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Internal Assessment Test 1 – SEPTEMBER 2016

Sub:	High Voltage Engineering					Code:	10EE73
Date:	07-09-2016	Duration: 90 mins	Max Marks: 50	Sem:	7	Branch:	EEE

Note: **Answer any five full questions. Sketch figures wherever necessary.**

1. a. Explain the necessity of transmitting electrical power at high voltages. **[6M]**

Reduces volume of conductor material:

We know that $I = P/(\sqrt{3} * V * \cos \Phi)$

But $R = L / a$

Where = resistivity of transmission line

L = length of transmission line in meters

A = area of cross section of conductor material

Hence Total Power Loss,

$W = 3 I^2 * R$

$= 3 (P/(\sqrt{3} * V * \cos \Phi))^2 * L / a$

$A = P^2 L / (W V^2 \cos^2 \Phi)$

Therefore Total Volume of conductor = 3 * area * length

$= 3 * P^2 L^2 / (W V^2 \cos^2 \Phi)$

From the above equation, the volume of conductor material is inversely proportional to the square of the transmission voltage. In otherwords, the greater the transmission voltage , lesser is the conductor material required.

Increases Transmission effiency:

Input power = P + total losses

$= P + P^2 L / (V^2 \cos^2 \Phi \, a)$

Let J be the current density, therefore $a = I/ J$

Then input power $= P + P^2 L J / (V^2 \cos^2 \Phi) * 1/I$

Transmission efficiency = Output Power / Input Power

$= P / (P [1+\sqrt{3} J L/ V \cos \Phi])$

Since J, ,L are constants, therefore transmissions efficiency increases when line voltage is increased.

Decrease percentage line drop:

Line drop = IR = I * L / a

= I * L * J/I = L J

% line drop = J L / V * 100

As J, and L are constants, therefore percentage line drop decreases when the transmission voltage increases.

b. What is meant by time lag of breakdown? Explain statistical and formative time lag. **[4M]**

Time Lags for Breakdown

Spark breakdown is considered as a function of ionization processes under uniform field conditions. In practical, breakdown occurs due to rapidly changing voltages, or impulse voltages.

The time difference between application of sufficient voltage to cause breakdown and occurrence of breakdown is called time lag.

Townsend's criterion is satisfied only if atleast one electron is present in the gap. With rapidly varying voltages of short duration ($\times 10^{-6}$s), the initiatory electron may not be present.

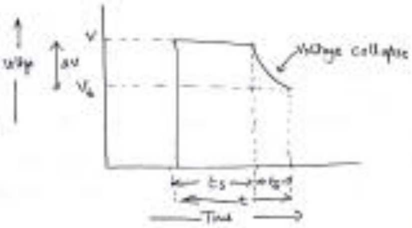
The time which lapses between application of voltage sufficient to cause breakdown and appearance of initiating electron is called statistical time lag (t_s)

Time required for ionization process to develop fully after the appearance of electron is called formative time lag (t_f)

Total Time lag $t = t_s + t_f$

t_s depends on amount of preionization, size of gap and quantity of radiation.

t_f depends on mechanism of avalanche-growth in gap.



Breakdown with a step function voltage pulse

2. a. Describe the various components of electrostatic precipitator (ESP) and its principle of working. **[8M]**

Electrostatic Precipitation (ESP).

- → ESPs are used to control particulate emissions in many industries such as cement plants and steel mills, that produce high temperature flue gases
- → ESPs have collection efficiency of ≥99%
- → ESPs can handle large exhaust-gas volumes at high temperatures.
- → The basic idea of an ESP is charging, collecting and Removing

→ ESPs removes 99% of ash particles, from a coal-fired power plant, from million cubic feet per minute (cfm) of fumes.

→ ESPs stand tens of meters tall.

ESP COMPONENTS:

→ All ESPs contain 6 essential components: discharge electrodes, collection electrodes, electrical systems, rappers, hoppers and a shell. (See fig 1).

1. DISCHARGE ELECTRODES:

→ These are usually small-diameter (thin) wires that hang vertically in the ESP or attached to rigid frame-s, between large plates which are grounded. (These large plates are called collection/grounded electro-des).

→ The discharge electrodes can however be rigid masts or plates with needle strips.

→ These electrodes can conduct or transmit electrici-ty.

→ A negative, high-voltage pulsating, direct-current is applied to the discharge electrode creating the negative electric field.

→ The electric field is strongest right next to the discharge electrode, weaker in inter-electrode region (region or area b/w discharge and collec-tion electrode) and weakest near the collection electrode. (see fig 2)

→ The region around the discharge electrode is where the particle charging process begins.

→ The discharge electrode imparts an electrical charge (usually negative) in particles in a gas stream.

2. COLLECTION ELECTRODES:

→ They can be either tubes or flat plates

→ They have a charge opposite to that of the discharge electrodes.

→ They collect the charged particles.

3. ELECTRICAL SYSTEMS:

→ They are also called T-R Sets (Transformer - Rectifier sets).

→ They are used to control the strength of the electric field b/w the discharge and collection electrodes.

4. RAPPERS:

→ It is a mechanism that provides vibration or shock to both the collection and discharge electrodes.

→ The vibration/shock causes the particles attached to these electrodes to fall into hoppers.

5. HOPPERS:

→ These are bins used to collect and Temporarily store the particles removed during rapping.

→ They are located at the bottom of an ESP.

6. SHELL:

→ The shell encloses the electrodes and supports the precipitator components in a rigid frame to maintain proper electrode alignment and configuration.

→ The Shell is covered with insulation to conserve heat and prevent corrosion.

→ The outer shell wall is usually made of Steel.

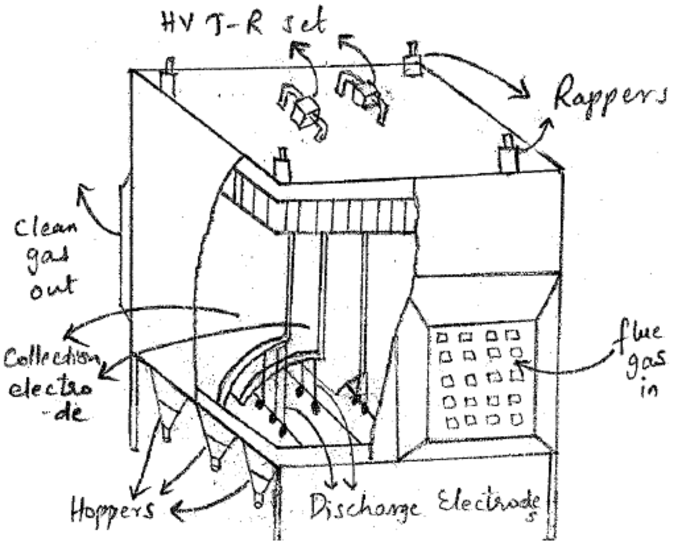


fig. 1

A typical ESP

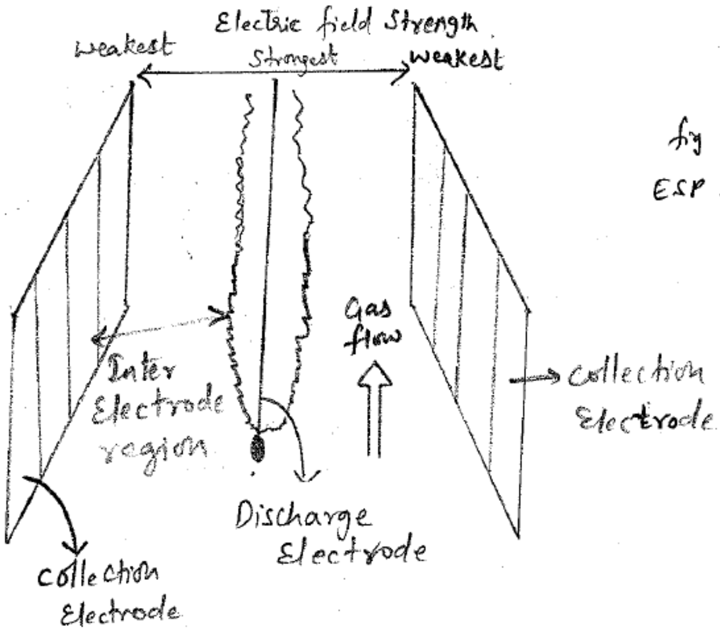


fig 2
ESP Electric field

ESP OPERATION:

→ The transformer (in T-R set) steps up the standard voltage of 400 V to 480 V to 20,000 V to 70,000 V. The rectifier part of T-R set converts this a.c to d.c.

→ This HVDC is applied to the discharge electrode, negatively charging it.

→ Voltage to the electrode is increased until a corona (a visible electric discharge) is produced around the electrode.

→ As the particle-laden flue gas passes through corona, the particles contained in the flue gas become negatively charged.

→ As discharge electrode is -vely charged & collection electrode is +vely charged, a strong electric field is created b/w them.

→ This electric field propels the -vely charged particles towards the +vely charged collection electrodes, where the particles attach themselves.

→ The collection & discharge electrodes are then rapped (in dry ESPs) or sprayed (in wet ESPs), which causes the particles attached to the electrodes to fall into a collection Hopper.

b. If the breakdown occurs in a certain gas when the gap distance was 0.9cm, determine the value of γ. Assume $\alpha = 7.676/cm$ **[2M]**

$$\gamma = \frac{1}{e^{\alpha d}}$$

$$\gamma = \frac{1}{e^{(7.676 \times 0.9)}} = 9.93 \times 10^{-4}$$

3. a. Write a short note on electrostatic painting. **[5M]**

ELECTROSTATIC PAINTING / COATING:

→ Electrostatic painting (EP) is an innovative method used for painting metals and certain types of plastics.

→ It makes use of charged particles to efficiently paint a workpiece.

→ paint, in the form of either powdered particles or atomized liquid, is initially projected towards a conductive workpiece using normal spraying methods, and is then accelerated toward the workpiece by a powerful electrostatic charge.

EP PROCESS:

→ EP works by creating an electric field b/w the object and the paint.

and the paint. ... object being painted) is

and the paint.

→ The grounded object (the object being painted) is positively charged in order to attract the negatively charged paint molecules to its surface.

→ By creating this electrostatic field, the grounded object acts like a magnet, pulling the paint molecules to its surface, forcing even disbursement.

→ Recent addition to electrostatic painting /coating is in the form of dipping electrically conductive part into a tank of paint that is than electrostatically charged.

→ The ionic bond of the paint to the metal creates the paint coating, in which its thickness is directly proportional to the length of time the parts are left in the tank and the time the charge remains active.

→ Once the parts are removed from the paint tank they are rinsed off to remove any residual paint that is not ionically bonded, leaving a thin film of electrostatically bonded paint on the surface of the part.

CHARACTERISTICS OF EP:

→ Uses a high voltage electrostatic charge which is applied to both the workpiece and the spraying mechanism.

→ Is incredibly efficient, uses 95% of sprayed paint due to reduced over-spray and better wrap-around.

→ paint materials can be powdered or liquid.

→ process can be either automatic or manual.

→ Workpieces must be conductive

→ workpieces are usually baked after coated.

→ The baked on paint adheres extremely well and is diffi-cult to remove without aggressive means of removal

ADVANTAGES OF EP:

→ Creates strong bond b/w the pa and the workpiece to be painted

→ It can cover 3D object more enly with good edge and wrap-around coverage

→ It saves paint by using least amount of paint since it has a higher transfer efficiency

→ Uniform and even coating especially on non-flat surfaces.

→ Dries quickly (within an hour).

→ Extremely durable.

DISADVANTAGES OF EP:

→ Material to be sprayed must be conductive or made conduc-tive for bonding.

→ Spray gun has to be handled very carefully as they are bulky

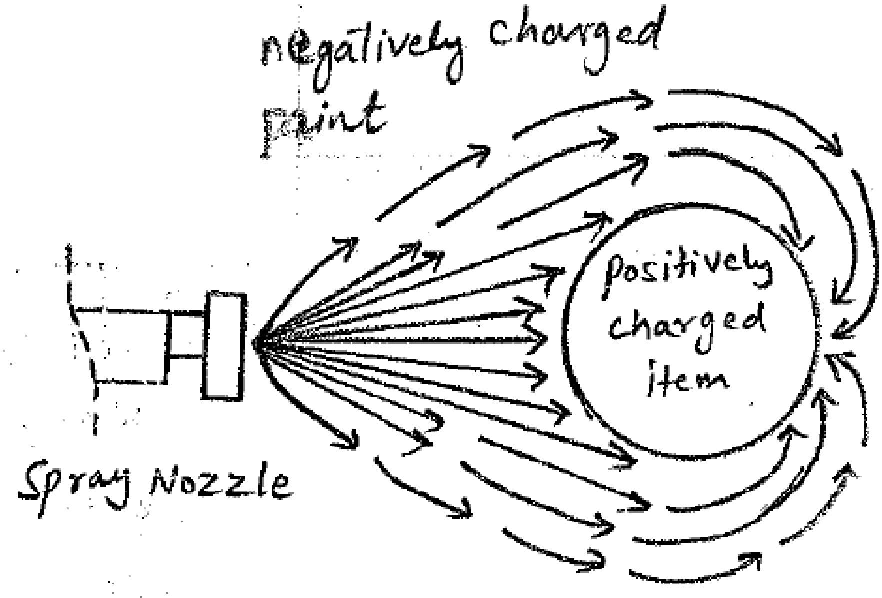


fig-5 Electrostatic painting

b. What will be the breakdown voltage of a spark gap in a gas at $p = 760\ torr$ at 25^oC if = $15/cm, B = 360/cm, d = 1mm$ and $\gamma = 1.5 \times 10^{-4}$? **[5M]**

$$V = \frac{Bpd}{ln\left[\frac{Apd}{ln\left(1+\frac{1}{\gamma}\right)}\right]}$$

$$V = \frac{360 \times 760 \times 0.1}{ln\left[\frac{15 \times 760 \times 0.1}{ln\left(1+\frac{1}{1.5 \times 10^{-4}}\right)}\right]} = 5.2\ kV$$

4) Derive the expressions for Townsend's current growth due to both primary and secondary process. Also obtain the condition for spark formation. **[10M]**

Townsends current growth equation

Let n_0 - electrons are emitted from the cathode
α - be the avg no. of ionizing collisions made by an electron per centimeter travel in the direction of the field.
It depends on gas pressure P and E/p
— Townsends first ionization coefficient.

At any distance x from cathode let the no. of electrons be n_x.
where these electrons travel a further distance of dx then they give rise to $\alpha n_x dx$ electrons

At $x = 0$, $n_x = n_0$

$$dn_x = \alpha n_x dx$$
$$\frac{dn_x}{n_x} = \alpha dx$$

$$\int \frac{dn_x}{n_x} = \int \alpha dx$$
$$\ln n_x = \alpha x + A$$
$$A = \ln n_0$$
$$\ln \frac{n_x}{n_0} = \alpha x$$
$$n_x = n_0 e^{\alpha x}$$

Also $\frac{dn_x}{dx} = \alpha n_x$ or $n_x = n_0 \exp(\alpha x)$

∴ no. of electrons reaching the anode $(x = d)$ will be
$$n_d = n_0 \exp(\alpha d)$$

No. of new electrons created on the average by each electron is

$$\exp(\alpha d) - 1 = \frac{n_d - n_0}{n_0}$$

∴ the average current in the gap is equal to the no. of electrons travelling per sec is

$$I = I_0 \exp(\alpha d)$$

I_0 ↓ Initial current at the cathode.

Current growth in the presence of secondary processes

Additional new electrons will be liberated in the gap by other mechanisms

— positive ions liberated may have sufficient energy to cause liberation of electrons from the cathode.
— excited atoms or molecules in avalanches may emit photons and will lead to emission of e due to photo emission.
— meta stable particles may diffuse back causing electron emission.

Electrons released by these processes are called secondary electrons

Secondary ionization coefficient γ is the net no. of electrons produced per incident positive ion / photon / metastable particle.

$$\gamma = \gamma_1 + \gamma_2 + \gamma_3$$

γ ↓ Townsends secondary ionization coefficient

γ is a function of gap pressure P and E/p

$n_0'' = n_0 + n_0'$

↓ total no. of $\bar{e}$ leaving cathode

↓ no. of secondary $\bar{e}$ produced due to secondary process

$n = n_0'' \exp(\alpha d)$

$= (n_0 + n_0') \exp(\alpha d)$ — similarly, no. of $\bar{e}$ released by gas molecules / of no. of positive ions

total no. of electrons reaching anode

$n_0' = \gamma [n - (n_0 + n_0')]$ — solve.

Eliminating n_0', $n = \dfrac{n_0 \exp(\alpha d)}{1 - \gamma [\exp(\alpha d) - 1]}$

$$I = \frac{I_0 \exp(\alpha d)}{1 - \gamma [\exp(\alpha d) - 1]}$$

Townsend's criterion for breakdown

$$I = \frac{I_0 \exp(\alpha d)}{1 - \gamma [\exp(\alpha d) - 1]}$$

is the total average current in a gap before the occurrence of breakdown.

As d is increased, the denominator of eqn tends to zero and at critical distance $d = d_s$

$$1 - \gamma [\exp(\alpha d) - 1] = 0.$$

For values $d < d_s$, $I \cong I_0$ and if external source for the supply of I_0 is removed, I becomes zero.

If $d = d_s$, $I \to \infty$ and current is limited only by the resistance of the power supply and external ckt.

This condition is called Townsend's breakdown criterion.

$$\gamma [\exp(\alpha d) - 1] = 1$$

↓ very large

$$\text{so } \gamma [\exp(\alpha d)] = 1$$

For a given gap spacing and pressure, the value of voltage V gives the values of α and γ satisfying the breakdown criterion is called spark breakdown voltage V_s and corresponding distance d_s is called sparking distance.

Townsend mechanism explains breakdown phenomena only at low pressure.

$$I = \frac{I_0 e^{\alpha d}}{1 - \gamma (e^{\alpha d} - 1)}$$

when the voltage b/w the anode and cathode is increased, the current at the anode is given by

Current become infinite if $1 - \gamma (e^{\alpha d} - 1) = 0$

i.e., $\gamma (e^{\alpha d} - 1) = 1$

↓ very large

i.e. $\gamma (e^{\alpha d}) = 1$ This condition defines the beginning of spark and is known as

Townsend criterion for spark formation

or

Townsend criteria for breakdown.

3 conditions

(i) $\gamma e^{\alpha d} = 1$

The net ion gain produced in the gap by the passage of one electron avalanche is sufficiently large and resulting positive ions on bombarding the cathode are able to release an secondary e and cause a repetition of avalanche process. This is self sustained and discharge will sustain even if I_0 is removed.

(ii) $\gamma e^{\alpha d} > 1$

ionization produced by successive avalanche is cumulative. The spark discharge grows more rapidly the more $\gamma e^{\alpha d}$ exceeds unity.

(iii) $\gamma e^{\alpha d} < 1$

current I is not self sustained i.e., on the removal of source the current I_0 ceases to flow.

5) What are the limitations of Townsend's Theory? Explain Streamer's Theory. **[10M]**

Limitations of Townsend Theory

i) Fails to explain the formative time lag of breakdown

ii) Fails to explain the effect of space charge

iii) Fails to explain the discharge under high pressure.

STREAMER THEORY OF BREAKDOWN IN GASES

Townsend's Theory → current growth occurs as a result of ionization only

But in practice → B.D. voltages depends on gas pressure & geometry of gap.

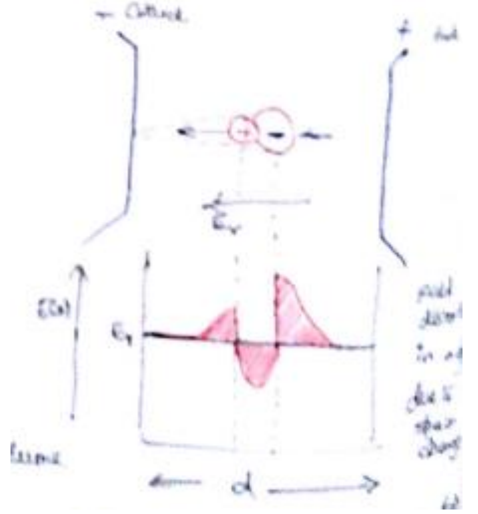
T. Mechanism predicts time lag of 10^{-5}s. In practice → 10^{-8}s

T Mechanism predicts diffused form of discharge. ∴ discharge filamentary

So in 1940 → Raether, Meek and Loeb independently proposed streamer Theory.

Streamer Theory

Raether observed that when space charge concentration was between 10^6 and 10^8 avalanche became weak, and when charge concentration was higher than 10^8, avalanche current was followed by steep rise leading to breakdown



For simplicity space charge volume is assumed to be spherical, containing negative charge on the ... because of higher electron mobility.

Field distortion occurs as shown in Fig.

Thus space charge fields play an important role in growth of avalanches and spark discharges in non uniform field gaps.

Transformation of avalanche to streamer occurs when charge within avalanche head reaches critical value of $n_0 \exp(\alpha x_c) = 10^8$ or $18 \leq x_c \leq 20$

where x_c is length of avalanche in which secondary electrons are produced by photo ionization, in the gap.

These secondary electrons under the influence of field in the gap develop into secondary avalanches as shown in Fig.

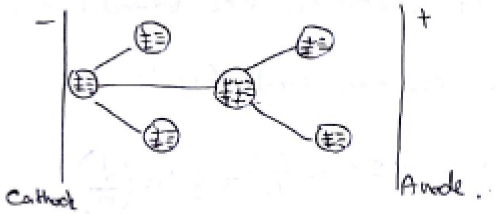


Fig. _ Formation of secondary avalanches due to photo ionization.

Raether proposed an empirical expression for the ~~strea~~ streamer spark criterion of the form,

$$\alpha x_c = 17.7 + \ln x_c + \ln (E_r / E) \longrightarrow (\_\_)$$

where $E_r \rightarrow$ space charged field directed radially at the head of the avalanche.

$E \rightarrow$ applied field.

~~When $E_r = E$~~ condition for transition from avalanche to streamer is when $E_r = E$

& eqn (__) becomes $\alpha x_c = 17.7 + \ln x_c \longrightarrow (\_\_)$

Minimum breakdown value is obtained on assuming that transition from avalanche to streamer occurs when avalanche has just crossed gap, d. Thus minimum breakdown voltage by streamer mechanism occurs only when a critical length $x_c = d$.

Meek proposed criterion to estimate the electric field E_r, produced by space charge, at radius r, & is given by,

$$E_r = 5.27 \times 10^{-7} \frac{\alpha \exp(\alpha x)}{(x/p)^{1/2}} \quad V/cm \quad —$$

$\alpha \rightarrow$ Townsend's first ionization coefficient

$p \rightarrow$ gas pressure in torr

$x \rightarrow$ distance to which streamer has extended in gap.

When $E_r = E$ & $x = d$, the equation simplifies to

$$\alpha d + \ln\left(\frac{\alpha}{p}\right) = 14.5 + \ln\left(\frac{E}{p}\right) + \frac{1}{2}\ln\left(\frac{d}{p}\right).$$

The equation is solved for satisfactory values of p & d.

The breakdown voltage is given by corresponding product of E and d.

This criterion enabled an agreement between calculated and measured breakdown voltages.

6) a) State and explain Paschen's Law. **[6M]**

PASCHEN'S LAW

The criterion for breakdown in gas is given by

$$\gamma\,[\exp(\alpha d) - 1] = 1 \quad \longrightarrow (1)$$

α & γ are functions of E/p. i.e

$$\frac{\alpha}{p} = f_1\left(\frac{E}{p}\right)$$

&

$$\gamma = f_2\left(\frac{E}{p}\right)$$

Also $E = \dfrac{V}{d}$

Substitute E in α & γ and eqn $(\to 1)$ becomes

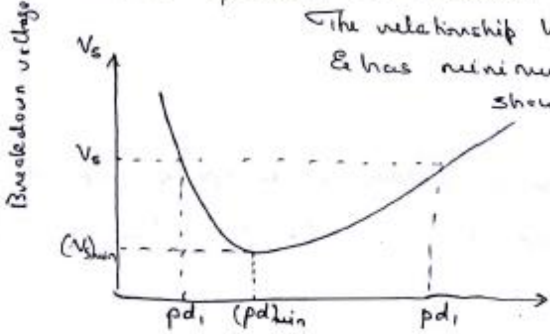
$$f_2\left(\frac{V}{pd}\right)\left[\exp\left\{pd\, f_1\left(\frac{V}{pd}\right)\right\} - 1\right] = 1 \longrightarrow (2)$$

The equation implies breakdown voltage varies as the product pd varies.

Known nature of f_1 & f_2 we can write

$$\boxed{V = f(pd)} \longrightarrow (3)$$

This equation is known as Paschen's law.



The relationship between V & pd is not linear & has minimum value for any gas. It is shown in Fig 1.

The value of spark gap d, in terms of α & γ from Eqn(1)

$$d = \frac{1}{\alpha}\ln\left[1 + \frac{1}{\gamma}\right] \longrightarrow (4)$$

$$= \frac{1}{p f_1\left(\frac{E}{p}\right)}\ln\left[1 + \frac{1}{f_2\left(\frac{E}{p}\right)}\right]$$

α may be assumed to follow exponential function & may be written as

$$\alpha = Ap\, e^{-Bp/E} = Ap\, e^{-Bpd/V} \qquad \because E = \frac{V}{d}$$

Substituting for 'α' in (4)

$$d = \frac{1}{Ap} e^{Bpd/V} \ln\left[1 + \frac{1}{\gamma}\right]$$

or

$$V = \frac{Bpd}{\ln\left[\frac{Apd}{\ln\{1+\frac{1}{\gamma}\}}\right]} \longrightarrow (5)$$

Minimum value for V can be obtained by making $\frac{dV}{d(pd)} = 0$

$$(pd)_{min} = \frac{e}{A} \ln\left[1 + \frac{1}{\gamma}\right] \qquad \text{where } e = 2.718 \longrightarrow (6)$$

$$V_{min} = \frac{eB}{A} \ln\left[1 + \frac{1}{\gamma}\right]$$

b) In an experiment in a certain gas it was found that the steady state current is $5.5 \times 10^{-8} A$, at $8kV$ at a distance of $0.4\ cm$ between the plane electrodes. Keeping the field constant and distance as $0.1\ cm$ results in a current of $5.5 \times 10^{-9} A$. Calculate Townsend's primary ionization coefficient α. **[4M]**

$$I = I_0 e^{\alpha d}$$

$$\frac{I_1}{I_2} = \frac{e^{\alpha\alpha}}{e^{\alpha d_2}} = e^{\alpha(d_1 - d_2)}$$

$$\frac{5.5 \times 10^{-8}}{5.5 \times 10^{-9}} = e^{\alpha(0.4-0.1)}$$

$$10 = e^{0.3\alpha}$$

$$0.3\alpha = \ln(10)$$

$$\alpha = \frac{2.3025}{0.3} = 7.657/cm$$