BREAKDOWN IN ELECTRONEGATIVE GASES, V-t CHARACTERISTICS & POST BREAKDOWN PHENOMENA

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- The gases in which attachment plays an active role are called electronegative gases. E.g. SF_6
- One process that gives high breakdown strength to a gas is the electron attachment in which free electrons get attached to a neutral atoms or molecules to form negative ions.
- Negative ions and positive ions are too massive to produce ionization due to collisions, attachment represents an effective way of removing electrons which otherwise would have led to current growth and breakdown at low voltages.

- Two types of attachment are encountered in gases
- Direct attachment: An electron directly attaches to form a negative ion.

$$AB + e \cdots \rightarrow AB^{-}$$

- Dissociative attachment: The gas molecules split into their constituent atoms and the electronegative atom forms a negative ion.

$$AB + e \cdots \rightarrow A + B^{-}$$

A simple gas for this type is the oxygen and others are sulphur hexafluoride, Freon, carbon dioxide and fluorocarbons. In these gases, 'A' is usually sulphur or carbon atom and 'B' is oxygen atom or one of the halogen atoms or molecules.

- The Townsend current growth equation is modified to include ionization and attachment with such gases. The current reaching the anode, can be written as,

$$I = I_0 \frac{\left[\frac{\alpha}{\alpha-\eta} e^{(\alpha-\eta)d}\right] - \left[\frac{\eta}{\alpha-\eta}\right]}{1-\left[\gamma \frac{\alpha}{\alpha-\eta} e^{(\alpha-\eta)d} - 1\right]}$$

where η is the number of attaching collisions made by one electron drifting one centimeter in the direction of the field

- The Townsend breakdown criterion for attaching gases can also be deduced from the denominator as,

$$1-\left[\gamma\frac{\alpha}{\alpha-\eta}e^{(\alpha-\eta)d}-1\right]=0$$

- When α >η, breakdown is always possible irrespective of the values of α,η and γ. If α < η then an asymptotic form is approached with increasing value of d,

$$\gamma\frac{\alpha}{\alpha-\eta}=1 \qquad \text{or} \qquad \alpha = \frac{\eta}{1-\gamma}$$

- Normally γ is very small, $(\leq 10^{-4})$ and the above equation can be written as $\alpha = \eta$
- This condition puts a limit for E/p below which no breakdown is possible irrespective of the value of d , and the limit value is called the critical E/p. For SF_6 it is 117 $Vcm^{-1}torr^{-1}$, for CCl_2F_2 121 $Vcm^{-1}torr^{-1}$ both at 20˚C. η values can also experimentally determined.
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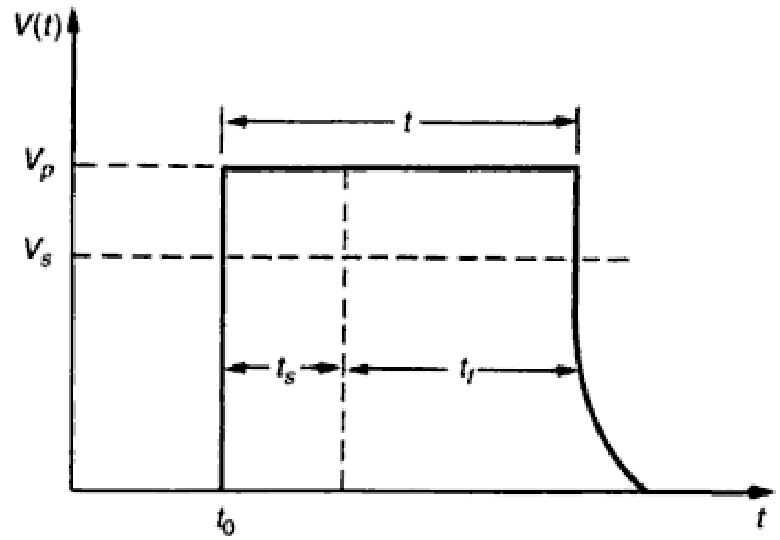
Time lags for Breakdown

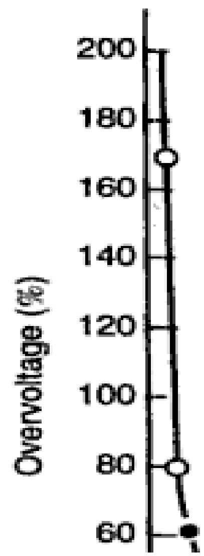
- In practical engineering designs, the breakdown due to rapidly changing voltages or impulse voltages is of great importance
- Actually there is a time difference between the application of a voltage sufficient to cause breakdown and the occurrence of breakdown itself. This time difference is called as the time lag.

- For breakdown to occur a suitable electron must appear which initiates an unbroken series of avalanches. It is considered that breakdown has occurred when the current has built up to some arbitrary value,e.g. 10^{-7} A cm^{-2}. The time between the appearance of this electron and the current reaching this value is called the formative time lag.
- The time between the application of the potential difference to the tube and the appearance of the electron which initiates breakdown is known as the statistical lag. Not every electron is successful in producing breakdown



Time lag components under a step voltage. V_s *minimum static breakdown voltage;* V_p *peak voltage;* t_s *statistical time lag;* t_f *formative time lag*

- The statistical time lag depends upon the amount of pre-ionisation in the gap. This in turn depends upon the size of the gap and the radiation producing the primary electrons. The appearance of such electrons is usually statistically distributed.
- The formative time lag depends entirely upon the mechanism of spark growth.The formative time lag increases with the gap length and non uniformity, but it decreases with the applied overvoltage.
- The formative time-lag is usually much shorter than the statistical time lag.



Time lag of spark gap as a function of overvoltage for short gap between spheres with intense u.v. illumination of the cathode in air

Paschen's law

- The breakdown criterion is $1-\gamma(e^{\alpha d}-1)=0$

where α and γ and are functions of E/p, $\alpha/p = f_1(E/p)$ and $\gamma = f_2(E/p)$. E = V/d.

Substituting we have

$$f_2\left(V/pd\right)\left[e^{pd\,f_1(V/pd)}-1\right]=1$$

- This equation shows a relationship between *V and pd,* and implies that the breakdown voltage varies as the product *pd* varies. Knowing the nature of functions f_1 and f_2 we can write the equation V= *f*(*pd*) known as Paschen's law and has been experimentally established for many gases. Paschen's law is a very important law in high voltage engineering.
- The relationship between *V and pd,* is not linear and has has a minimum value for any gas. The minimum breakdown voltages for various gases are as follows
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Gas	$V_s min(V)$	pd at $V_s min(torr\text{-}cm)$
Air	327	0.567
H_2	273	1.15
CO_2	420	0.51
O_2	450	0.7
SO_2	457	0..33
Helium	156	4.0

- The existence of a minimum sparking potential in Paschen's curve may be explained as follows:
- For values of $pd > (pd)_{min}$ electrons crossing the gap make more frequent collisions with gas molecules than $(pd)_{min}$, but the energy gained between collisions is lower. Hence to maintain the desired ionization more voltage has to be applied.
- For $pd < (pd)_{min}$ electron may cross the gap without even making a collision or making only less number of collisions. Hence more voltage has to be applied for breakdown to occur.

- For the effect of temperature, the Paschen's law is generally stated as V = *f (Nd)* where *N* is the density of the gas molecules. This is necessary since the pressure of the gas changes with temperature according to the gas law *pv = NRT.* The breakdown potential of air is expressed due to the experimental results as;

$$V = 24.22\left[\frac{293pd}{760T}\right] + 6.08\left[\frac{293pd}{760T}\right]^{1/2}$$

- At 760 torr and 293˚K

$$E = {}^{V}\!/_{d} = 24.22 + \left[\frac{6.08}{\sqrt{d}}\right] {}^{kV}\!/_{cm}$$

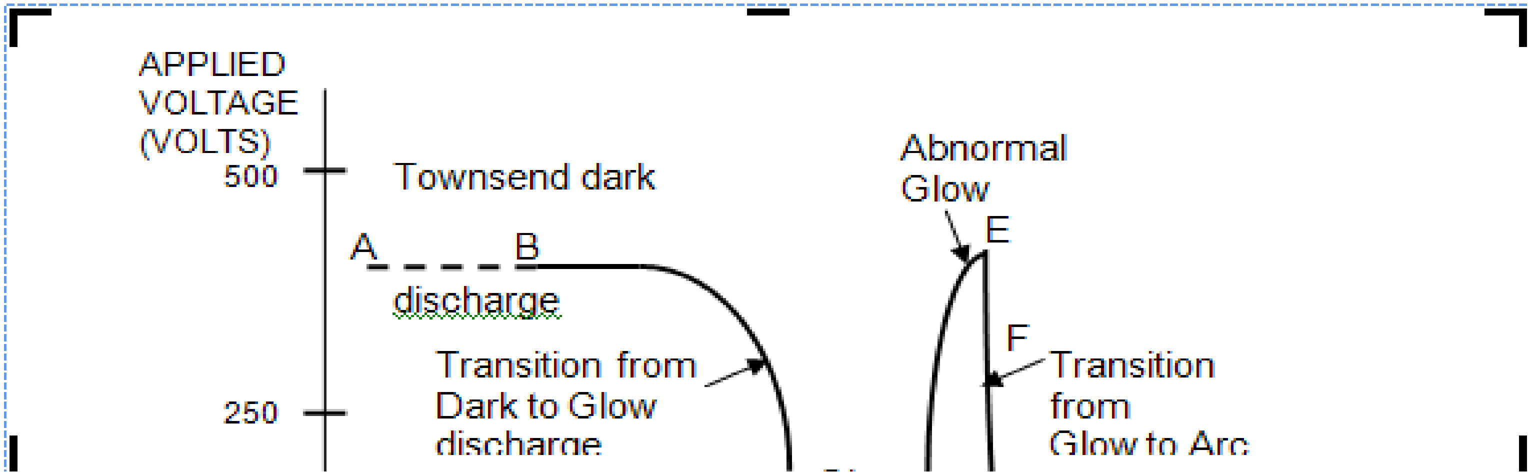
- This equation yields a limiting value for *E* of 24 kV/cm for long gaps and a value of 30 kV/cm for ,

$$\left[\frac{293\,pd}{760\,T}\right] = 1$$

which means a pressure of 760 torr at 20˚C with 1 cm gap. This the breakdown strength of air at room temperature and at atmospheric pressure.

Post-Breakdown Phenomena and Applications

- Post-Breakdown phenomenon is of technical importance which occurs after the actual breakdown has taken place. Glow and arc discharges are the post-breakdown phenomena and there are many devices that operate over these regions.


APPLIED
VOLTAGE
(VOLTS)
500
250
Townsend dark
A
B
discharge
Transition from
Dark to Glow
discharge
Abnormal
Glow
E
F
Transition
from
Glow to Arc

- The current increases gradually as a function of the applied voltage from point A. Further to this point B only the current increases and the discharge changes from the Townsend type to Glow type (BC). Further increase in current results in a very small reduction I voltage across the gap (CD) corresponding to the normal glow region. The gap voltage again increases (DE), when the current increase more, but eventually leads a considerable drop to the applied voltage. This is the region of the Arc discharge (EG). The phenomena occur in the region CG are the post-breakdown phenomena consisting of glow discharge CE and the arc discharge EG.

- Glow Discharge

A glow discharge is characterized by a diffused luminous glow. The color of the glow discharge depends on the cathode materials and the gas used. The glow discharge covers the cathode partly and the space between the cathode and the anode will have intermediate dark and bright regions. In a glow discharge the voltage drop between the electrodes is substantially constant, ranging from 75 to 300 V over a current range of 1 mA to 100 mA depending on the type of the gas. The properties of the glow discharge are used inj many practical applications, such as, voltage regulation (VR) tubes, for rectification and as an amplifier.

- Arc Discharge

  If the current in the gap is increased to about 1 A or more, the voltage across the gap suddenly reduces to a few volts (20-50 V). The discharge becomes very luminous and noisy (region EG). The current density over the cathode region increases to very high values of 10^3 to 10^7 . Arcing is associated with high temperature, ranging from 1000˚C to several thousands degrees celsius. The discharge contain very high density of electrons and positive ions, and called as arc plasma. The study of arcs is important in circuit breakers and other switch contacts. It is convenient high temperature high intensity light source. It is used for welding and cutting of metals. It is the light source in lamps such as carbon arc lamp. High temperature plasmas are used for generation of electricity through magneto-hydro dynamic or nuclear fusion processes.