E 1530 High Voltage Eng. الاجابة النموذجية لمادة

Q1 (a) 1- Ionization: The process of build-up of high currents in a breakdown, in which electrons and ions are created from neutral atoms or molecules, and their migration to the anode and cathode respectively leads to high current.

2- Townsend's first ionization coefficient or primary ionization coefficient (α) *: It is the* average number of ionizing collisions made by an electron per centimeter travel in the direction of the field where it depends on gas pressure p and E/p.

3-Townsend's secondary ionization coefficient γ : It is defined in the same way as α, then the net number of secondary electrons produced per incident positive ion, photon, excited particle or metastable particle and the total value of γ due to the four different processes. It is the probability of addition new electrons being liberated by these mechanisms, further avalanches are initiated and are called as secondary electron avalanches.

4- SELF SUSTAINED DISCHARGE:

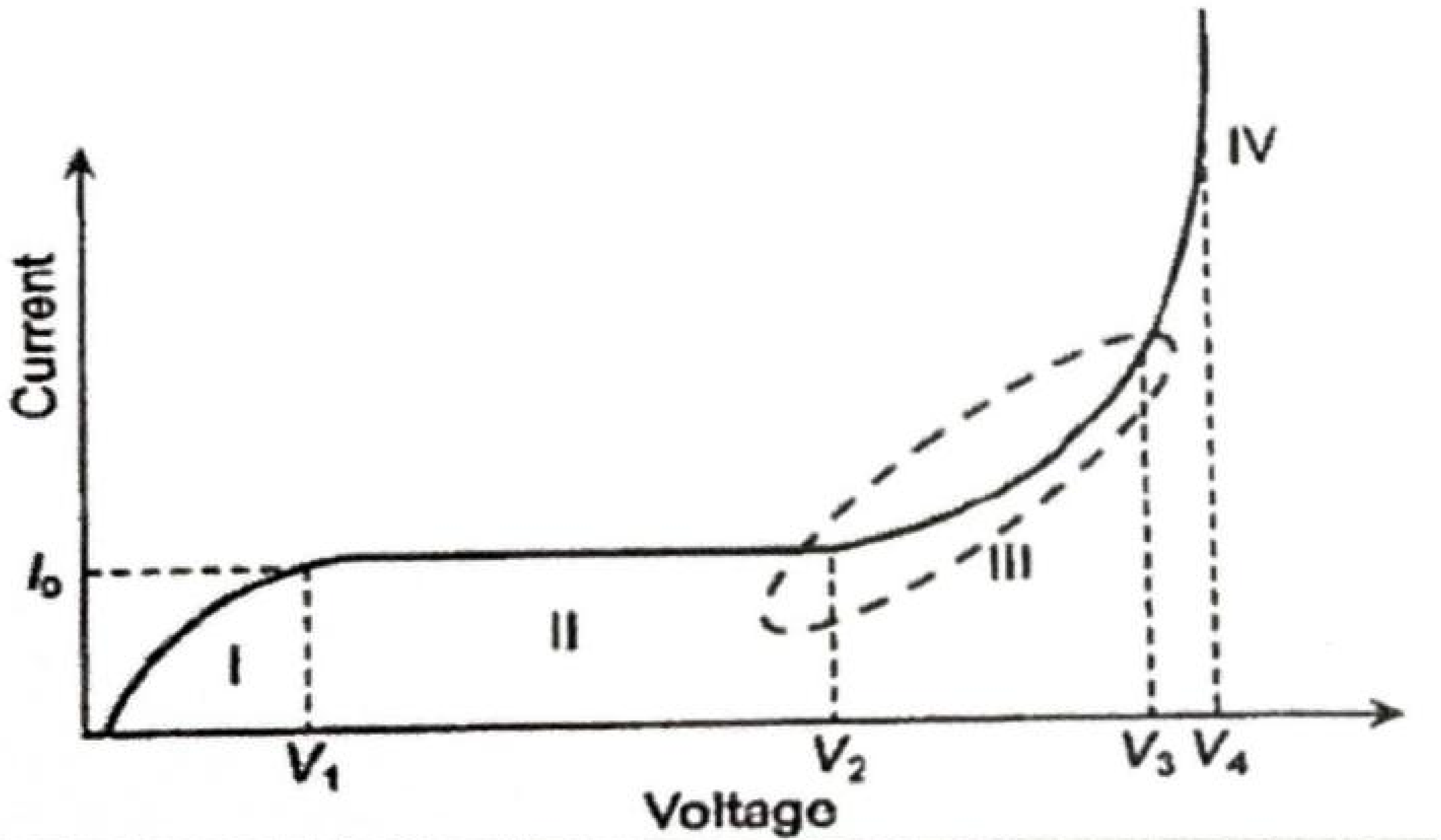


Figure : I-V characteristics for Townsend's breakdown mechanism

The rapid increases of ionization processes in the gap region are called avalanches process. When the region IV, anode current will be increased very sharply depending on secondary ionization processes initiated from the primary avalanche. This is called self- sustained discharge. The current magnitude could reach infinity and the value is limited only by the external resistance. Even the current behavior would not change even if the UV light source is removed, and the process is independent of light source or voltage source. Finally, the gas is to be breakdown. The

Scanned by TapScanner

Q1 (b) 1-THE MAIN PROPERTIES OF A SOLID DIELECTRIC FOR ELECTRICAL INSULATION :A good dielectric should have low dielectric loss, high mechanical strength, should be free from gaseous inclusions, and moisture, and be resistant to thermal and chemical deterioration. Solid dielectrics have higher breakdown strength compared to liquids and gases.

2- TYPES OF SOLID INSULATING MATERIALS: Solid insulating materials, which are generally used in practice, are of two types, namely, the organic materials, such as paper, wood and rubber, and the inorganic materials, such as mica, glass and porcelain, and synthetic polymers, such as perspex, PVC, epoxy resins, etc.

3- Insulsation Classes: The insulating materials are grouped into different classes O, A, E, and B with temperature limits of 90°C, 105°C, 120 and 130°C , respectively. Classes O and A cover the various organic materials without and with impregnation respectively, class E for synthetic materials, while classes B to C cover inorganic materials, respectively with and without a binder.

Class Y (formerly O) 90°C Paper, cotton, silk, natural rubber, polyvinyl chloride, etc., without impregnation.

Class A 105°C Same as class Y but impregnated, and nylon.

Class E 120°C Polyethylene terephthalate (terylene fibre, melinex film), cellulose triacetate, polyurethanes, polyvinyl acetate enamel.

Class B 130°C Mica, fibreglass (alkali free alumino borosilicate), bitumenized asbestos, Bakelite, polyester enamel.

Class F 155°C As class B but with alkyd and epoxy-based resins.

Class H 180°C As class B with silicone resin binder, silicone rubber, aromatic polyamide, polyimide film (enamel, varnish and film).

Class C Above 180°C As class B, but with suitable non-organic binders; teflon (polytetrafluoroethylene), and other high-temperature polymers. Sub-groups in class C are 200°C, 220°C and 250°C and above.

Scanned by TapScanner

QI (B)- 4 Streamer Theory

Townsend mechanism when applied to breakdown at atmospheric pressure is found to have certain drawbacks. Firstly, according to the Townsend theory, current growth occurs because of ionization processes only. But in practice, breakdown voltages were found to depend on the gas pressure and the geometry of gap and electrodes. Secondly, the mechanism predicts time lags of the order of 10^{-5} s, while in actual practice breakdown is observed to occur at very short time of the order of 10^{-10} s. the Townsend mechanism failed to explain the observed phenomena and Streamer theory is proposed.

Streamer process

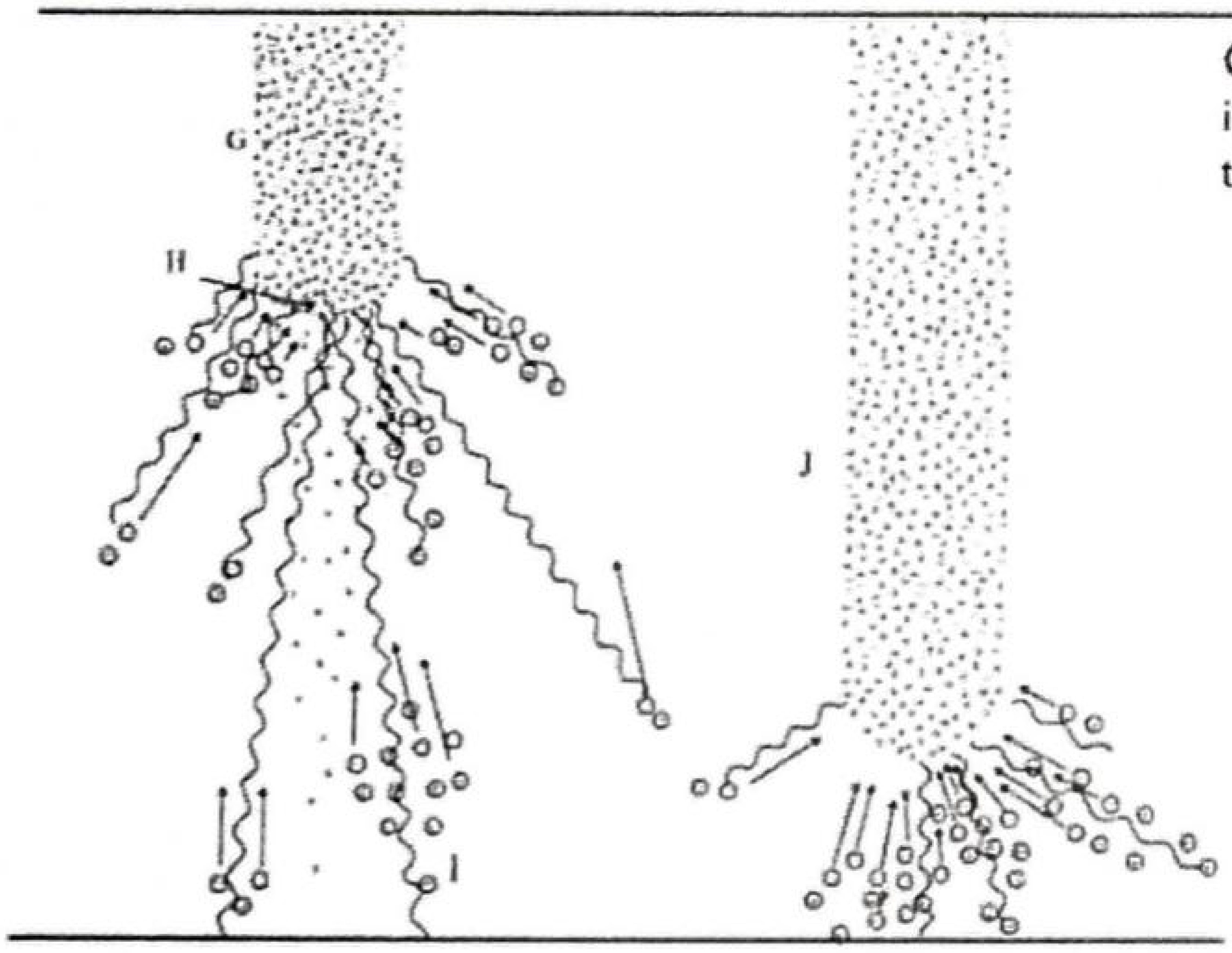
Figure shows the streamer mechanism. The streamer mechanism have several process, there were

Process 1 : Ionization process by collision cause negative charges to anode and positive charge to cathode. This process will create avalanches of electron that must lighter and higher mobility compare to positive ion. Therefore, the electron will be filled the head and the positive ion occupied the tail.

Process 2 : Space charges cause by ionization will distort the uniform field. The spherical volumes concentrate at negative charges at the head and positive charge at the tail. The field behind and a head of avalanches is increase by the space charge. The field between the electron and the cloud is reduced. This condition created an intense ionization and excitation of the gas particle in front of the avalanches head. Excited atoms return to normal immediately. The process will release of photon, which turn generate secondary electron by the photo ionization process. The generated secondary electrons from the photo-ionization will generate further auxiliary avalanches as in figure . Since photons travel with the speed of light, the process leads to rapid development of conduction channel across the gap and develop as self-propagating streamer. Streamer is initiated when the field is high enough to build up a critical primary avalanche size of 10^{8} The streamer proceeds across the gap and to form a conducting filament of high ionized gas between electrodes, the gas was breakdown .

Scanned by TapScanner

Streamer Mechanism

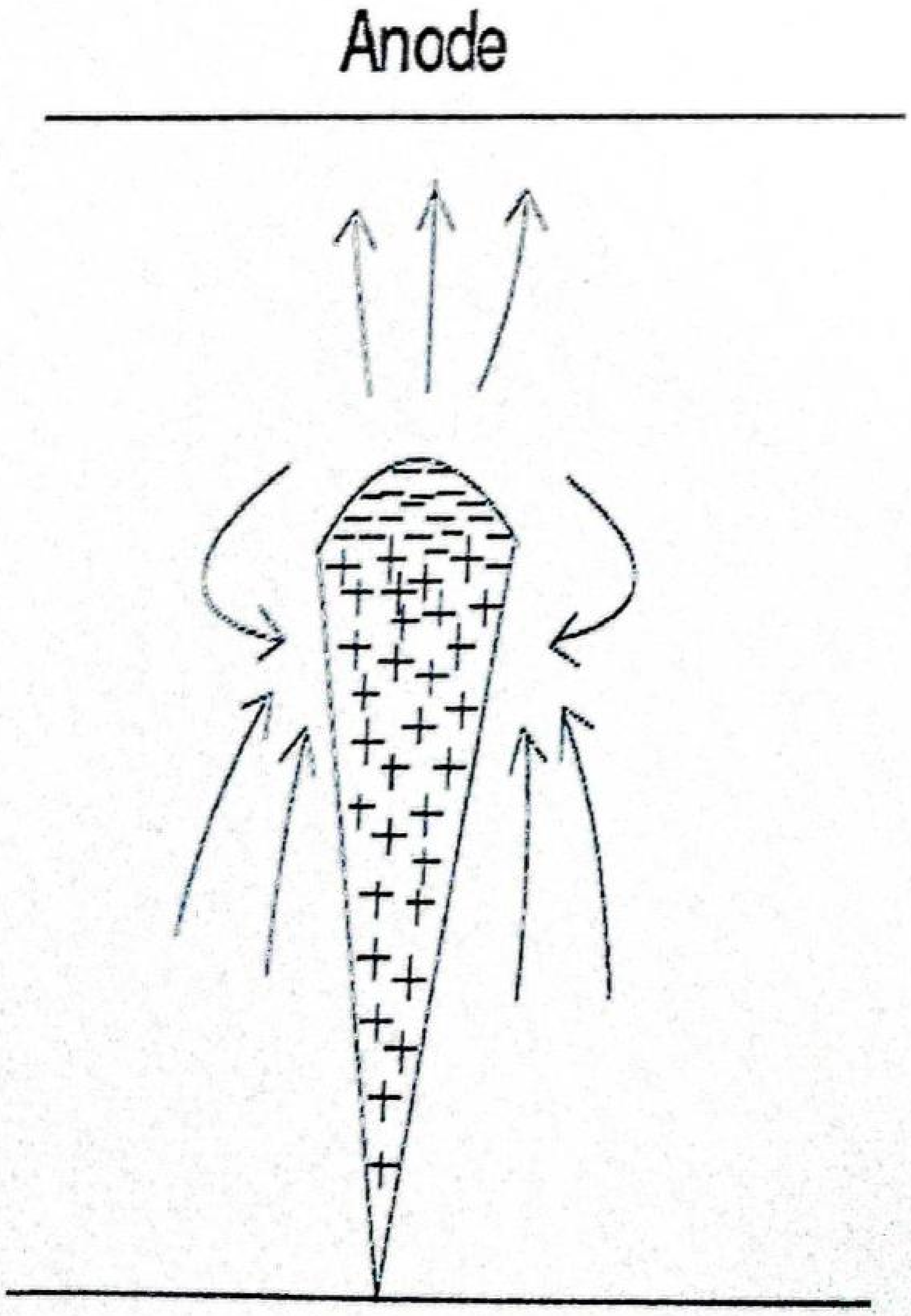


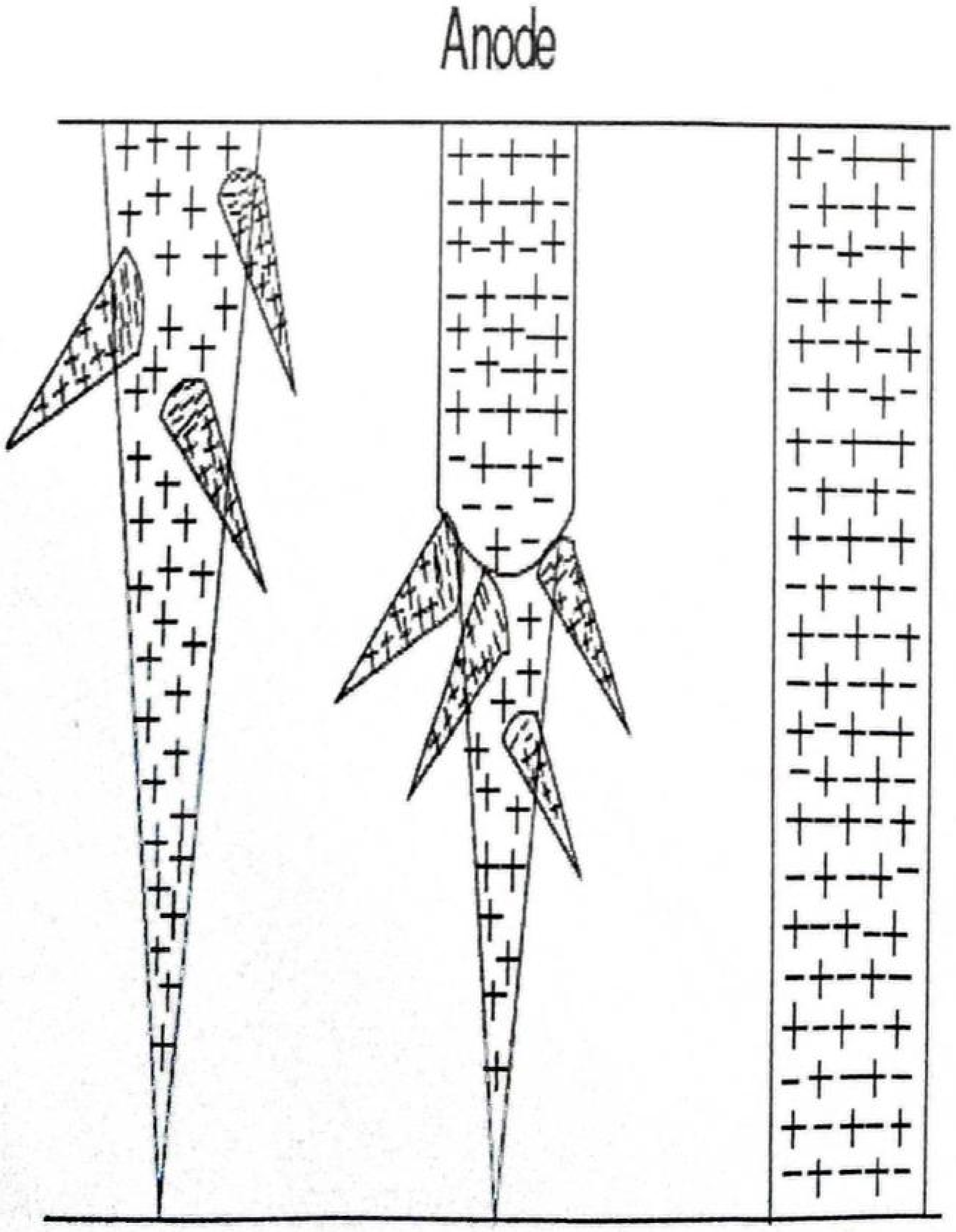
G – Plasma of positive ions and electrons forms the streamer channel

H – Streamer tip

I – Production of free electrons by photon

J – Streamer propagating close to cathode

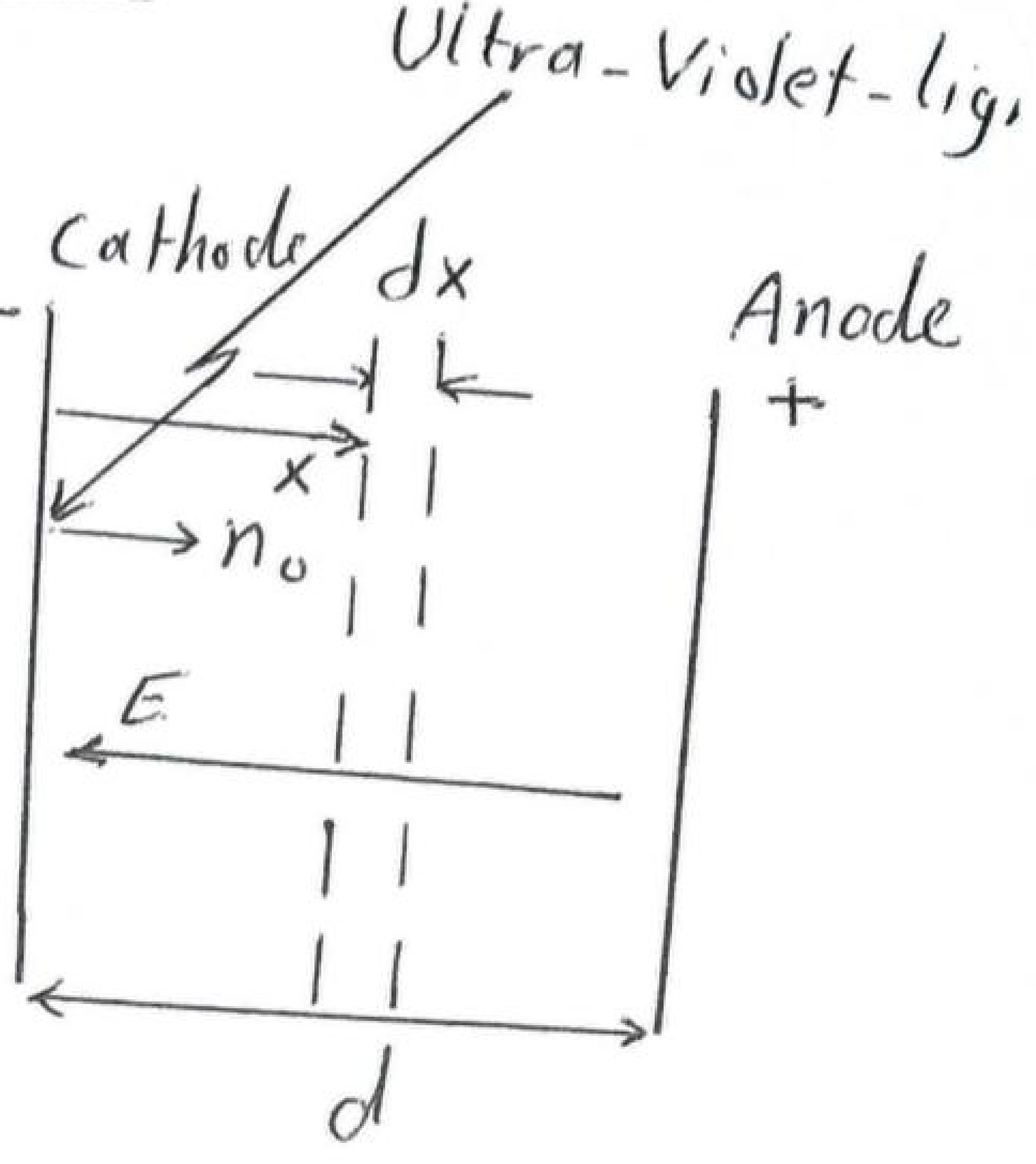




Scanned by TapScanner

Q_2 (a) Townsend's BD criterion in gases : اجابة السؤال الثانى

- Current growth



n_o are electrons emitted from $K/m^2 \cdot sec$

α : 1st ionization Coef.

n_x : number of electrons at dist. x

dn_x : the additional number of electrons produced in the slab dx

$$\therefore dn_x = \alpha n_x dx$$

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

By integration $n_o \to n_x$, $o - d$

$$\therefore n = n_o e^{\alpha d}$$

- Breakdown Criterion

γ : is the secondary electrons produced per incident positive ions, photons, metastable particles, - - her the first secondary process is considered.

n_o' : the total number of electrons liberated from the cathode $/m^2 \cdot sec$

$n - n_o'$: the number of ionizing events, this number is the number of positive ions reach the cathode and liberate $\gamma(n - n_o')$ electrons

$$\therefore n_o' = n_o + \gamma(n - n_o')$$

$$n_o' = \frac{n_o + \gamma n}{1 + \gamma}$$

Scanned by TapScanner

$$(\, n = n_0' e^{\alpha d}$$

$$= \frac{n_0 + \gamma n}{1+\gamma} e^{\alpha d}$$

$$(1+\gamma) n = (n_0 + \gamma n) e^{\alpha d}$$

$$\therefore n = \frac{n_0 e^{\alpha d}}{1 - \gamma (e^{\alpha d} - 1)}$$

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

$I \rightarrow \infty$ when $1 - \gamma(e^{\alpha d} - 1) = 0$

and the current will be limited by the circuit limiting resistance.

$(\, \gamma (e^{\alpha d} - 1) = 1$, $\because e^{\alpha d} >>> 1$

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

Scanned by TapScanner

Q_2 (b) Pachen's Law for breakdown voltage

Townsend's BD criterion is

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

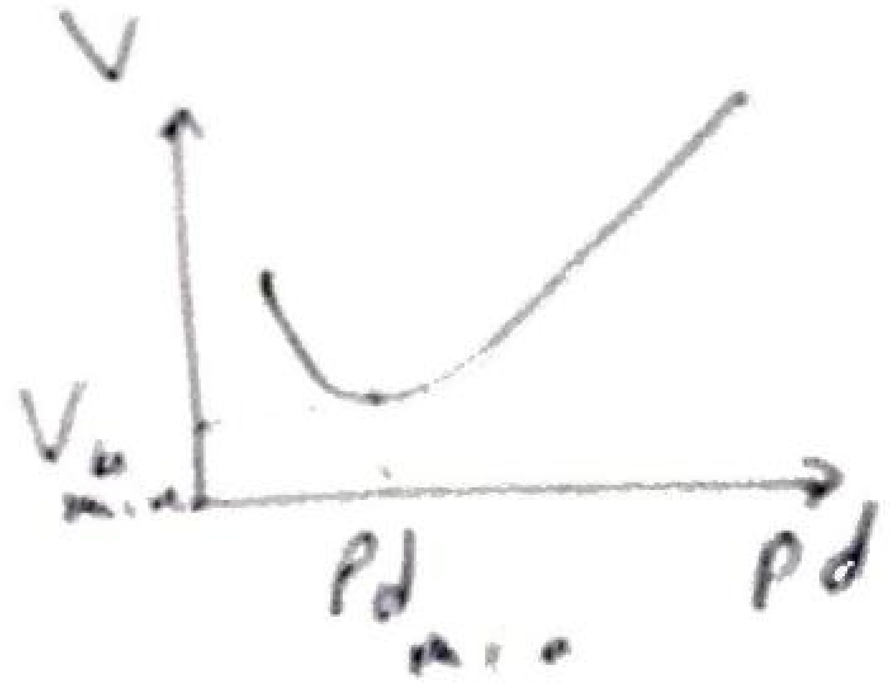
$$\therefore \alpha d = \ln\left(1+\frac{1}{\gamma}\right)$$

$\left(\alpha = APe^{-\frac{BP}{E}}\right.$, where P is the gas pressure the electric field, A, B are constan.

$$APd\,e^{-\frac{BP}{E}} = \ln\left(1+\frac{1}{\gamma}\right)$$

$$\frac{APd}{\ln\left(1+\frac{1}{\gamma}\right)} = e^{\frac{BPd}{V_b}}$$

$$\frac{BPd}{V_b} = \ln\left[\frac{APd}{\ln\left(1+\frac{1}{\gamma}\right)}\right]$$



$$\therefore V_b = \frac{BPd}{\ln\left[\frac{APd}{\ln\left(1+\frac{1}{\gamma}\right)}\right]}$$

To obtain V_b min $\therefore \frac{dV_b}{d(Pd)} = 0$

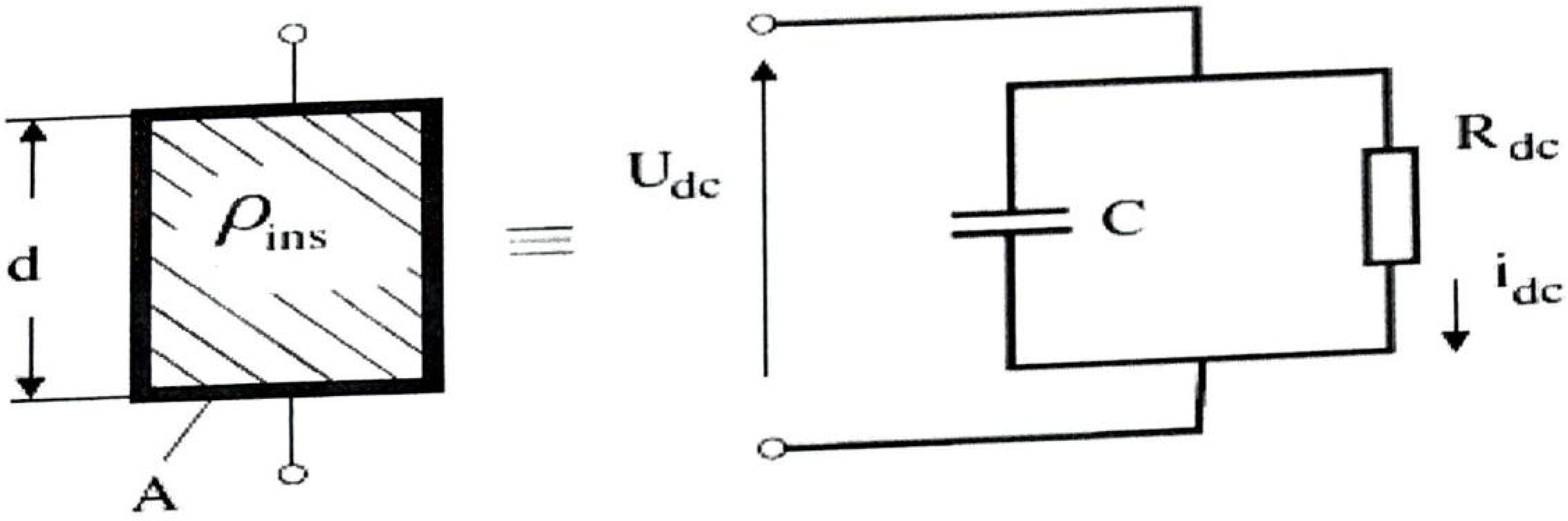
$$\frac{dV_b}{dPd} = 0 = \frac{B}{\ln\left[\frac{APd}{\ln\left(1+\frac{1}{\gamma}\right)}\right]} - \frac{B}{\left[\ln\frac{APd}{\ln\left(1+\frac{1}{\gamma}\right)}\right]^2}$$

$$\therefore \ln\frac{APd}{\ln\left(1+\frac{1}{\gamma}\right)} = 1 \qquad \therefore Pd_{min} = \frac{e^1}{A}\ln\left(1+\frac{1}{\gamma}\right)$$

$$V_{b\,min} = e^1\frac{B}{A}\ln\left(1+\frac{1}{\gamma}\right), \quad e^1 = 2.71828$$

Scanned by TapScanner

Q2 (C) HEAT GENERATED IN A SOLID DIELECTRIC SPECIMEN



When alternating voltage of rms magnitude *U* and frequency f is applied to an insulator having total effective capacitance *C.* The reactive part of the total insulation current is

$$I_C = \omega C U$$

The active part of the total insulation current is

$$i_R = I_C \tan\delta$$

$$i_R = \omega C U \tan\delta$$

Hence the active power loss " P_{ac} " is given by ,

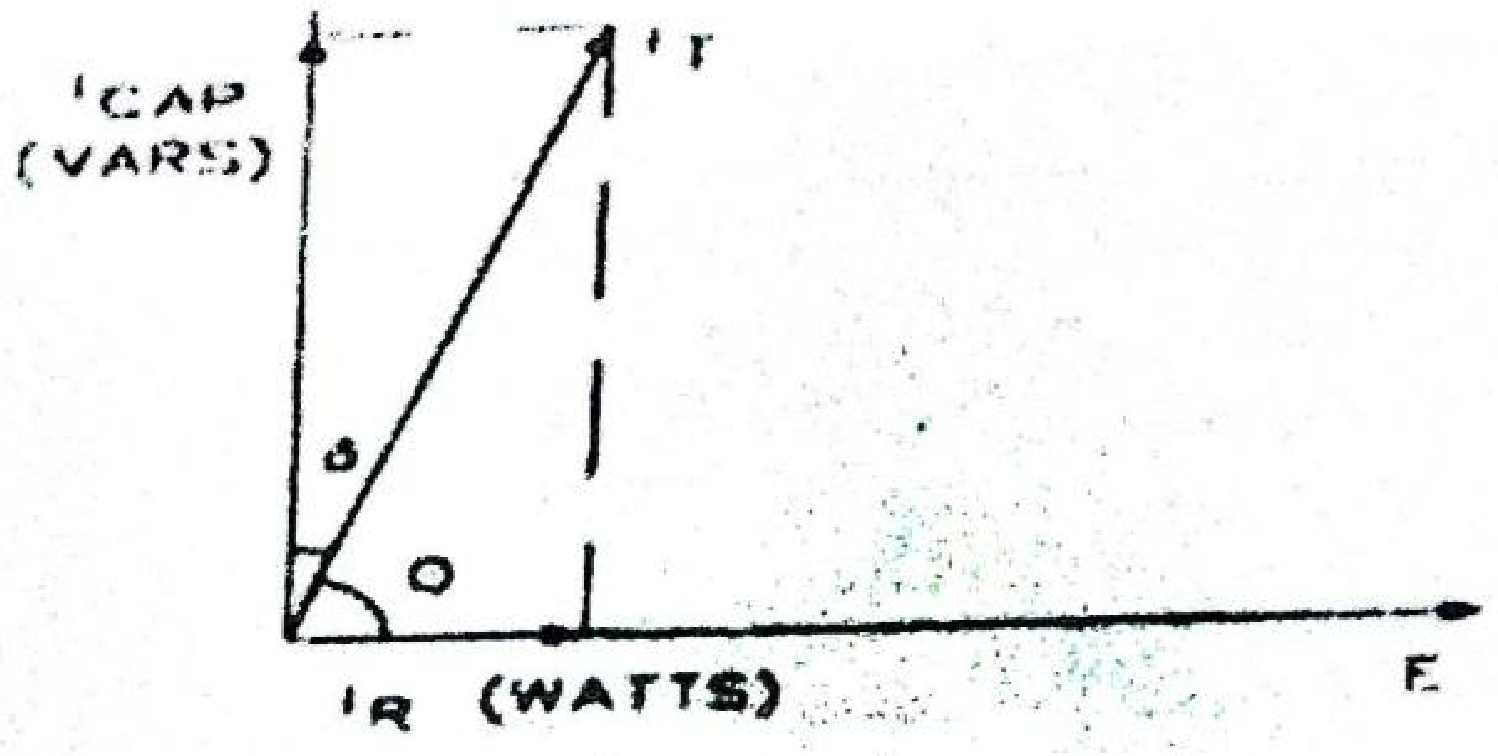
$$P_{ac} = i_R U$$

$$P_{ac} = \omega \cdot C \cdot U^2 \cdot \tan\delta$$

Considering a parallel plate condenser of area *A* and gap distance *d* having dielectric with relative permittivity ε_r forming a uniform field E

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$U = Ed$$



Scanned by TapScanner

$$P_{ac} = \omega \cdot \varepsilon_o \varepsilon_r \frac{A}{d} \cdot (E \cdot d)^2 \tan\delta$$

or

$$P_{ac} = \varepsilon_o \cdot \omega \cdot E^2 \cdot V \cdot \varepsilon_r \tan\delta$$

where V, the volume of the dielectric, is given by (Ad) in this case. the dielectric losses depend upon the applied field intensity and its frequency, volume of the dielectric, its relative permittivity, and the loss tangent.

$$P_{dc} = E^2 . V. \sigma_{dc} \quad \text{watt ,}$$

$$P_{dc} = E^2 . \sigma_{dc} \quad \text{watt/cm3}$$

$$\begin{aligned} P_{ac} &= \varepsilon_0\, \varpi\, E^2 V \varepsilon_r \tan\delta \qquad watt \\ &= \varepsilon_0\, \varpi\, E^2 \varepsilon_r \tan\delta \qquad watt/cm^3 \end{aligned}$$

$$\varepsilon_0 = \frac{10^{-9}}{36\pi} \quad \mathrm{F}/m = \frac{10^{-11}}{36\pi} \quad \mathrm{F}/cm$$

$$P_{ac} = \frac{10^{-11}}{36\pi}\, \varepsilon_r \,.\, 2\pi\, \mathrm{f}\, \mathrm{E}^2 \tan\delta \qquad watt/cm^3$$

$$P_{ac} = \frac{E^2 f \varepsilon_r \tan\delta}{1.8\times10^{12}}\, watt/cm^3$$

$$P_{dc} = E^2 . \sigma_{dc} \quad \text{watt/cm3}$$

$$\therefore \quad Heat\ generated\ E_1 = P_{ac} t\ watt\ \ \sec$$

Scanned by TapScanner

Q2 (d) Cascade transformer for HV AC GENERATION

For voltages higher than 400 KV, it is desired to cascade two or more. The weight of the whole unit is subdivided into single units and, therefore, transport and erection become easier. Also, with this, the transformer cost for a given voltage may be reduced, since cascaded units need not individually possess the expensive and heavy insulation required in single stage transformers for high voltages exceeding 345 kV. It is found that the cost of insulation for such voltages for a single unit becomes proportional to square of operating voltage.

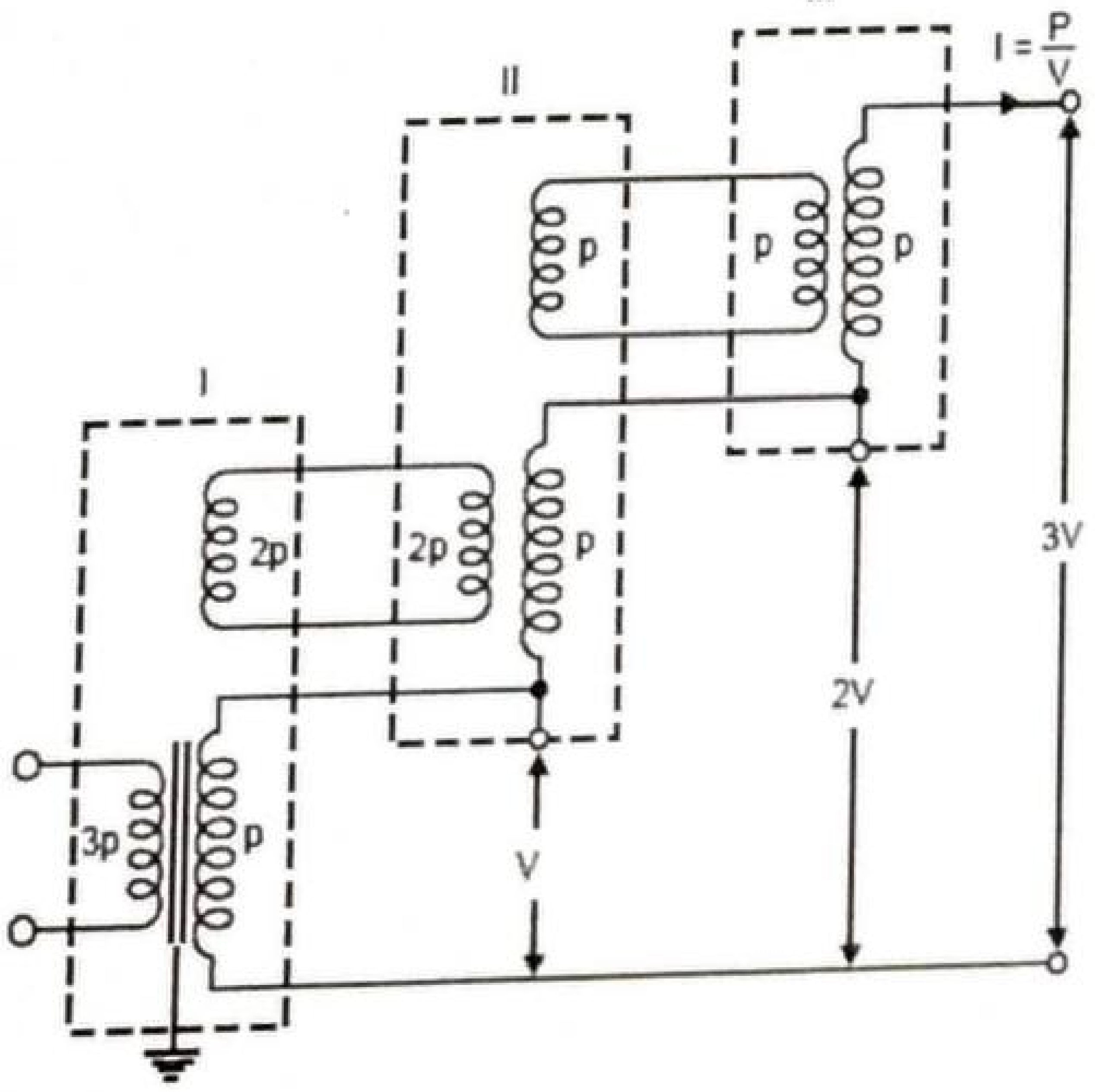


Figure 1 : A basic scheme for cascading three transformers.

- Figure 1 shows a basic scheme for cascading three transformers. The primary of the first stage transformer is connected to a low voltage supply. A voltage is available across the secondary of this transformer. The tertiary winding of first stage has the same number of turns as the primary winding and feeds the primary
- The secondary winding of the second stage transformer is connected in series with the secondary winding of the first stage transformer, so that a voltage of 2V is available between the ground and the terminal of secondary of the second stage transformer.
- Similarly, the stage-III transformer is connected in series with the second stage transformer. With this the output voltage between ground and the third stage transformer, secondary is 3V.

- 4- Figure 1 shows metal tank construction of transformers . The low voltage terminal of the secondary winding is connected to the tank. The tank of stage-I transformer is earthed. The tanks of stage-II and stage-III transformers have potentials of V and 2V, respectively above earth and, therefore, these must be insulated from the earth with suitable solid insulation.
- 5- The loading of various windings is indicated by P in Figure 1. For the three-stage transformer, the total output VA will be 3VI = 3P and, therefore, each of the secondary winding of the transformer would carry a current of I = P/V. The primary winding of stage-III transformer is loaded with P and so also the tertiary winding of second stage transformer. Therefore, the primary of the second stage transformer would be loaded with 2P. Extending the same logic, it is found that the first stage primary would be loaded with P. Therefore, while designing the primaries and tertiaries of these transformers, this factor must be taken into consideration.

Scanned by TapScanner

5 marks

Q3 (a) $\alpha = a - b\sqrt{x}$

$= 0$ $\quad \therefore x = \frac{a^2}{b^2} = \frac{(4\times10^4)^2}{(15\times10^5)^2}$

$\therefore x = \frac{16}{225\times100} = 0.711$ mm

$= 0.000711$ m

∴ ionization thickness $= x = 0.000711$m

$$n = e^{\int_0^{0.000711}\alpha\,dx}$$

$$\int_0^{0.000711}\alpha\,dx = \int_0^{0.000711}(a-b\sqrt{x})\,dx$$

$$= \left[ax - \frac{b\,x^{3/2}}{3/2}\right]_0^{0.000711}$$

$$= 4\times10^4 \times 0.000711 - 15\times10^5\,\frac{(0.000711)^{3/2}}{3/2}$$

$$= 28.44 - 18.96 = 9.48$$

$\therefore n = e^{9.48} = 13095$

at a distance $= x = 0.000711$ $\quad n = 13095$

after the ionization zone boundary i.e

if $x > 0.000711$ the avalanche will die

Q3-(b)

Two Concentric spheres $a = 0{\cdot}25$ cm
$b = 5$ cm

SF6 gas $\frac{\alpha - \eta}{p} = 27\left(\frac{E}{p} - 89\right)$

$\frac{E}{p}$ kV/cm.atm

$P = 2$ atm

(a) $E = \frac{q}{4\pi\epsilon_0 x^2}$, $V = -\int_R^r E\,dx$

$$V = \frac{q}{4\pi\epsilon_0}\left[\frac{1}{r} - \frac{1}{R}\right]$$

$$\therefore \frac{q}{4\pi\epsilon_0} = \frac{RrV}{(R-r)}$$

$$\therefore E_x = \frac{V\,R.r}{x^2.(R-r)}, \quad E_{max} = \frac{V.R}{r(R-r)}$$

when $E_{max} = 89P = \frac{V \times 5}{0{\cdot}25(5-0{\cdot}25)}$

$= 178 = 4.21\,V$ $\therefore V = 42.28$ kV

(b) $E = 89P = 178 = \frac{V\,R.r}{x^2(R-r)}$

$$\therefore x^2 = \frac{50 \times 0{\cdot}25 \times 5}{178\,(5-0{\cdot}25)} = 0{\cdot}07392$$

$\therefore x = 0{\cdot}2719$ $\therefore$ thickness $= 0{\cdot}0219$ cm (12)

Scanned by TapScanner

$$\int_{0.25}^{0.2719} (\alpha - \eta)\, dx = \int_{0.25}^{0.2719} 27P\left(\frac{E}{P} - 89\right) dx$$

$$= \int_{0.25}^{0.2719} 27\left[E(x) - 89\times 2\right] dx$$

$$= \int_{0.25}^{0.2719} 27\left[\frac{50\times 5\times 0.25}{x^2\times 4.75} - 178\right] dx$$

$$= \int_{0.25}^{0.2719} 27\left[\frac{250}{19\, x^2} - 178\right] dx$$

$$= \frac{27\times 250}{19}\cdot\left[-\frac{1}{x}\right]_{0.25}^{0.2719} - \left[178x\right]_{0.25}^{0.2719}\times 27$$

$$= 355.263\left[\frac{1}{0.25} - \frac{1}{0.2719}\right] - 4806\times 0.0219$$

$$= 114.4577 - 105.2514 = 9.2$$

$$\therefore n = e^{9.2} = 9897$$

Scanned by TapScanner

اجابة السؤال الرابع

(A) $d_1 = 1\,mm$, $d = 11\,mm$, $\epsilon_r = 4$

$V = 70\,kV_{rms}$, $50\,Hz$

$V_1 = 3\,kV$

$$V_1 = \frac{V\,d_1}{d_1 + \frac{1}{\epsilon_r}\cdot d_2} =$$

$$3 = \frac{V\cdot 1}{1 + \frac{10}{4}} = \frac{V}{3.5}$$

$$V_{inst} = 3 \times 3.5 = 10.5\,kV$$

$$V_{inst} = 3\left(1 + \frac{1}{4}\left(\frac{11}{1} - 1\right)\right]$$

$$= 3(1 + 2.5) = 10.5\,kV$$

Scanned by TapScanner

(B) $\epsilon_r = 3$, $\rho = 10^{11}\ \Omega . m$ 4 mark

$\tan\delta = 0.002$, $f = 50\ Hz$

$E = 100 kV/cm$

$$P_{\underset{a-c}{loss}} = \frac{E^2 . f \epsilon_r \tan\delta}{1.8 \times 10^{12}} \quad w/cm^3$$

$$= \frac{100 \times 100 \times 10^6 \times 50 \times 3 \times 0.002}{1.8 \times 10^{12}}$$

$$= 1.66\ mW/cm^3$$

$$P_{dc} = \frac{E^2}{\rho} = \frac{10^{10}}{10^{11}} = 0.1\ W/cm^3$$

$$= 100\ mW/cm^3$$

Scanned by TapScanner

اجابة السؤال الخامس :

(a) Impulse G. $n = 10$ $nC_1 = 0.2\,\mu f$ $C_2 = 10\,nf$. R_1, R_2 ?? for $1.2/50\,\mu s$ wave and V_{peak}, if $V_{ch} = 120\,KV$

Solution

$$C_1 = \frac{0.2}{10} = 0.02\,\mu f, \quad C_2 = 0.01\,\mu f$$

$$1.2\,\mu sec = 3 R_1 \cdot \frac{0.02 \times 0.01}{0.02 + 0.01}$$

$$R_1 = \frac{1.2}{0.02} = 60\,\Omega$$

$$50 = 0.7 (R_1 + R_2)(C_1 + C_2)$$

$$= 0.7 \times 0.03 (50 + R_2)$$

$$\frac{50}{0.7 \times 0.03} = 50 + R_2 \quad \therefore R_2 = 2331\,\Omega$$

$$V_{dc\ charging} = 10 \times 120 = 1200\,KV$$

$$V_0(t) = 1200 \left(e^{-0.0215 \times 1.2} - e^{-2 \times 1.2}\right)$$

$$\frac{1}{R_2 C_1} = \frac{10^6}{2331 \times 0.02} = 0.0215\,\mu sec^{-1}$$

$$\frac{1}{R_1 C_2} = \frac{1}{50 \times 0.01} = 2\,\mu sec^{-1}$$

$$\therefore V_0 = 1200 (0.9745 - 0.0907)$$

$$= 1060\,KV$$

Scanned by TapScanner

(b) 220/66 KV power transf.
is tested at 1.5 V_{rated} $C_n = 5nF$
$K = 1.5$

$V_{rated\ l-l} = 1.5 \times 220 = 330$ KV

$Q = K V^2 \omega C$ (VA)
$= 1.5 (330)^2 \times 2\pi \times 50 \times 5 \times 10^{-9}$
$= 0.2565$ MVA

$I_{ph} = \frac{330 \times 10^3}{\sqrt{3}} \times 2\pi \times 50 \times 5 \times 10^{-9}$

$= 0.3$ A

Scanned by TapScanner

(C) 100 KVA 250V/200KV, 50Hz

$R_T = 1\%$, $X_T = 5\%$

$V_{test\ Cable} = 400\,kV$, 50Hz

$I_{ch} = 0.5\,A$ at 400 kV

determine L_{ind} where its $R_L = 1\%$

V_{inp}, I_{inp}, KVA input

solution

$$I_{rated\ H.V} = \frac{100\times10^3}{200\times10^3} = 0.5\,A$$

$$I_{rated\ L.V} = 0.5 \times \frac{200000}{250} = 400\,A$$

$$X_c = \frac{V_C}{I} = \frac{400\times10^3}{0.5} = 800\,k\Omega$$

$$X_{LT} = \frac{5}{100}\times\frac{200\times10^3}{0.5} = 20\,k\Omega$$

$$X_{L\,tot} = X_{LT} + X_{L\,ind} \quad \therefore X_{L\,ind} = 780\,k\Omega$$

$$\therefore L = \frac{780\times10^3}{314} = 2484\,H$$

$$R_{tot} = \frac{2}{100}\times\frac{200\times10^3}{0.5} = 8\,k\Omega$$

$$V_{sec\ Tr} = 0.5\times8 = 4\,kV$$

$$V_{prim\ T} = 4\times10^3\times\frac{250}{200\times10^3} = 5\,V$$

$$\therefore \text{Input KVA} = 5\times400 = 2\,KVA$$

Scanned by TapScanner

إجابة السؤال السادس :

1- $I_f = \frac{2000}{\sqrt{3} \times 132} = 8.74\ KA$

2- Assume a mat of hard drawn copper $K_f = 7.06$

$A_{kcmil} = I_f \cdot K_f \sqrt{t_c}$

$= 8.74 \times 7.06 \sqrt{0.25}$

$= 30.85$ kcmil

$A_{mm^2} = \frac{30.85}{1.974} = 15.63\ mm^2$

∴ Cable size AWG # 2 $\approxeq 33.63\ mm^2$ at least

3- check for the step and touch criteria without crushed rocks soil surface

$E_{step\ 70} = (1000 + 6 \times 50) \frac{0.157}{\sqrt{0.25}} = 408V$

$E_{touch\ 70} = (1000 + 1.5 \times 50) \frac{0.157}{\sqrt{0.25}} = 338V$

4- Earthing mat resistance :

$R = \frac{\rho}{4r} + \frac{\rho}{L}$ ~

Scanned by TapScanner

Assume the earthing mat to have crossed wires spaced 10m. Then, the total length of the wires is $L = 2 \times 21 \times 100$
$= 4200$ m

Area $A = 100 \times 100 = 10^4 m^2$

$$\pi r^2 = 10^4 \quad \therefore r = \left[\frac{10^4}{\pi}\right]^{1/2}$$

$\therefore r = 56.42$ m

$$R = \frac{50}{4 \times 56.42} + \frac{50}{4200}$$

$$= 0.2216 + 0.0119 = 0.2335 \Omega$$

5- Ground Potential Rise GPR =

$$GPR = R S_f \cdot I_f = 0.2335 \times 0.6 \times 8740$$
$$= 1224.5 V$$

which is higher then the allowable step and touch voltage 408 and 338 V

6- Increasing the earth resistivity by adding crushed rocks soil surface which allows raising of allowable step and touch voltages

Scanned by TapScanner

$\cdot\ \rho_s = 2500\ \Omega m$, $h_s = 0.15\,m$

$$C_s = 1 - \frac{0.09\left(1 - \frac{50}{2500}\right)}{2 \times 0.15 + 0.09}$$

$$= 1 - \frac{0.09 \times 0.98}{0.39} = 1 - 0.22615$$

$$= 0.7738$$

$$E_{touch70} = (1000 + 1.5 \times 0.7738 \times 2500)\frac{0.157}{\sqrt{0.25}}$$

$$= 1225\,V$$

$$E_{step\,70} = (1000 + 6 \times 0.7738 \times 2500)\frac{0.157}{\sqrt{0.25}}$$

$$= 12607 \times 0.314 = 3958\,V$$

Hence, Allowable step and touch voltages are higher then GPR So, the design of the ground mat is good and satisfactory.

Scanned by TapScanner