High Voltage Generation

Major topics covered

- **Introduction**- significance of HV & HV testing-basic requirements
- **HVDC Generation -** half & full wave rectifiers, voltage multipliers, doublers, cascaded circuits, cockroft Walton circuit &electrostatic generators- Principles-comparisons- insulation and isolation requirements
- **HVAC Generation** - simple transformers, cascaded arrangements, resonators
- **Impulse voltage & current Generations** - wave shaping , circuits, constraints during tests
- **HFHV Generation** - significance of HFHV tests- tesla coil approach

INTRODUCTION

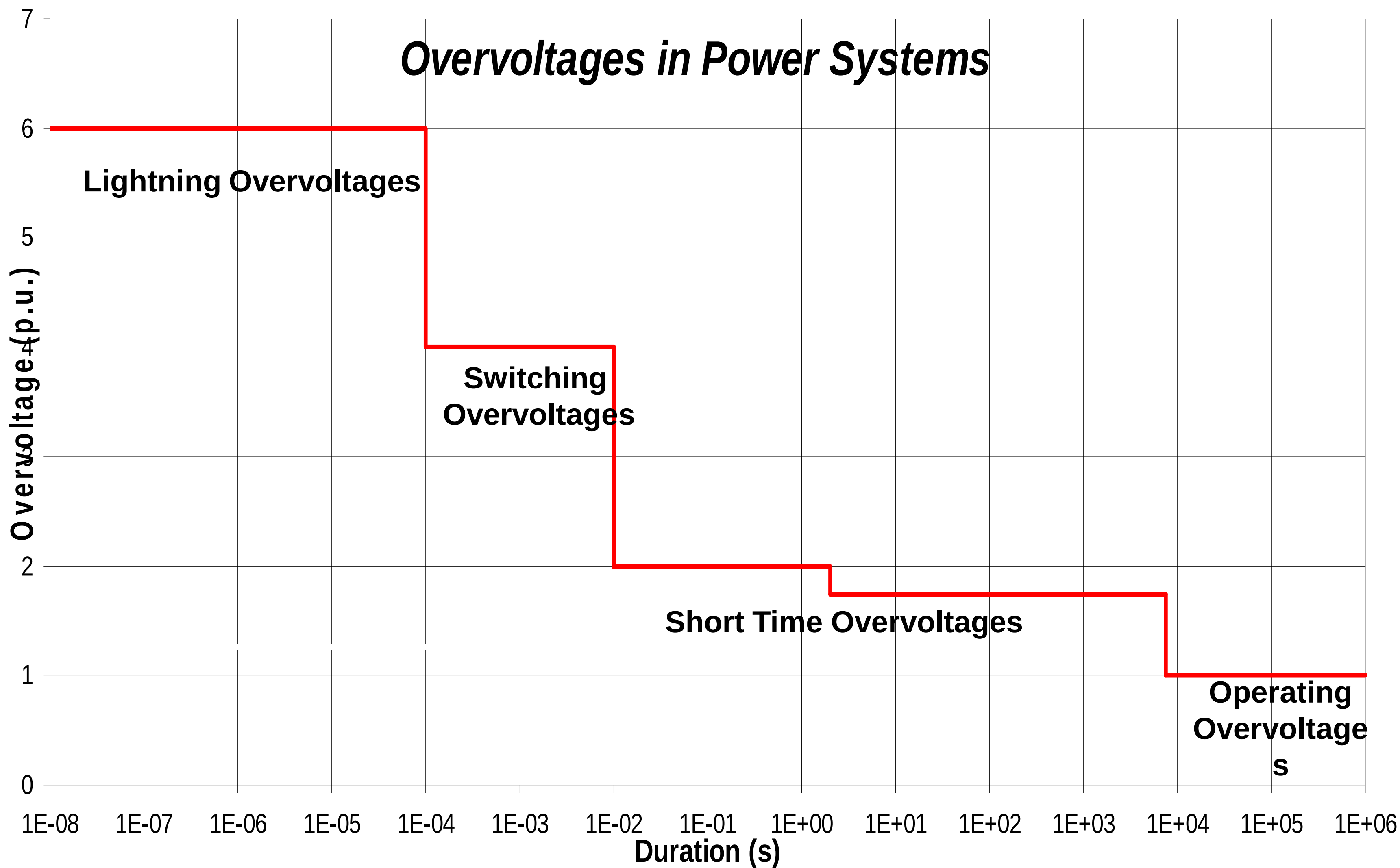
- **NEED FOR A.C. SYSTEMS AND A.C. GENERATION FOR TESTING:**
- **Generation of Electrical Power in large Hydro/ Turbo Generators (60 MW, 100MW, 200 MW, 500 MW) is with a.c. only.**

  Since, d.c. generators have limitation of rating due to commutator problems and it is not economical to use d.c. generators for large power stations.
- **Transmission of Electrical Power over Long Distance is by EHVAC Transmission System (220kV, 400kV etc)**

  Transmission of large blocks of power (500 MW, 1000 MW) requires high voltages.

  The electric power (P) transmitted on an overhead a.c.line increases approximately with the surge impedance loading (or) the square of the system voltage. ($P= V^2 / Z_L$).
- **Figure shows an overview of the voltage levels and the duration of these different types of over voltages.**

INTRODUCTION



INTRODUCTION

- Every type of over voltages corresponds to special tests, which are defined in different International and National Standards.
- In order to evaluate the performance and the ability of power apparatus to withstand continuous system voltage (50 Hz) and short time over voltages (LI and SI), they have to be tested either at the factory or at HV Test Laboratories as per the relevant Standards.
- Since, alternating voltages can be easily stepped up and stepped down by means of Power Transformers bulk power transfer and distribution is generally by means of EHVAC system.
- For testing of Power Apparatus of such HVAC and EHVAC system voltages, AC & DC Test Generation Equipment are required for ascertaining their satisfactory operation.

INTRODUCTION

- NEED FOR D.C. SYSTEMS AND D.C. GENERATION FOR TESTING:
- HVDC systems are used for long distance (above 800km) high power (above 1000 MW) transmission systems.

  For asynchronous Ties

  As Back to Back Stations

  Underground or Submarine Cabling
- The other applications of HVDC systems are for electrostatic precipitation (ESP in Process Industries as HVR – High Voltage Rectifiers), Electrostatic Painting (HCR- High Current Rectifiers), Medical Equipment (X Rays).
- For testing of Power Apparatus of such HVDC systems, DC Testing Equipments are required for ascertaining their satisfactory operation/ functioning.

CLASSIFICATION OF DC, AC & IMPULSE GENERATION BASED ON CONSTRUCTION /OPERATION

- CLASSIFICATION OF VARIOUS GENERATION TECHNIQUES IN DC SYSTEMS:
- HALF WAVE AND FULL WAVE CIRCUITS (VILLARD CIRCUIT)
- VOLTAGE DOUBLER CIRCUITS

  GREINACHER CIRCUIT

  ZIMMERMANN WITTKER CIRCUIT
- VOLTAGE MULTIPLIER CIRCUITS- CASCADED ARRANGMENT

  ALLILONE CIRCUIT

  COCKROFT WALTON CIRCUIT (USES GREINACHER CIRCUIT)

  CASCADED TRANSFORMERS (IMPROVEMENT OF ALLILONE CIRCUIT)

  ENGETRON OR DELTATRON CIRCUIT (IMPROVEMENT OF COCKROFT WALTON CIRCUIT)

CLASSIFICATION OF DC, AC & IMPULSE GENERATION BASED ON CONSTRUCTION /OPERATION

- ELECTROSTATIC PRINCIPLE
  VAN DE GRAFF GENERATOR
  FELICI GENERATOR
  SYNCH. ELECTROSTATIC GENERATOR
- CLASSIFICATION OF VARIOUS GENERATION TECHNIQUES IN AC SYSTEMS:
- SINGLE TRANSFORMER
- CASCADED TRANSFORMERS SET UP
- RESONANT CIRCUITS – SERIES, PARALLEL
- VOLTAGE DOUBLER CIRCUITS
- HIGH FREQUENCY AC HIGH VOLTAGE CIRCUIT (TESLA COIL)

DEFINITIONS AND TERMS ASSOCIATED WITH HV DC GENERATION CIRCUITS

- The following definitions as specified by IEC:60-1 and IEEE-4 are applicable for HV DC Generation Test Circuits:
- ARITHMETIC MEAN VALUE (V_d):
- $V_d = 1/T \int_0^T v(t)\, dt$

  T- Time Period of voltage wave with f = 1/T

  Test Voltages generated with rectifier is not of constant value (magnitude).
- Ripple (δV):
- The magnitude of the ripple voltage is defined as half the difference between the maximum and minimum values of the voltage i.e.,

  $\delta V = \frac{1}{2}(V_{max} - V_{min})$
- Ripple Factor:
- This is the ratio of ripple magnitude to the mean value.

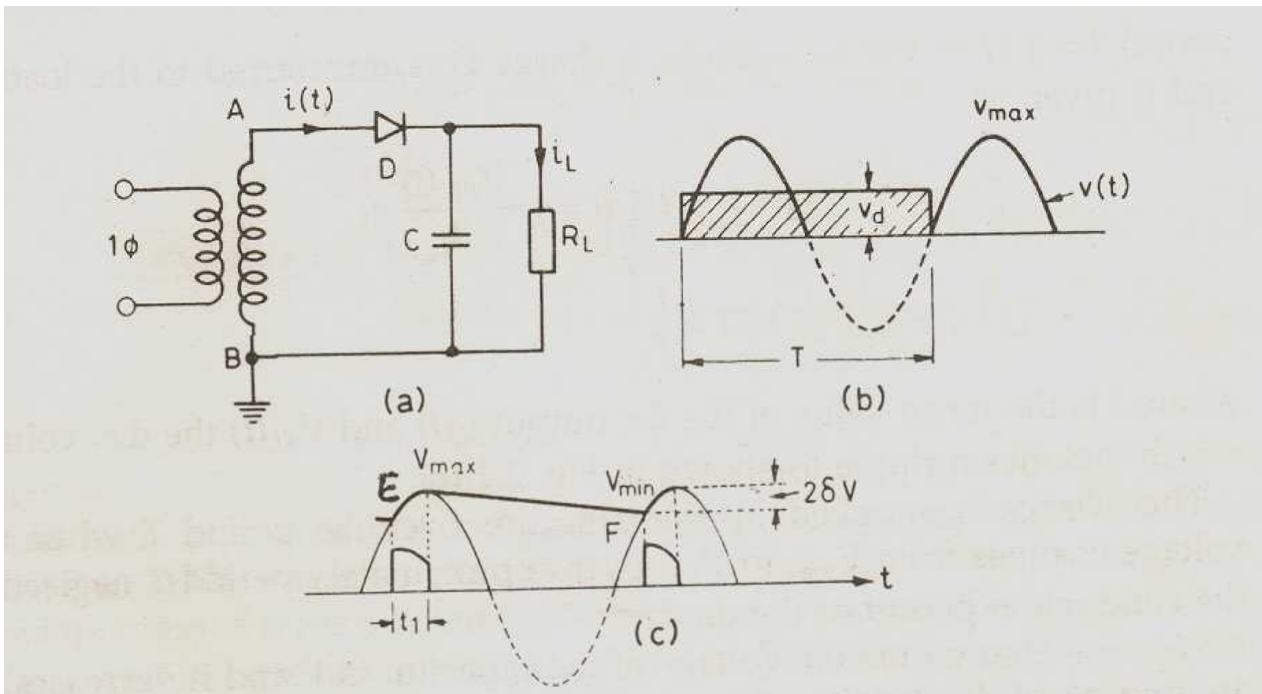
  Ripple Factor = $\delta V / V_d$

  Usually the test voltage should not have ripple factor more than 5%. (Test Standards specify 3% as the upper limit)

RECTIFIER CIRCUITS USED FOR HV DC GENERATION

- HALF WAVE RECTIFIER CIRCUIT:
- In the figure shown, if the capacitor is not connected, pulsating d.c. voltage is obtained at the output.
- With C in the circuit the pulsation at the output is reduced.
- Assuming that there is no load connected (R_L), the d.c. voltage across the capacitance across the capacitor remains constant at V_{max} while the supply voltage oscillates between + / – V_{max}.
- During the negative half cycle the potential of point A becomes $-V_{max}$ and hence the diode must be rated for $2V_{max}$.
- If the circuit is loaded, the output voltage does not remain constant at V_{max}.
- After point E, the supply voltage becomes less than the capacitor voltage, diode stops conducting.
- The capacitor cannot discharge back into the a.c. system because of the "one way action" of the diode.
- Thus, the current flows out of the capacitor as i_L through the load.
- While giving up this stored energy, the capacitor voltage also decreases at a rate based on the time constant (T = RC) of the circuit and reaches the point F (point corresponding to V_{min} of the figure).

Half Wave Rectifier Circuit



RECTIFIER CIRCUITS USED FOR HV DC GENERATION

- At F and beyond, since the supply voltage is greater than the capacitor voltage , diode D starts charging the capacitor C again to V_{max}.
- Thus, while each pulse of diode current lasts less than a half cycle, the load receives current more continuously from C.
- During one period T = 1/f of the a.c. voltage, a charge Q is transferred to the load R_L.

  $Q = \int_T i_L(t)dt = \int_T V_{RL}(t) / R_L \, dt = IT = I/f$

  where I is the mean value of the d.c. output $i_L(t)$ and $V_{RL}(t)$ the d.c. voltage.
- It is also evident that this charge is supplied by the capacitor over the period T when the voltage changes from Vmax to Vmin over approximately T. (neglecting the conduction period of the diode)
- If the voltage of the capacitor is V and it decreases by an amount dV in time dt, then charge delivered by the capacitor is

  $dQ = CdV$

  $\int dQ = \int CdV = -C (V_{max} - V_{min})$

  $Q = C(V_{max} - V_{min})$

  $Q = 2\, \delta V C$

  $\delta V = IT/2C = I/2fC$

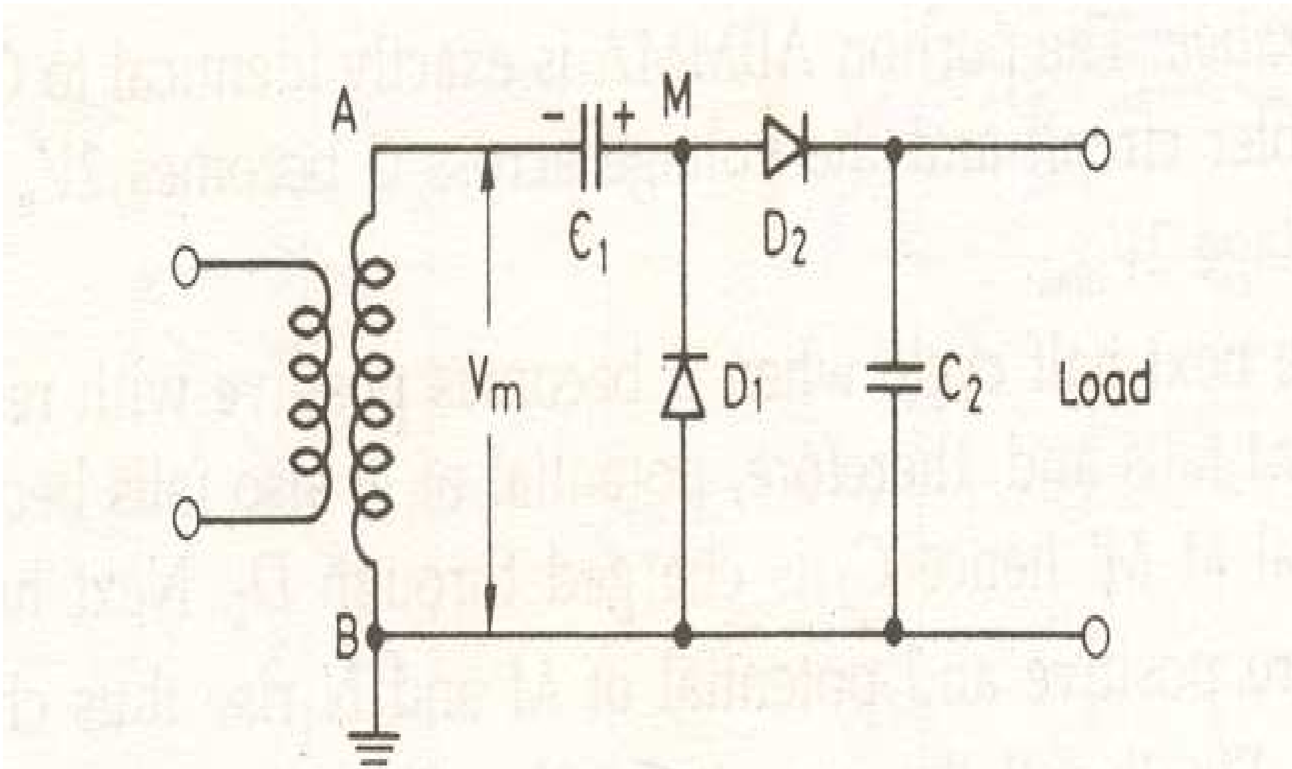
RECTIFIER CIRCUITS & DOUBLERS USED FOR HV DC GENERATION

- From the above equation it is evident that the higher the voltage, the frequency of supply and larger the value of filter capacitor, the smaller will be ripple in the d.c. output.
- DISADVANTAGES:
- The size of the circuit is very large (if high and pure d.c. output voltages are required).
- HT transformer may get saturated if amplitude of d.c. is comparable with nominal a.c. of the transformer.
- These circuits are able to supply relatively low currents and hence are not suitable for high current application.
- In the case of a full wave rectifier circuit it should be noted that the source transformer requires a centre tapped secondary with a rating of 2V.
- The Villard Circuit is the implementation of the above circuit used for HV generation in d.c. systems.
- DOUBLER CIRCUITS:

1. GREINACHER CIRCUIT:

- Suppose B is more positive with respect to A the diode D, conducts.
- Thus the capacitor C_1 is charged to V_{max} as shown in figure.

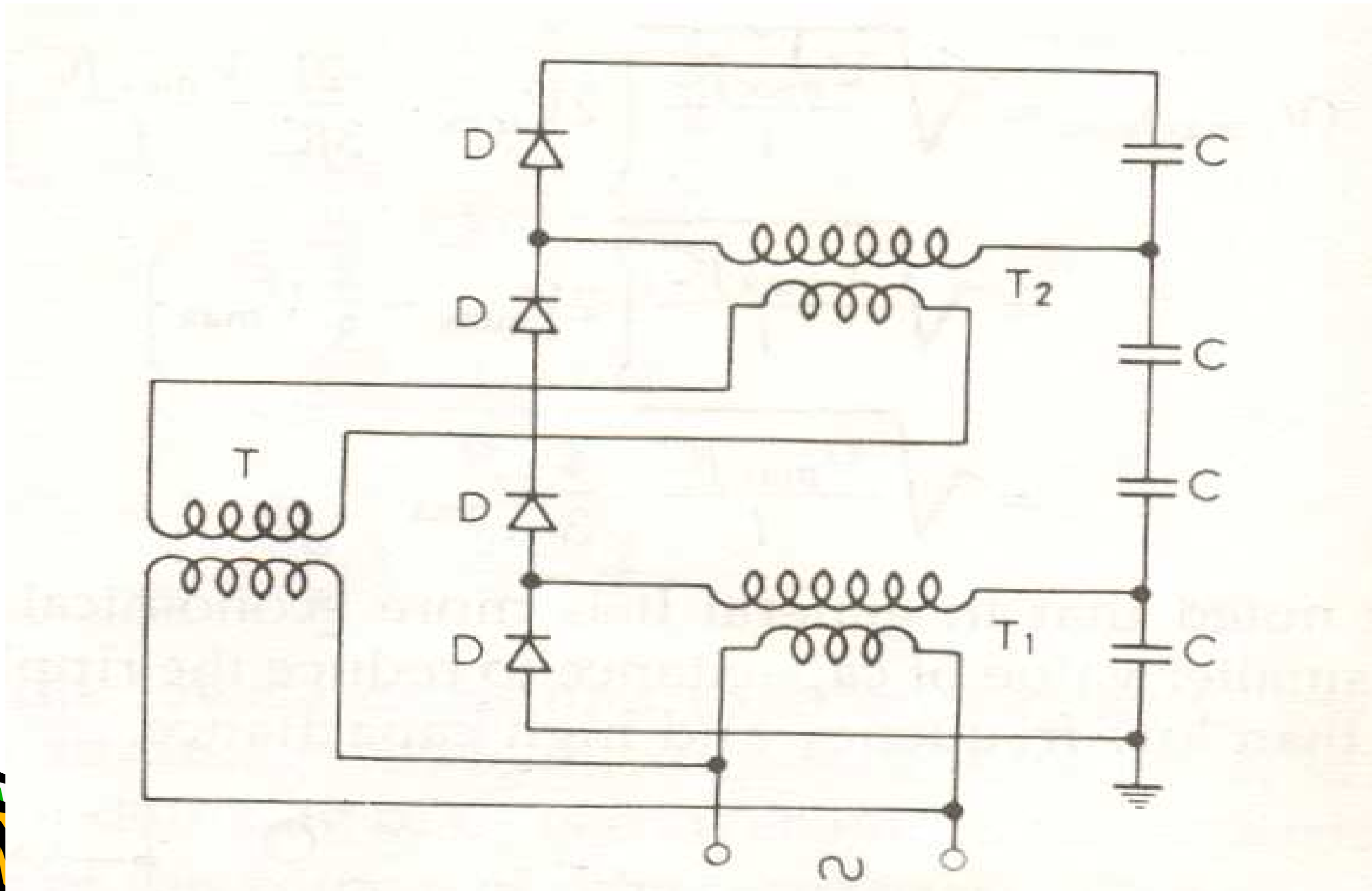
Greinacher DC Voltage Doubler Circuit



VOLTAGE DOUBLERS USED FOR HVDC GENERATION

- In the next half cycle A, the voltage across capacitor C_1 rises to V_{max} and hence terminal M attains a potential of $2V_{max}$. Hence, the capacitor C_2 is charged to $2V_{max}$ through D_2.
- Usually, the voltage across the load will be less than 2Vmax depending upon the time constant of the circuit (C_2R_L).
- The rectifiers are rated to a peak inverse voltage(PIV) of $2V_{max}$ and the condensers C_1 and C_2 must also have the same rating.
- CASCADED VOLTAGE DOUBLER OR ALLILONE'S CIRCUIT :
- These are used when larger output voltages are needed without changing the input transformer voltage level.
- The Allilone's circuit shows rectifiers R_1 and R_2 with transformer T_1 and condenser C_1 and C_2 which produces an output voltage of 2V.
- This circuit is duplicated (reproduced) and connected in series (cascaded) to obtain a further voltage doubling to 4V.
- Here "T" is an isolating transformer and it requires to be given an insulation for $2V_{max}$. (since the transformer T2 is at a potential of $2V_{max}$ above the ground).

Allilone's Circuit



VOLTAGE DOUBLERS USED FOR HVDC GENERATION

- The voltage distribution along the rectifiers R_1, R_2, R_3 and R_4 is made uniform by having C_1, C_2, C_3 and C_4 of equal values.
- This arrangement may be extended to give 6V, 8V, … by using further stages with suitable isolating transformers.
- The arrangement becomes cumbersome if more than 4V is needed with cascaded steps.
- ZIMMERMANN WITTKER CIRCUIT:
- It comprises two Villard Circuits connected back to back.
- Voltage multiplication is about approximately three times the a.c. r.m.s. system voltage.
- DISADVANTAGES OF CASCADED VOLTAGE MULTIPLIER:
- Cascaded Voltage Multiplier circuits for higher voltages are cumbersome and require too many supply and isolating transformers.
- Hence, the alternative approach is to use a single supply transformer ,with extended simple voltage doubler circuits. (COCKROFT-WALTON MULTIPLIER CIRCUIT)
- This set-up is simple and compact when the load current requirement is less than 1 mA. (Cathode Ray Tubes)

VOLTAGE MULTIPLIERS USED FOR HVDC GENERATION

- **COCKROFT-WALTON MULTIPLIER CIRCUIT:**
- In 1932 Cockroft Walton suggested an improvement over the Grienacher Circuit for producing high d.c. voltages.
- The figure shows a multistage single phase cascade circuit of the Cockroft Walton type.
- CASE A: NO LOAD OPERATION
- The portion ABMM'A is exactly identical to Grienacher Voltage Doubler Circuit and the voltage across C_1' becomes $2V_{max}$ when M attains a voltage $2V_{max}$.
- During the next half cycle when B becomes positive with respect to A, potential of M falls and therefore potential of N also falls becoming less than potential at M' hence C_2 is charged through D_2.
- Next half cycle A becomes more positive and potential of M and N rises thus charging C_2' through D_2'.
- Finally all the capacitors C_1', C_2', C_3', C_1, C_2, C_3 are charged.
- The voltage across the column of capacitors consists of C_1, C_2, C_3 which keep oscillating as the supply voltage alternates. Hence, called as the "oscillating column".

VOLTAGE MULTIPLIERS USED FOR HVDC GENERATION

- The voltage across the capacitances $C_1^{'}$, $C_2^{'}$, $C_3^{'}$ remains constant and hence known as "smoothening column".
- The voltages M',N' and O' are $2V_{max}$, $4V_{max}$ and $6\ V_{max}$.
- The voltage across all the capacitors is $2nV_{max}$ where n is the number of stages.
- Designing the elements (capacitors and diodes) to take on equal stresses helps in modular design of these generators.
- CASE B: GENERATOR LOADED
- When loaded, the generator output voltage will not reach $2nV_{max}$. Also, the output will consist of ripples on the voltage.
- Thus, two quantities are of importance i.e., ΔV and δV.
- $q = I/f = IT$
- The charge comes from the smoothening column the series connection of $C_1^{'}$, $C_2^{'}$, $C_3^{'}$.
- If no charge were transferred during T from this stack via D1, D2, D3 to the oscillating column, the peak to peak ripple would be $2\delta V = IT\ \Sigma_{n=0}^{\infty} 1/\ C_i^{'}$ (since $q=CV$; $C2\delta V= I/f$;)

VOLTAGE MULTIPLIERS USED FOR HVDC GENERATION

- The figure shows the arrangement when point A is more positive with reference to B and charging of smoothing column takes place. Also, figure shows the arrangement when in the next stage half cycle B becomes positive with reference to A and charging of oscillating column takes place.
- If the potential at point O' is $6V_{max}$, this discharges through the load resistance R_L and the charge lost is q=IT in one cycle.
- This is regained during the "charging cycle".
- Similarly, the other cycle is termed as "transfer cycle".
- For an "n" stage circuit the total ripple will be

  $2\delta V = I/f\ [\ 1/C_n' + 2/C'_{n-1} + 3/C'_{n-2} + \ldots + n/\ C'_1]$

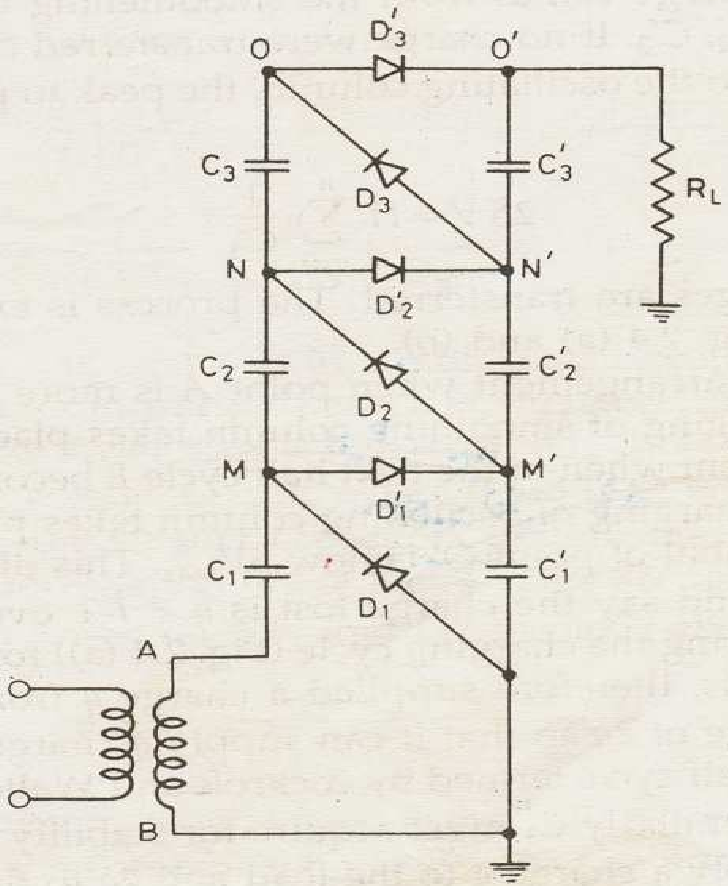
  $\delta V = I/f\ [\ 1/C_n' + 2/C'_{n-1} + 3/C'_{n-2} + \ldots + n/\ C'_1]$
- Capacitors of equal value are used in practical circuits

  $C_n' = C'_{n-1} = C'_{n-2} = C'_1 = C$

  $\delta V = I^*\ n(n+1)/2^*2fC = I^*n(n+1)/\ 4fC$

  $\delta V = I^*n(n+1)/\ 4fC$
- Voltage drop ΔV is different between the theoretical no load voltage 2nVmax and the on load voltage.

Cockroft-Walton Circuit



VOLTAGE MULTIPLIERS USED FOR HVDC GENERATION

- From figure(a) it is evident that the capacitor C'_1 is not charged to the full load voltage $2V_{max}$ but only to $2V_{max}-3q/C$ (because of the charge given up through C_1 in one cycle) which gives a voltage drop of

  $3q/C = 3I/fC$.

- Assuming the voltage drop in the transformer to be negligible C_2 is charged to the voltage

  $(2V_{max}-3I/fC)\ -3I/fC$

  (since the reduction in voltage across C'_2 again is $3I/fC$. Hence C'_2 attains the voltage

  $2V_{max}-((3I/+3I+2I)/fC)$

Contd.,

Thus in a 3 stage generator,

$\Delta V_n = 3I/fC$

$\Delta V_2 = \{2*3+(3-1)\}I/fC$

$\Delta V_3 = \{2*3+2*2+1\}I/fC$

Hence in an n stage generator

$\Delta V_1 = nI/fC$

$\Delta V_{n-1} = I/fC\{2n+(n-1)\}$

$\Delta V_{n-2} = I/fC\{2n+(n-1)+(n-2)\}$

Similarly,

$\Delta V_1 = I/fC\{2n+2(n-1)+2(n-2)+ \ldots+2*3+2*2+1\}$

$\Delta V = \Delta V_n + \Delta V_{n-1} + \ldots + \Delta V_1$

VOLTAGE MULTIPLIERS USED FOR HVDC GENERATION

- Removing the term I/fC for the present consideration the equation can be rewritten as

  $T_n = n;$

  $T_{n-1} = 2n + (n-1);$

  $T_{n-2} = 2n + 2(n-1)+(n-2);$

  $T_{n-3} = 2n + 2(n-1)+2(n-2)+(n-3);$

  Similarly this can be extended to

  $T_1 = 2n + 2(n-1)+2(n-2)+\ldots+2*3+2*2+1;$

  Thus $T = T_n + T_{n-1} + T_{n-2} +\ldots+ T_1$

The last terms of all the terms are added first. Likewise the last term of the remaining term is added.

[n+(n-1)+(n-2)+…+2+1]+
[2n+2(n-1)+2(n-2)+…+2*2]+
[2n+2(n-1)+…+2*4+2*3]+
[2n+2(n-1)+…+2*4]+
[2n+2(n-1)+2(n-2)+…+2*5]+…[2n]

Hence rearranging the terms and simplifying we have

$$T=\Sigma n + 2(n-1)\, \Sigma n - \Sigma(n2 - n) = 2n\, \Sigma n - \Sigma n2$$

(Sum of squares of the first "n" natural numbers)

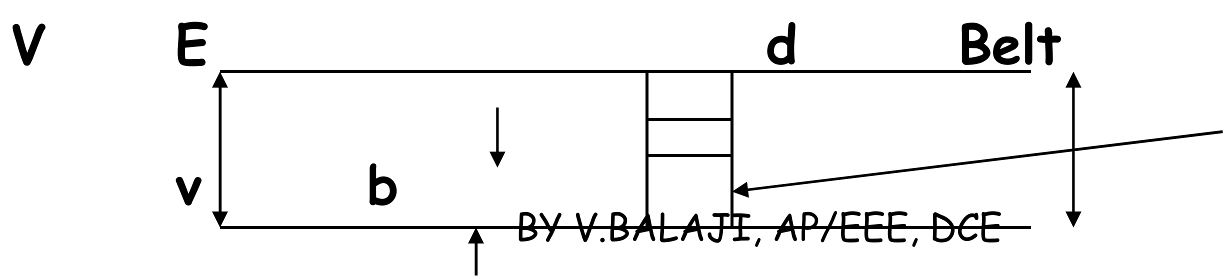
$$T = 2n\{n(n+1)/2\} - \{n(n+1)(2n+1)/6\}$$

VOLTAGE MULTIPLIERS USED FOR HVDC GENERATION

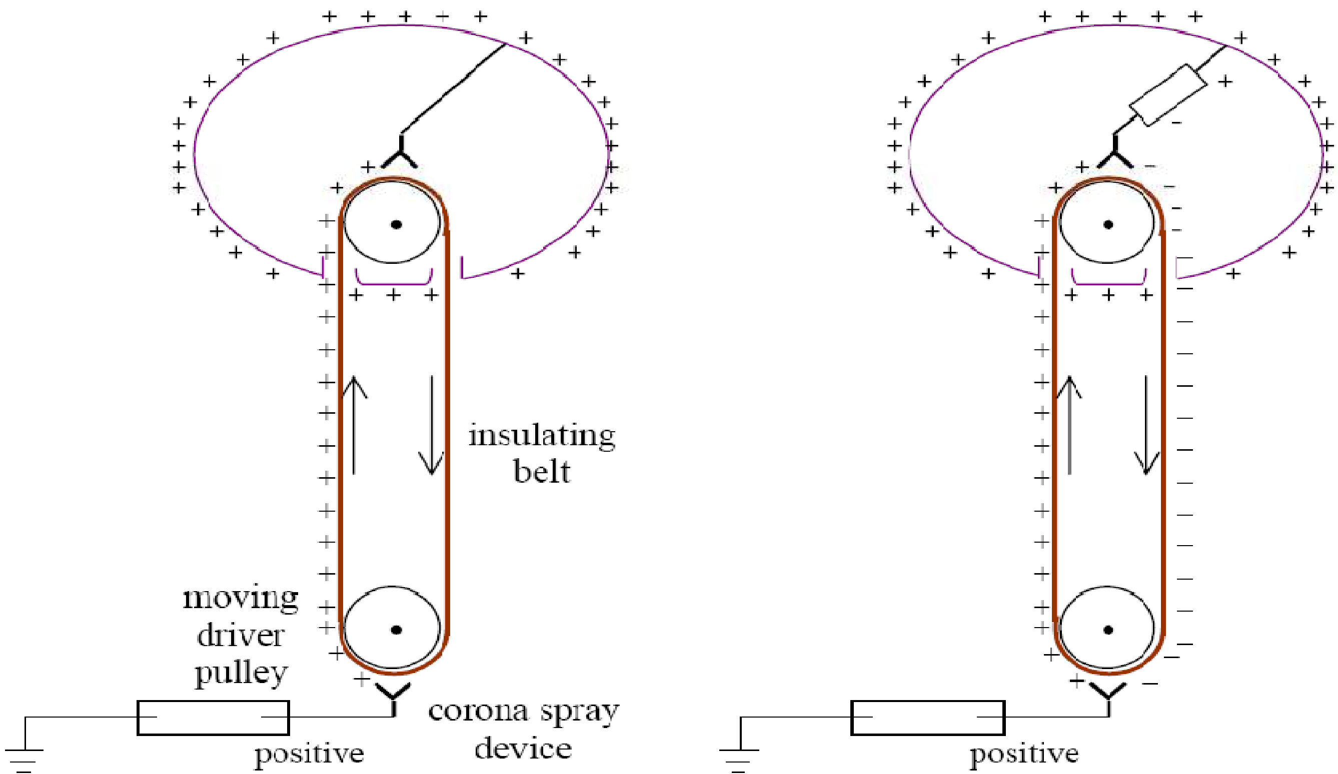
- $T = 2/3*(n^3) + n^2/2 - n/6$;
- Now substituting back I/fC and simplifying the expression given above we have the voltage drop as
  $\Delta V = I/fC[2/3*(n^3) - n/6]$ or approximately as $I/fC[2/3*(n^3)]$
- The condition for maximum output voltage is given by
  $V_{0max} = 2nV_{max} - (I/fC) * (2/3* n^3)$
- Cascaded generators of Cockroft Walton type are used widely.
- In general a d.c. current up to 20mA is required for high voltages between 1MV and 2 MV.
- In case higher value of current is required, symmetrical cascaded rectifiers are being used. (this is what we had seen earlier as Allilone's Circuit)

GENERAL ASPECTS OF ELECTROSTATIC PRINCIPLES FOR HVDC GENERATION

- **ELECTROSTATIC GENERATORS:**
- In electromagnetic generators the current carrying conductors are moved against the electromagnetic forces acting upon them. In electrostatic generators, conversion of mechanical energy into electrical energy is done directly. (the electric charges are moved against the force of electric fields and higher potential energy is gained at the cost of mechanical energy)
- **PRINCIPLE OF OPERATION:**
- An insulation belt is moving with uniform velocity v in an electric field of strength E(x). Assume the width of the belt as b and the charge density σ and a small length on the belt dx as shown in figure below



Van De Graff Generator



GENERAL ASPECTS OF ELECTROSTATIC PRINCIPLES FOR HVDC GENERATION

- The charge $dq = \sigma bdx$ (Since, σ= charge/ area)
- The force experienced by this charge is (the force experienced by the belt)

  $E = F/q$; hence,

  $dF = Edq = E\sigma bdx$

  $F = \sigma b \int Edx$
- Normally the electric field is uniform. Hence,

  $F = \sigma bV$
- Power required to move the belt = Force * Velocity

  $= Fv = \sigma bV v$

GENERAL ASPECTS OF ELECTROSTATIC PRINCIPLES FOR HVDC GENERATION

- Hence, the power required to move the belt is
- Current is $I = dq/dt = \sigma b\, dx/dt = \sigma b v$

  $P = Fv = \sigma b V v = VI$
- Assuming no losses the power output is also equal to VI.
- This principle is made use of in the Van De Graaf Generator.
- VAN DE GRAAF GENERATOR:
- An insulated belt runs over pulleys.
- The width of the belt may vary from a few centimeters to metres.
- This is driven at a speed of about 15 to 30 m/sec by means of a motor connected to the lower pulley.

GENERAL ASPECTS OF ELECTROSTATIC PRINCIPLES FOR HVDC GENERATION

- The belt near the lower pulley is charged electro statically by an excitation arrangement.
- The lower charge spray unit consists of a number of needles connected to the controllable d.c. source (10 to 100kV) so that the discharge between the points and the belt is maintained.
- The charge is conveyed to the upper end where it is collected 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 filled with insulating gases of good dielectric strength (Freon, SF6, Air etc) so that, the potential of the electrode could be raised to a relatively higher voltage without corona discharges or for a certain voltage a smaller size of the equipment will result.

ELECTROSTATIC GENERATOR

- An isolated sphere is the most favorable electrode shape and will maintain a uniform field E with a voltage of Er where r is the radius of the sphere.
- As the h.t. electrode collects charges its potential rises. The potential at any instant is given as V = q/C where q is the charge collected at that instant.
- The moving belt also distorts the electric field and therefore, it is placed within properly shaped field grading rings.

GENERAL ASPECTS OF ELECTROSTATIC PRINCIPLES FOR HVDC GENERATION

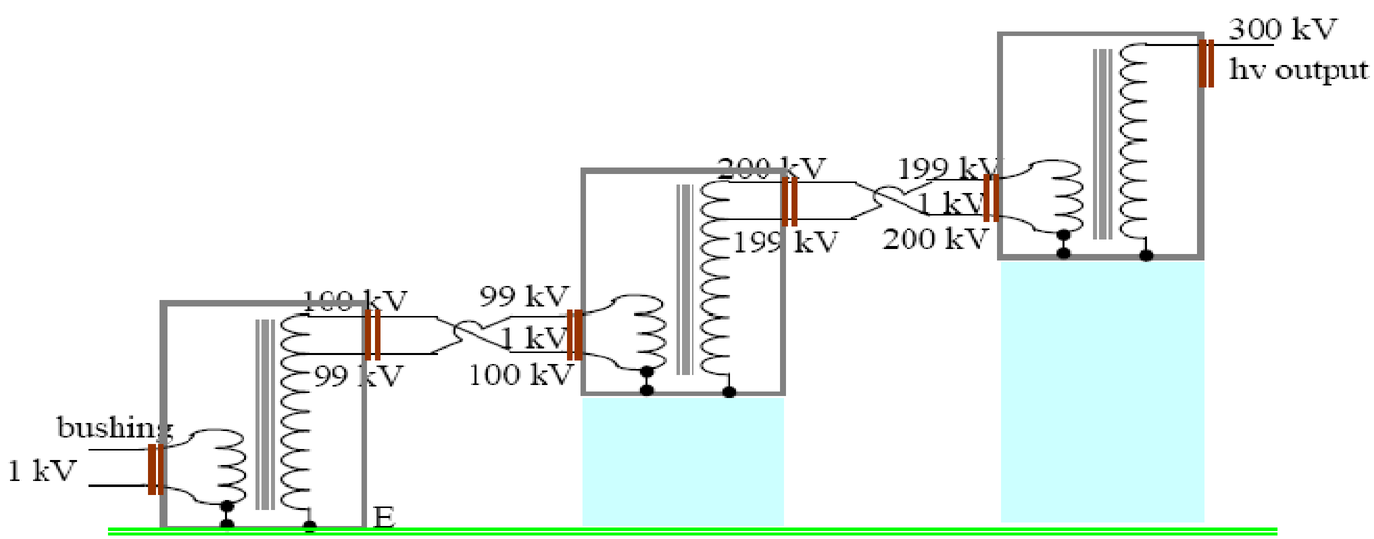
- The collector needle system is placed near the point where the belt enters the h.t. terminal.
- A second point system excited by a self –inducing arrangement enables the down going belt to be charged to the polarity opposite to that of the terminal and thus the rate of charging of the latter, for a given speed is doubled.
- ADVANTAGES:
  - ✓ Very high voltages can be easily generated.
  - ✓ Ripple free output.
  - ✓ Precision and flexibility of control.
- DISADVANTAGES:
  - ✓ Low current output.
  - ✓ Limitations of belt velocity due to tendency of vibration.

Generation of High Alternating Voltages

- Single transformer test units are made for high alternating voltages up to about 200 kV.

- However, for high voltages to reduce the cost (insulation cost increases rapidly with voltage) and make transportation easier, a cascade arrangement of several transformers is used.

Cascade arrangement of transformers



Cascaded transformer arrangement

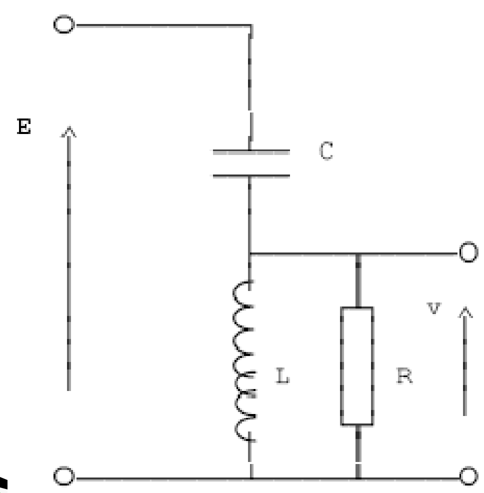
- Figure shows a typical cascade arrangement of transformers [6] used to obtain up to 300 kV from three units each rated at 100 kV.
- The low voltage winding is connected to the primary of the first transformer, and this is connected to the transformer tank which is earthed. One end of the high voltage winding is also earthed through the tank.
- The high voltage end and a tapping near this end is taken out at the top of the transformer through a bushing, and forms the primary of the second transformer.
- One end of this winding is connected to the tank of the second transformer to maintain the tank at high voltage. The secondary of this transformer too has one end connected to the tank and at the other end the next cascaded transformer is fed.
- This cascade arrangement can be continued further if a still higher voltage is required. In the cascade arrangement shown, each transformer needs only to be insulated for 100 kV, and hence the transformer can be relatively small.
- If a 300 kV transformer had to be used instead, the size would be massive.

CASCADED TRANSFORMER

- High voltage transformers for testing purposes are designed purposely to have a poor regulation.
- This is to ensure that when the secondary of the transformer is short circuited (as will commonly happen in flash-over tests of insulation), the current would not increase to too high a value and to reduce the cost.
- In practice, an additional series resistance (commonly a water resistance) is also used in such cases to limit the current and prevent possible damage to the transformer.

Resonant Transformers

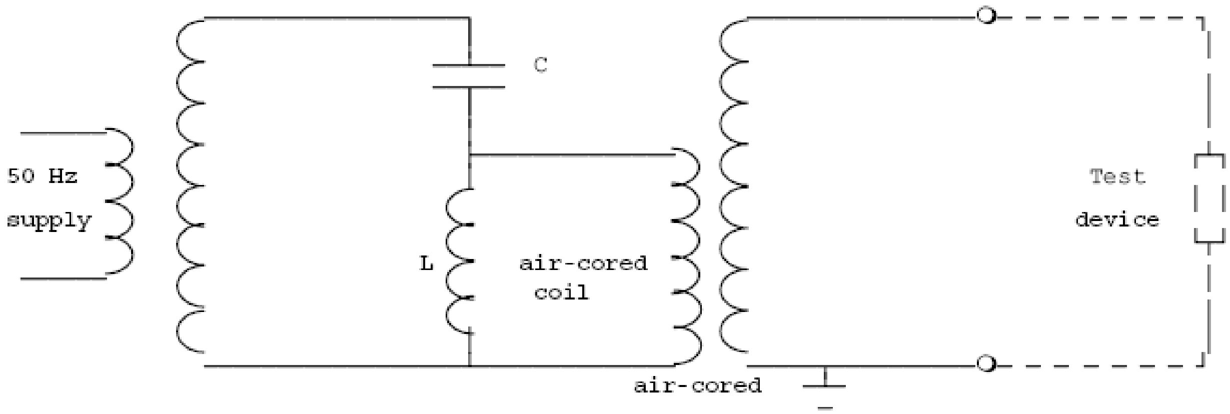
- The resonance principle of a series tuned **L-C** circuit can be made use of to obtain a higher voltage with a given transformer.



$$|v| = E\,.\frac{R}{L\omega} = E\,.Q$$

$$\text{at resonance} \quad \omega = 2\pi f = \frac{1}{\sqrt{LC}}$$

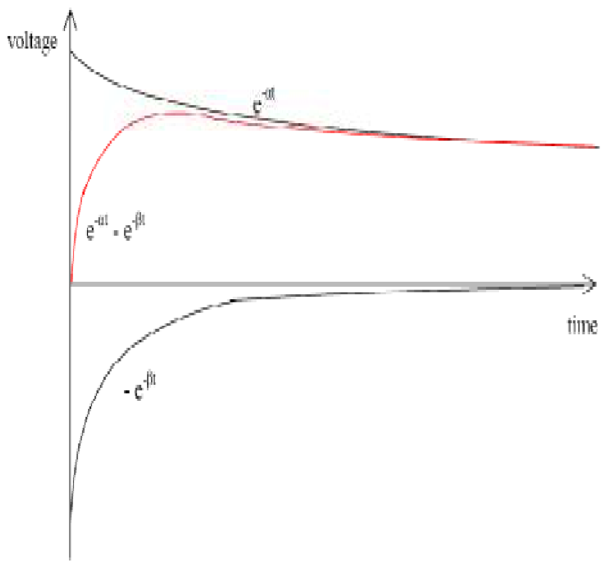
Application of resonant principle to power frequency

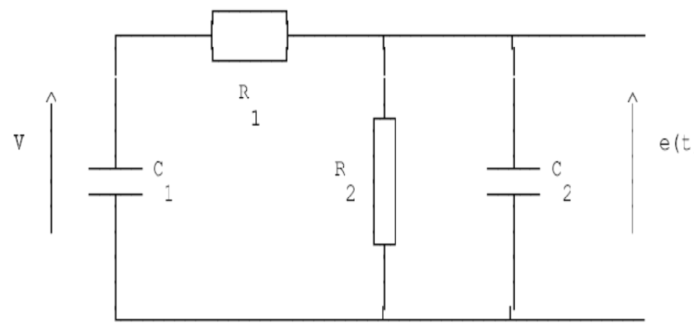


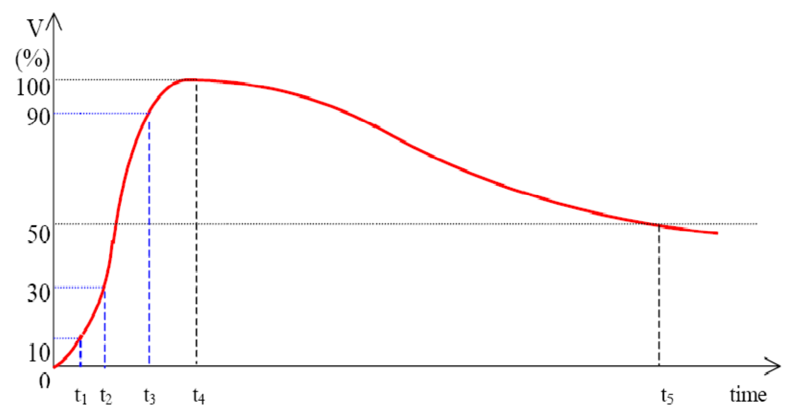
High Voltage Impulse Generation

- 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.
- A full impulse wave is one which develops its complete wave shape without flashover or puncture, whereas a chopped wave is one in which flash-over occurs causing the voltage to fall extremely rapidly.
- The rapid fall may have a very severe effect on power system equipment.
- The lightning waveform is a unidirectional impulse of nearly double exponential in shape.
- That is, it can be represented by the difference of two equal magnitude exponentially decaying waveforms. In generating such waveforms experimentally, small oscillations are tolerated.

Double Exponential Waveform during HV Impulse Generation



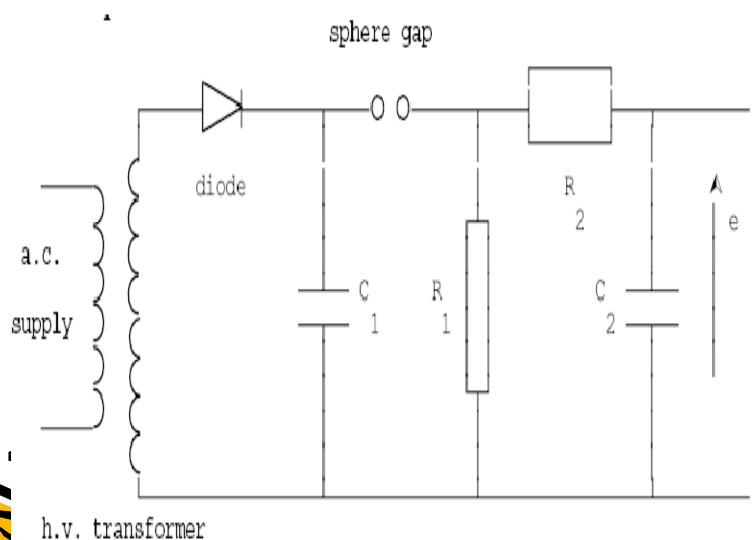


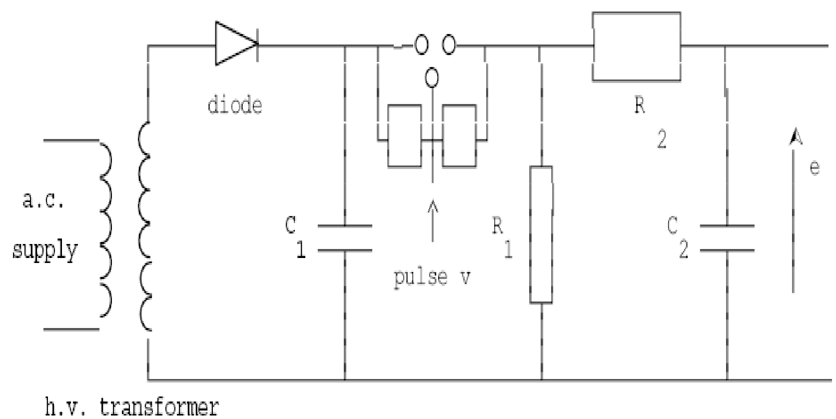


The wavefront time is given as $(t_3 - t_1)/(0.9 - 0.1)$ or $1.25\,(t_3 - t_1)$ for the 10% to 90% measurement and as $(t_3 - t_2)/(0.9 - 0.3)$ or $1.67\,(t_3 - t_2)$ for the 30% to 90% measurement.

Operation of Impulse Generator

- In the simplest form of the single stage impulse generator, shown in Figure.
- The high direct voltage required is obtained from a high voltage transformer through a high voltage rectifier.
- The direct voltage need not be smooth as it only has to charge the first capacitor to peak value.
- A sphere gap is used as the switch, and as the charge on the capacitor builds up, so does the voltage across the sphere gap.

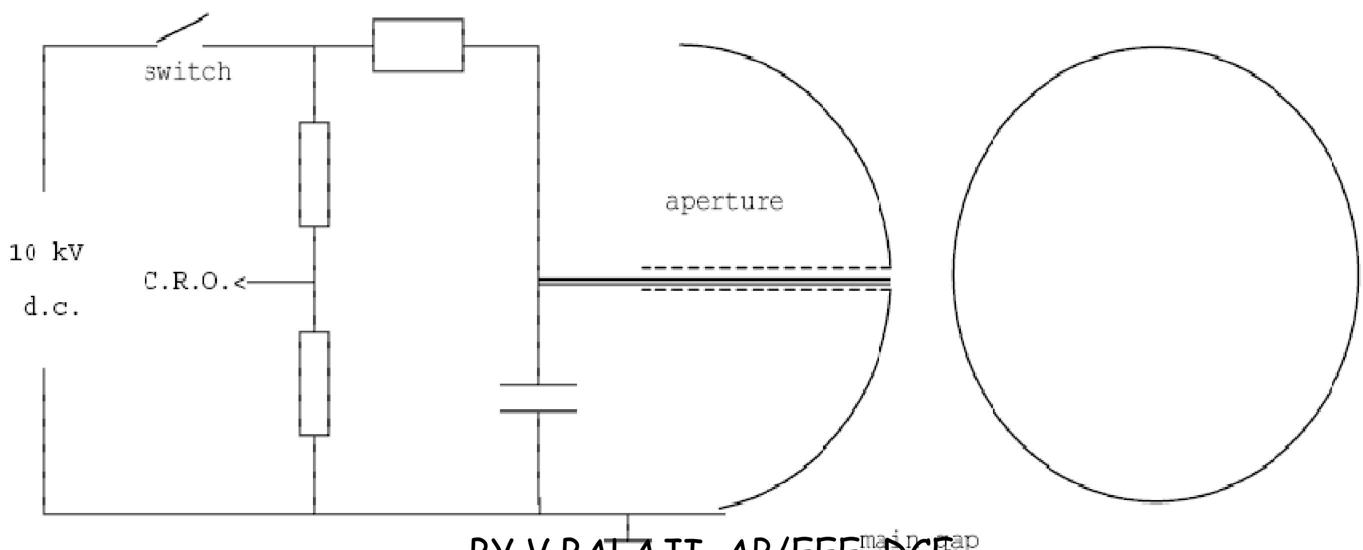




Trigatron gap

➢The third sphere arrangement described for the trigger arrangement is not very sensitive.

➢ A better arrangement is to have an asymmetrical gap arrangement. The trigatron gap is such an arrangement which is in general use.



Wavefront and Wavetail Control

$$\alpha = \frac{1}{R_1(C_1 + C_2)}, \quad \beta = \frac{C_1 + C_2}{R_2 C_1 C_2}, \quad \eta = \frac{C_1}{C_1 + C_2}$$

$$\text{giving} \quad \frac{1}{\alpha} = \frac{R_1 C_1}{\eta}, \quad \frac{1}{\beta} = \eta R_2 C_2$$

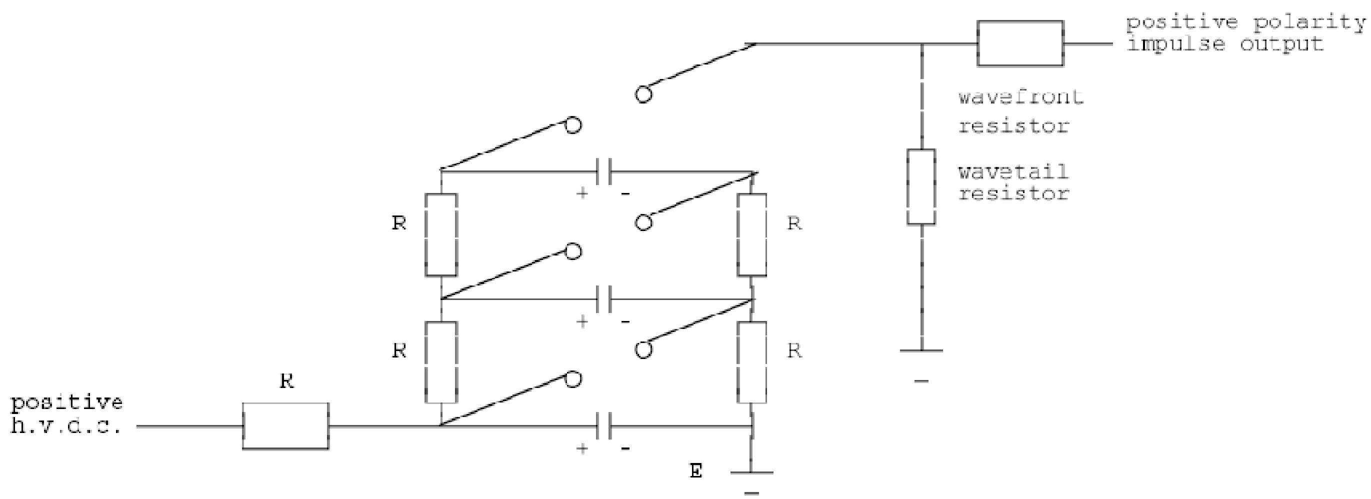
$$t_f = 2.75\, \eta\, R_2 C_2$$

OR

$$t_f = 3.243\, \eta\, R_2 C_2$$

$$t_t = \frac{0.693\, R_1 C_1}{\eta}$$

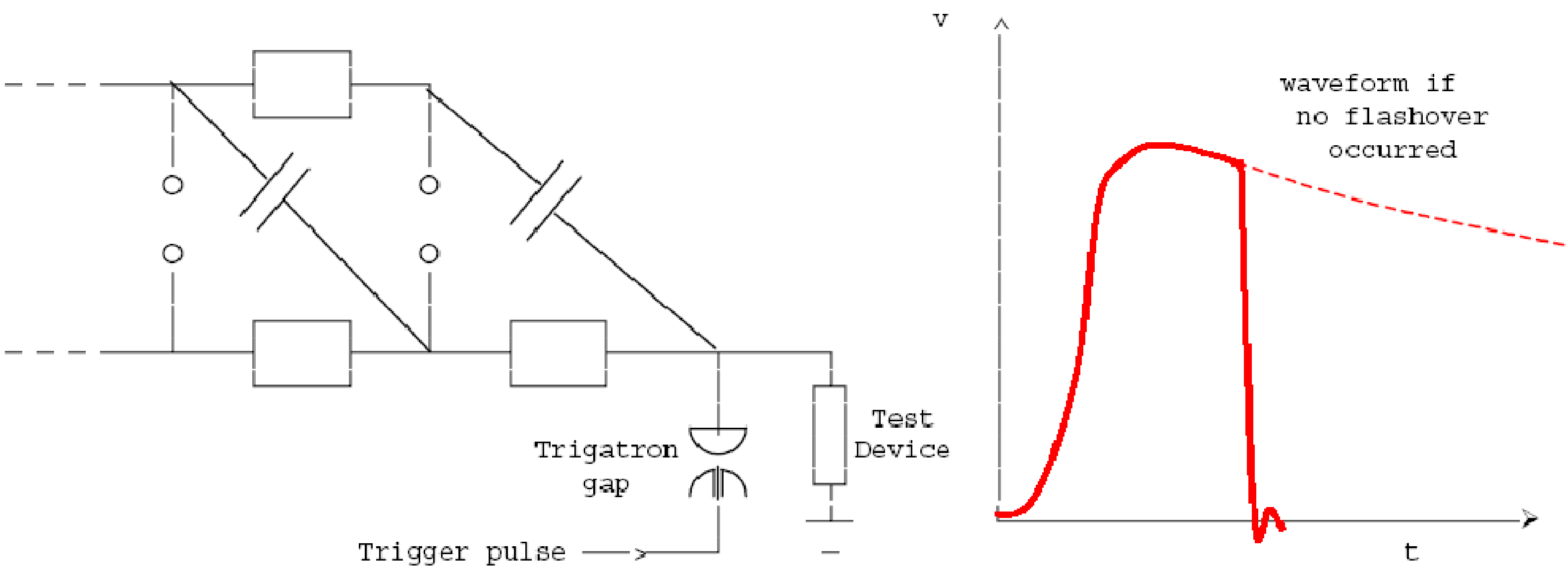
Multistage Marx Impulse Generator



Multi-stage Impulse Generators

- Marx was the first to propose that multistage impulse generators can be obtained by charging the capacitors in parallel and then connecting them in series for discharging.
- In the circuit shown , the resistances R are the charging resistors which are very high in value and selected such that charging of all capacitors occurs in about 1 minute.
- The wave shaping circuit is external to the capacitor stages shown.
- The waveform of the surge generated depends on the resistance, inductance and capacitance of the testing circuit connected.
- In the modified Marx circuit is more common use, the part of the charging resistors are made use of for wave shape control [6]

Chopped waveform &
Circuit to obtain chopped waveform



Experimental Setup of HFHV Tuned Circuit