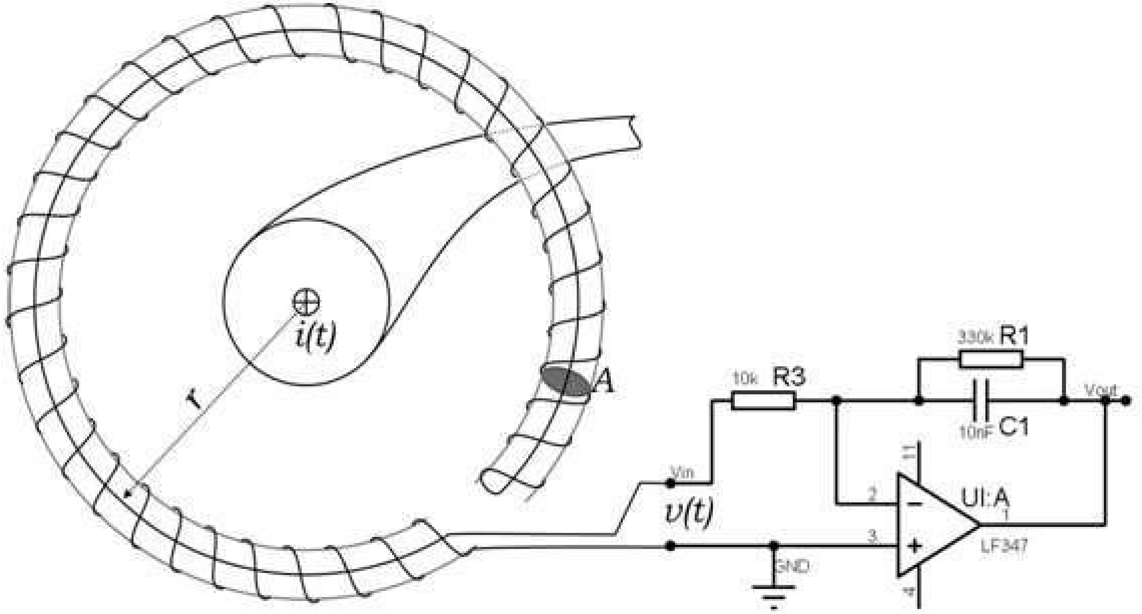
Measurement of High Impulse Currents: Rogowski Coils CTs & Magnetic Links

- It is an electrical device for measuring Alternating Current(AC) or high speed current pulses.
- It consists of a helical coil of wire with the lead from one end returning through the centre of the coil to the other end, so that both terminals are at the same end of the coil.
- The whole assembly is then wrapped around the straight conductor whose current is to be measured.
- The voltage induced in the coil is proportional to the rate of change of current in the straight conductor.
- There is no metal (iron) core

Measurement of High Impulse Current: Rogowski Coils CTs & Magnetic Links

- The output of the Rogowski coil is an integrator circuit to provide an output signal that is proportional to the current





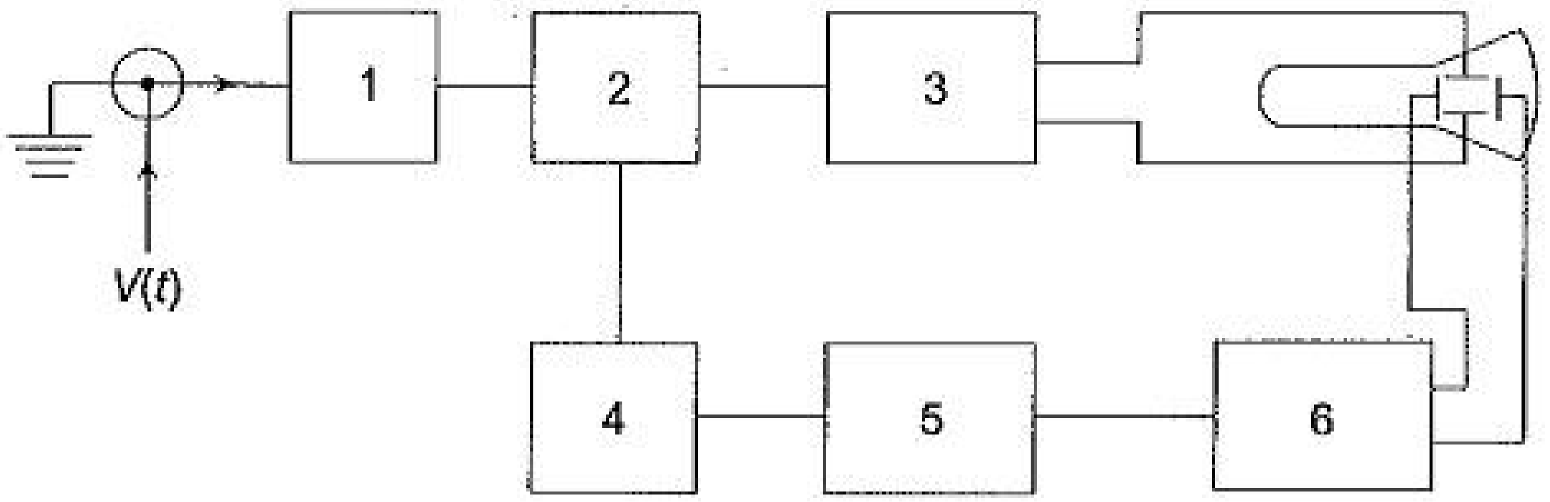
Measurement of High Impulse Currents: Rogowski Coils CTs & Magnetic Links

- The output of the Rogowski coil is an integrator circuit to provide an output signal that is proportional to the current
- If a coil is placed surrounding a current carrying conductor, the voltage signal induced in the coil is $v_i(t) = M\,dI(t)/dt$
- The output voltage is given by : $V_m(t) = \frac{1}{CR}\int_0^t v_i(t) = \frac{M}{CR} I(t)$

Measurement of High Impulse Currents: Rogowski Coils CTs & Magnetic Links

- Magnetic links can be used for measurement of peak value of impulse currents.
- Magnetic links are highly retentive steel strips arranged on a circular wheel or drum
- The strips will be kept at a known distance from the current carrying conductor and parallel to it.
- The Remanent magnetism (Residual magnetism) is then measured in the laboratory from which the peak value of the current can be estimated.
- These are useful for field measurements, mainly for estimating the lightning currents on the transmission lines and towers.

Cathode Ray Oscillographs for Impulse Voltage & Current Measurements



1. *Plug-in amplifier*
2. *Y amplifier*
3. *Internal delay line*
4. *Trigger amplifier*
5. *Sweep generator*
6. *X amplifier*

Cathode Ray Oscillographs for Impulse Voltage & Current Measurements

- A long interconnecting coaxial cable 20 to 50 in long. The required triggering is obtained from an antenna whose induced voltage is applied to the external trigger terminal.
- The measuring signal is transmitted to the CRO by a normal coaxial cable. The delay is obtained by an externally connected coaxial long cable to give the necessary delay.
- The impulse generator and the time base of the CRO are triggered from an electronic tripping device. A first pulse from the device starts the CRO time base and after a predetermined time a second pulse triggers the impulse generator

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