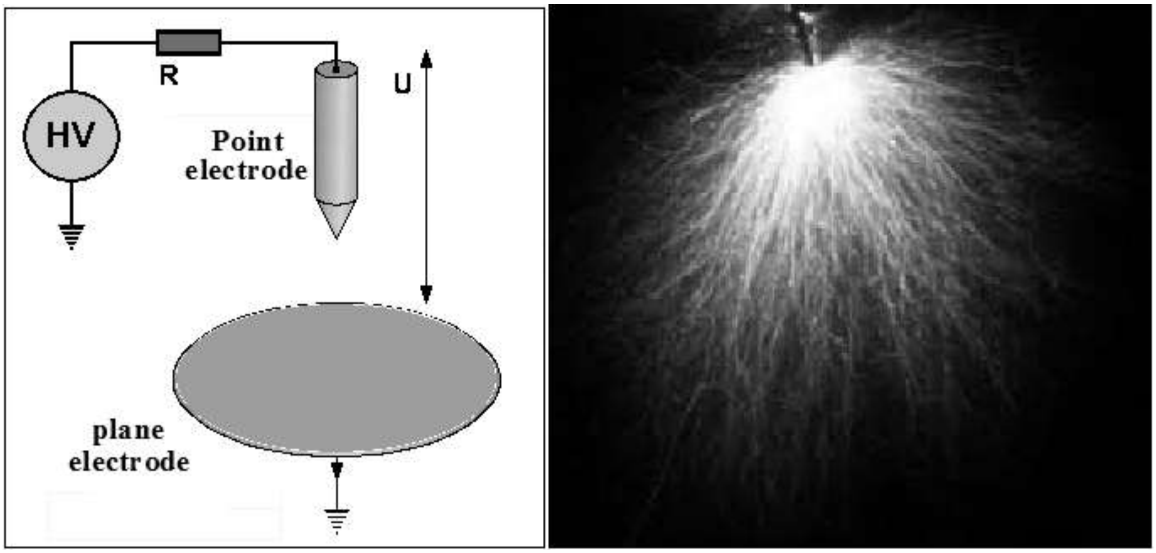
Lecture # 7

Laboratory Study of Corona and Radio Interference

Corona occurs only under non-uniform or asymmetrical electric fields (also referred to as divergent electric field). In the laboratory, corona is studied using special electrode arrangements, mainly constituting point-plane symmetry across a high voltage DC source. If the point is connected to the positive DC source with the plane electrode grounded, it will result in positive point corona or simply positive corona. In case when point electrode is connected to the negative DC with plane electrode grounded, the resultant corona is referred to as negative point corona or simply negative corona. The small radius of curvature of the point electrode acts as stress raiser and thus produces a high potential gradient around this electrode. The mathematical relation between electric field, applied voltage and the geometry of the electrode system for uniform field is given by the famous Mason's formula:

$$E_{\max} = \frac{2V}{r\ln(4d/r)} \qquad 1$$

Where: V is the applied voltage, d is the separation between the tip of point electrode and the plane electrode's surface and r is the radius of curvature of point electrode. The maximum electric field E_{max} is experienced at the tip of the point electrode and the field lines are directed towards the plane electrode and are concentrated at the tip of the point electrode, spreading apart towards the plane electrode, thus forming a highly divergent field. Fig (1) shows point-plane electrode arrangement and typical shape of visual corona in a laboratory experiment.



(a) **(b)**

Figure 1: (a) Point-Plane Electrodes (b) Typical Corona

Corona is classified as positive or negative, more elaborately as positive point and negative point corona; the terminology is used according to the polarity of the voltage on the point electrode. If the point electrode is positive with respect to the plane electrode, the corona so formed is referred to as a positive point corona. If the point electrode is connected to the negative terminal of the high voltage DC source, then the corona so formed is referred to as negative point corona. In case of AC voltages, it simply referred to as corona.

Example: Calculate the maximum electric field in MV/cm experienced at the tip of the point electrode of point-plane electrode geometry in air. The radius of curvature of the point electrode is 10µm and the electrodes are 1.5cm apart when a voltage of 5kV DC is applied. Also calculate the electric field for the same gap separation and applied voltage for uniform field electrodes.

Solution:

Given that: V = 5kV, d = 1.5cm or 0.015m and $r = 10\times10^{-6}$ m

Using:

$$E_{max} = \frac{2V}{r\ln\left(\frac{4d}{r}\right)}$$

Or

$$E_{max} = \frac{2\times5}{10\times10^{-6}\ln\left(\frac{4\times0.015}{10\times10^{-6}}\right)} = 0.115\times10^{6}\text{ kV/m} = \mathbf{1.15\ MV/cm}$$

For uniform field electrodes, the electric field will be:

$$E = \frac{V}{d} = \frac{5}{1.5} = \mathbf{3.33 kV/cm}$$

It can be seen that the electric field created between point-plane electrode configurations is much higher as compared to field experienced in the case of uniform field electrodes. The field in highly non-uniform electrode geometry (point-plane) in this example is about 345-times higher than uniform-field electrode configuration.

Mechanism of Corona

The physical mechanism of the formation of positive and negative corona is different. Due to unique feature of negative corona, we will focus our discussion on the mechanism of negative point corona.

Negative Point Corona

A negative point corona, cathode corona, more generally negative corona is characterized by pulse-type activity, varying according to the surface features and irregularities of the point electrode. The first study of such pulse characteristic experienced in negative corona was made by Trichel and therefore these pulses are referred to as "Trichel Pulses". It often appears as tufts of corona at sharp edges, though the number of tufts altering with the strength of the electric field as shown in Fig (2).

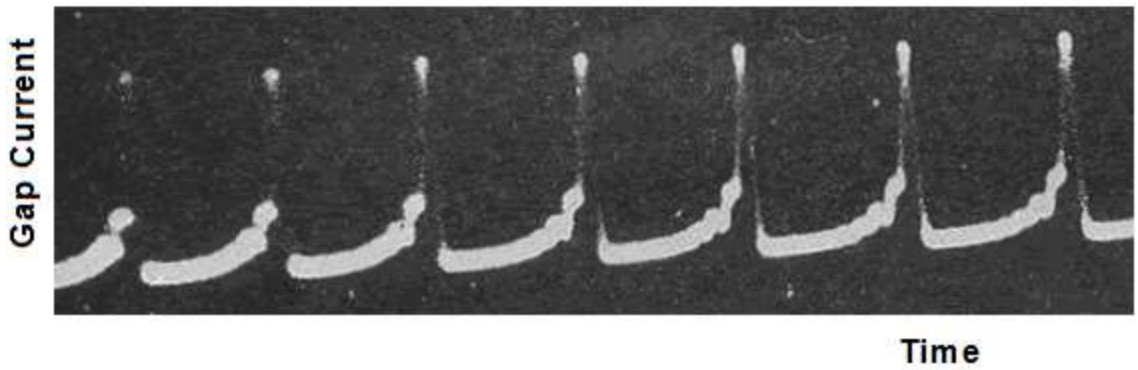


Figure 2: Trichel Pulses in Negative Corona

The mechanism of negative point corona is as follows: In air or other gases, few positive ions and electrons in the gap may be formed as a result of pre-ionization by cosmic radiations and UV rays. The initiation of a negative point corona begins with a approaching of random positive ions towards the high-field region of the point electrode (cathode). In the high-field region of the point electrode, the energy imparted to the positive ion may be sufficient to eject electrons from the point electrode on impact, resulting in electron emission from the point electrode if condition $KE \geq 2\phi$ is satisfied. If the work function of the electrode is considerably lower, it will make the point electrode a more liberal source of electrons. These electrons act as initiatory electrons for starting of massive collision-ionization event generating further electrons and positive ions, resulting in electron multiplication in the gap towards the plane electrode, followed by an electron avalanche as in Townsend current growth-type conditions. The gap current therefore grows in an exponential fashion according to the factor $e^{\alpha d}$.

The growth of current ceases when the positive ions formed during the ionization process drift towards the point electrode and therefore strengthens the local gap between the point electrode and positive ions cluster but weakens the main field between point and plane electrode resulting in a negligibly small or almost zero gap-current. The field regains its strength when most of the positive ions are neutralized by gap electrons. The process is repeated and the gap current again increases by the process described above. This explains the pulse characteristics of negative point corona, as in a typical pattern shown in Fig (2).

A negative corona can be divided into three radial areas, around the point electrode as shown in Fig (3). The region near the point electrode; where high-energy electrons collide with neutral atoms and cause avalanches is the plasma region. The outer region (near the plane electrode) consisting of both high energy electrons that are absorbed by plane electrode and electrons (usually of a lower energy) combine with neutral electronegative atoms to produce negative ions is the unipolar region. The intermediate region where electrons combine to form negative ions, but typically have insufficient energy to cause avalanche ionization, however, remain part of plasma owing to the different polarities of the charged species present and the ability to take part in characteristic plasma process. The inner region (near point electrode) is an ionizing plasma, whereas, the middle region constitutes a non-ionizing plasma. The outer region is unipolar (consisting mostly of negative charge species; electrons and negative ions).

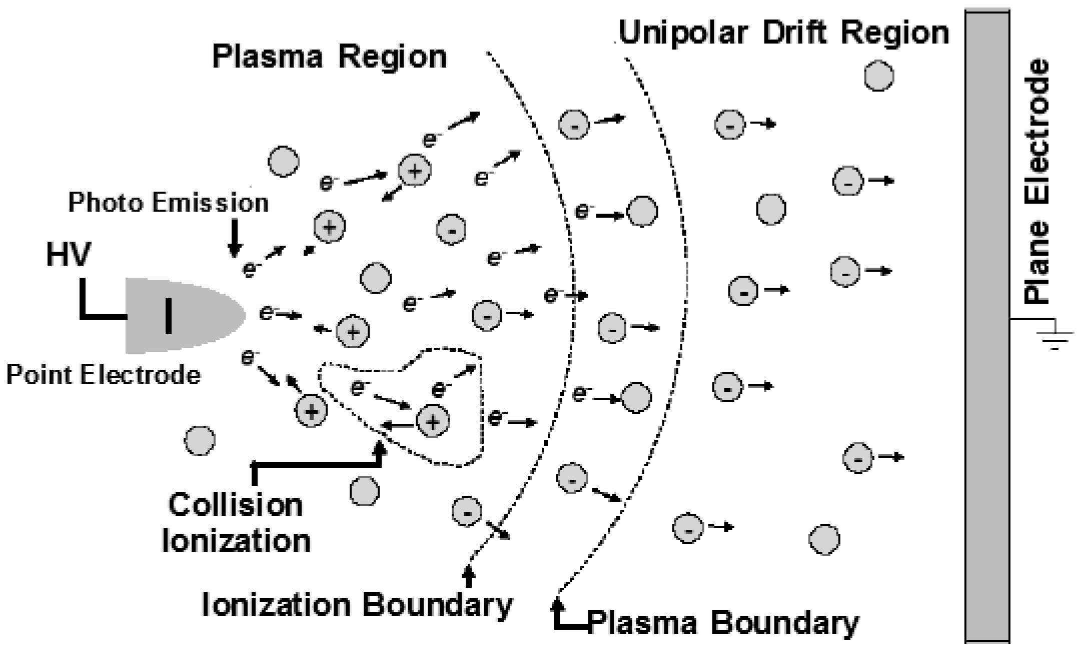


Figure 3: Illustration of Negative Corona

The pulse frequency increases with voltage and is a function of the radius of curvature of the cathode, the gap length and the pressure. When the gap pressure decreases the frequency of the pulses also decreases.

Radio Interference

Audible and visual effects generated by corona produce stray radiations that have frequencies in the radio range, typically between 3 kHz to 30 MHz. Stray radiations from corona sites usually superimpose on the information signal, thus causing its amplitude modulated which interfere with the normal Amplitude Modulated (AM) broadcast signals and produce noise in radio and television receivers. The stray radiations from corona sites interfere with nearby communication lines, especially those in the direct vicinity, thereby producing electrical interference. Interference thus appears in the audio radio receivers with standard AM broadcast band between 500 kHz to 1.6 MHz and video signal of television receiver. Information broadcasted by Frequency Modulation (FM) is virtually free from such interference. Radio interference is the phenomena generally referring to any unwanted radio frequency stray signal that prevents from clearly watching television picture, listening to radio set or conversation on cordless or cellular phone. Radio interference may prevent reception altogether, may cause only temporary loss of a signal, or may affect the quality of the sound or picture produced by the equipment. The most important source of radio interference from power system area is the corona or other discharges that take place from time to time in the hardware of transmission line and other power system equipments, and arcing, possibly due to faulty or loose connections. Interference energy from its originating source can travel by one, or a combination of processes illustrated in Fig (4), which are as follows:

1. **Radiation:** The energy is radiated into space in all directions by the overhead line, which acts as a broadcast antenna.
2. **Induction:** When the power line conductor or power supply lead carrying the interference energy is in the closes vicinity of the antenna or some portion of the receiver circuit to inductively couple the interference energy into the receiver system.
3. **Conduction:** Through transmission lines, via transformer or by means of a neutral wire into the receiver power supply wiring.

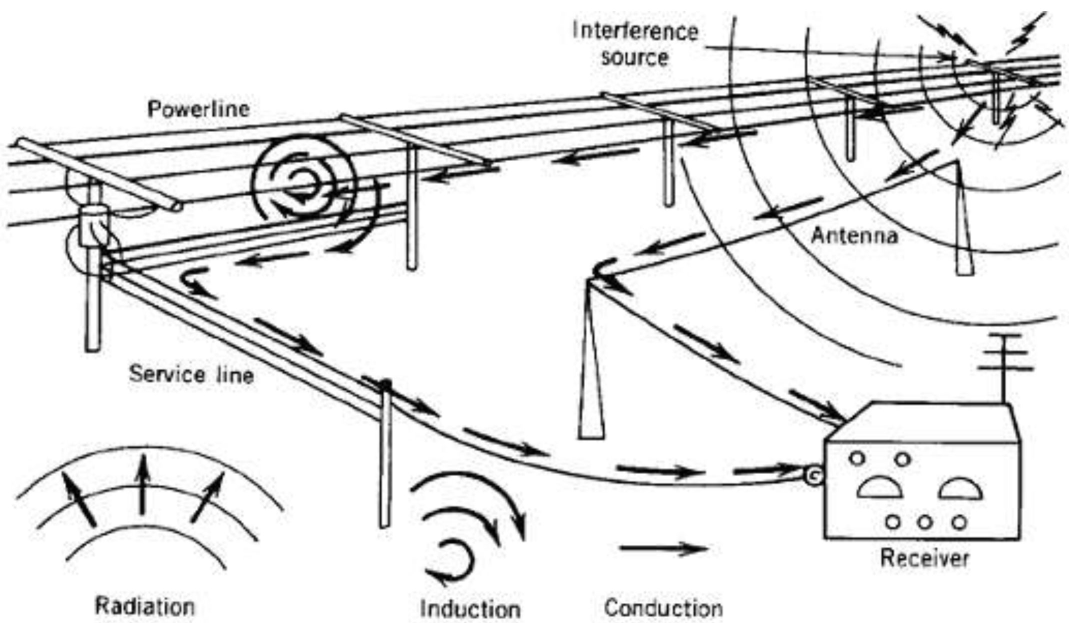


Figure 4: Modes of Flow of Interference Signal.

Transmission of interference energy by methods of conduction and induction is important at low frequencies since the conduction current decreases gradually with distance along the line as the frequency is decreased. Method of radiation becomes more important at relatively higher frequencies. Overhead power lines or other high-voltage equipments installed at, for example in a substation stations may cause electrical interference. Energy from corona-type and other visible and invisible discharges in power system equipment is the most important factor. The energy radiated from the source, when incident on antenna will induce a voltage, the magnitude of which is directly proportional to the strength of the stray signal and inversely proportional to the distance of the equipment from the interference generating source. The radio interference characteristics of a transmission line conductor are specified by Radio Influence Voltage (RIV) generated on the surface of the conductor, the threshold of which coincides with the appearance of visual corona.

During audible corona, the RIV is negligibly small, but with the initial appearance of visual corona, RIV level increases, reaching very high values for small increases above the visual corona voltages. Ambient conditions of rain, snow and humidity increase radio interference and thus RIV.

A simple method of determining the location of electrical interference is by using a special portable AM receiver tuned to 1 MHz (in standard AM broadcast band) with a bandwidth of 5 kHz, using a quasi-peak detector having a charging time constant of 1 ms and a discharging time constant of 600 ms. For measurements in the radio interference range, a rod antenna is usually used for determination of the electric field component and a loop antenna is normally used for the determination of the magnetic field component.