CHAPTER III.

THE BREAKDOWN OF INSULATION.

3.1 Theories of the Breakdown of Air.[9]

The first theory to give a satisfactory explanation of the electrical breakdown of air was advance by Townsend. Briefly this theory may be summarized as follows: Upon the application of sufficient voltage, the free electrons in the field move toward the anode and swept out of the field. During this movement they collide with the molecules of the gas and produce new ions by collision. The newly created positive ions move toward the cathode, creating more new ions by collision, although the rate of ionization is much less than for the electrons. If the positive ions in their movement toward the cathode produce more electrons than were in the field originally, the discharge will become unstable; that is, the current will continue to increase as long as a constant impressed voltage is maintained.

Two important conclusions may be drawn from this

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[9] J.J. Torok and F.D.Fielder, Ionization Currents and the Breakdown of Insulation; Trans. A.I.E.E. Vol.49 No. 1, January, 1930. P. 352.

theory. First, breakdown takes place throughout the whole field simultaneously; second, the time of breakdown cannot be any shorter than that required for the movement of an electron from one electrode to the other and for the return movement of the positive ion. Townsend's theory, although checked and proved experimentally at low pressures, appears inadequate at atmospheric pressures. Rogowski has shown that the ionization process according to Townsend's theory requires a time of the order of 10^{-5}sec. Suppressed discharges show that breakdown does not take place simultaneously throughout the whole field. Actually, streamers form in the most intense parts of the field and these streamer cause breakdown by developing until the two electrode are linked.

Scelpian's Theory, more recently may summarized briefly as follows: Upon the application of suitable potential, free electrons in the field move toward the anode and multiply by collision. The rapidly increasing electrons, in forcing their way through the gas, produce sufficient heat to cause thermal ionization, and a streamer is formed. This sequence takes place in the most highly stressed parts of the field, which are usually at the electrode surfaces. Immediately upon the formation of the streamer the gradient at its tip becomes very high, thus increasing its growth in the same manner in which it was formed. One end of the streamer becames attached to the adjacent electrode; the other end develops at an increasing rate until the gap is spanned.

When this occurs the gap may be said to be broken down.

3.2 The Nature of Dielectric Breakdown.[10]

Generally Thermal Theory is used to explain the phenomena of dielectric breakdown. K.W. Wagner and Prof. Miles Walker stated the breiftly as follows:

" Dielectric losses occur in insulating materials, when an electrostatic field is applied to them. These losses result in the formation of heat within the material. Most insulating materials are bad thermal conductors, so that, even though the heat so produced is small, it is not rapidly carried away by the material. Now the conductivity of such materials increases considerably with in crease of temperature and the dielectric losses, therefore, rise and produce more heat, the temperature thus building up from the small initial temperature rise. If the rate of increase of heat dissipated, with rise of temperature, is greater than the rate of increase of dielectric loss with temperature rise, a stable condition (thermal balance) will be reached. If, however the latter rate of increase is greater than the former, the insulation

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[10] E.W. Golding, Electrical Measurements and Measuring Instruments, Sir Isaac Pitman & Sons Ltd. London P. 455

will breakdown owing to the excessive heat production, which burns the material.

Now, the dielectric losses per cubic centimatre in a given material and at a given temperature, are directly proportional to the frequency of the electric field and to the square of the field strength. These facts, together with the thermal theory, explain the decrease in breakdown voltage with increasing time of application and increasing temperature, and also the dependence of this voltage upon the shape, size and material of the electrodes and upon the form of the electric field.

The dielectric strength of a given material depends, apart from the chemical and physical proporties of the material itself, upon many factors as follows:

(a) The thickness of the sample tested.

(b) The shape of the sample.

(c) The previous electric and thermal treatment of the sample.

(d) The shape, size, material, and arrangement of the electrodes.

(e) The nature of the contact which the electrodes make with the sample.

(f) The wave form and frequency of the applied voltage (if alternating)

(g) The rate of application of the testing voltage and the time during which it is maintained at a constant value.

(h) The temperature and humidity when the test is carried out.

(i) The moisture content of the sample. "

3.3 Dielectric Strength of Air.

Dielectric strength of air in a uniform linear electric field at standard air density (barometric pressure of 760 mm. of mercury and temperature of 25^{o}C) is approximately 31 KV. (crest) per cm. at commercial a.c. frequencies, or 21.9 KV. (rms, sine wave) per cm. These gradients represent the dielectric strength when the duration of the voltage application is not limited in time. The disruptive gradient is proportional, within certain limits, to the air density factor; it is also affected by the shape, dimensions, and separation of the electrodes or metal terminals and by the characteristics of the applied voltage.

3.4 Corona VS Spark - over in Air.[11]

When the continuous potential applied to a pair of parallel wirs is slowly increased, a voltage will be reached at which a hissing noise is heard and a pale violet light can be seen (in the dark) to surround the wires. The voltages is defined by Peek as the "critical visual corona point. The glow or breakdown starts first at the point of maximum gradient, or at the conductor surface. The air in the broken down region is conducting and increases the effective diameter of the conductor, The corona envelope the conductor as a concentric cylinder, and the outside diameter becomes such that the gradient at that point decreases to the rupting point of the air, beyond this point the corona cannot increase, with a constant applied voltage, because the gradient decreases with increasing radial distance from the wire. When the potential is increased sufficiently, after the appearance of corona, a spark will strike across from conductor to conductor. Peek shows that the critical spacing below which spark over will occur before corona starts, are as follows for three different types of electrode: for concentric cylinder the critical spacing is $R/r = 2.72$ where r = inner radius, and R = outer radius; for parallel wires the critical spacing is $S/r = 5.85$ where r = radius of the wires, and S = spacing between their centers; for equal spheres the critical spacing is $x/R = 2.04$ where R = radius of the spheres, and x = lenght of the gap between their nearest surfaces.

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[11] A.E. Knowlton, Standard Handbook for Electrical Engineering, New York, McGraw - Hill Book Company, Inc. 1949 P. 415.

3.5 Effect of Air Density on Dielectric Strength.

The density of air varies directly as the pressure and inversely as the absolute temperature. The actual standards of reference are 760 mm. of barometric pressure and 20°C of temperature. The breakdown voltage of the sphere gap decreases with decreasing pressure (in the region of atmospheric pressure) and increasing temperature. The breakdown voltage of a sphere gap is nearly proportional to the relative air density, the value of which is given by the expression[12]

$$\delta = \frac{p\ (273+20)}{760\ (273+t)} = \frac{0.386p}{273+t}$$

where p = barometric pressure in mm. Hg.

t = temperature °C

δ = relative air density.

For higher accuracy the factor k, given below should be used instead of δ for correction of air density.

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[12] W.G. Hawley, Impulse Voltage Testing, London, Chapman & Hall Ltd. 1959 P. 69.

δ	k
0.70	0.72
0.75	0.76
0.80	0.81
0.85	0.86
0.90	0.90
0.95	0.95
1.00	1.00
1.05	1.05
1.10	1.09

3.6 The Effect of Humidity on the Dry Flashover.[13]

In their report shows that humidity affect the flashover voltages of porcelain. The flashover potential rises as the humidity is increased. W.L. Lloyd, Jr. discuss that the effect of humidity on the needle gap. The spark- over voltage increases with the humidity . The sphere gap on

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[13] J.T. Littleton, JR; and W.W. Shaver; The Effect of Humidity on the Dry Flashover, Trans. A.I.E.E. Vol. 47 No.2 April 1928 P. 438.

the other hand is apparently not effected by humidity;

J.T. Littleton and W.W. Shaver. also stated that the surface resistance of all insulators depends upon the humidity. Even a material such as fused quartz shows very large humidity effect, sothat a difference in the surface resistance of all insulators and Pyrex insulators would be expected.

Mr. Eby called attention to the fact that even number extremely dry conditions the flashover potential was not reduced to a value below the wet flashover value and he concluded therefore that humidity curves were desirable only for the purposes of rating the insulators and really had no bearing in actual service.

3.7 The Sixty-Cycle Flashover of Long Suspension Insulator Strings.[14]

R.H. Angus carried out the flashover of the string in both horizontal position and vertical position. He found that the dry flashover of similar clean strings in the two positions was not thought to be different, although the form of the electrostatic field about vertical and horizontal strings cannot be the same.

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[14] R.H. Angus A.I.E.E. Trasaction Vol. 49. No. 1 January 1930 P.15

3.7.1 The Nature of Flashover.

The flashover of an insulator string is the breakdown of surrounding air. The process of breakdown is thought to consist of ionization of the air and disturbance of the electronic orbits, consequent on the applied voltage gradient till the air attains a conducting or chemically reactive state. When this occurs a sharp spark takes place, the spark having many of the characteristics of a condenser discharge. The power arc immediately follows. In the preparation for breakdown, ionization is dependent on voltage gradient and therefore on the form of the electrostatic field. Previous to power frequency point-gap arc-overs of above 500 KV, long "streamers" sparks reach out from the electrodes. The air in the paths of these sparks is conducting and their presence must influence the distribution of the field. It is conceivable that their influence is the main cause of the widely varying arc-over values which are observed.

The field about an insulator string is, as is well known, by no means uniform. The equal capacities of the units, as they are in series, give a higher stress at the line end of the string that at any other place.

R.H. Angus stated that as the flashover of a string of insulators to a certain extent is dependent upon the initial state of ionization of the surrounding air, a constant flashover voltage cannot be expected, and the values may be represented rather by an area than by a line curve.

3.7.2 Lowest Observed Values

(1) Strings in the Vertical Position; the insulators with shields; arcing rings and tower members the lowest flashover voltage for the same arc-over distances are very similar to those for unshielded strings; the effect of the conductor is nearly as much as that of the shields is equalizing the stresses on individual units and preventing both priming and cascading.

The flashover voltage of a double string when shielded, is sufficiently near to that of a similar single string to assume that they are equal, provided they have equal arc-over distances.

(2) Strings in the Horizontal plane; in the horizontal position the conductor provides no shielding effect.

He concluded the results as following:

1) Variation in pitch, a strings in any position which are shielded, a 15 percent variation in pitch does not effect. With strings which are not shielded may result on an increase in pitch.

2) Shielding, all strings should be shielded. With vertical strings the conductor may provide sufficient shielding if the pitch and therefore the variation in stress on individual units, is not too great; though to be certain that the flashovers clear the string; arcing rings be used. In other positions the conductor may not provide sufficient shielding; then ring shields must be fitted.

3) The lowest flashover are obtained with strain strings. But these values are not below the point to grounded-plane arc overs for the same distances.

4) Double strings have the same flashover as single strings of the same length, if both are adequately shielded.

B. Cozzens stated that the voltage distribution on a wet insulator string is anything but uniform. Taking a double string that is wet, the voltage may pile up on the two or three lines units of one of the strings; so that the remaining portion of the string is practically entirely at ground potential. On the other string of the pair the high voltage stress may be on the tower end of the string. This means that the entire string with the exception of the two or three units at the tower end of the string will be at line potential. The fourth unit in this string will be at line potential, while the fourth unit in the paralleling string is at ground potential. This high potential difference between the two strings is in many cases sufficient to break down the air between the two strings, and result in a complete arc over of the string.