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RESEARCH ARTICLE OPEN ACCESS

LIGHTNING PROTECTION ON TRANSMISSION LINES

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ABSTRACT

Installation of ground wires is the basic method for protection of an OHL against lightning. Back-flashovers are the most frequent kind of trip outs in the case when an OHL is equipped with ground wires. At medium voltage OHL with high tower footing impedance almost every lightning strike to the line causes a trip out. The secondary effect of the lightning stroke became the major concern due to strong magnetic field around the downward conductor connecting the lightning rod to the grounding system. The prevention of the direct lightning strokes into the premise is one of the ways to eliminate the damaging consequences of the secondary effect. This report deals with brief overview on Prevention methods of lightning protection namely Charge Transfer System. The efforts to evaluate the influence of the space charge on the total electric field are undertaken in this paper. It illustrate emphatically the lightning protection technique that we advanced by rejecting and combining rejection with attraction.

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INTRODUCTION

Lightning protection systems can be classified into the following classifications:

- Collection of lightning strokes
- Prevention of lightning strokes
- Combination of both Collection and Prevention

The Franklin rod is considered a collector, as it is provide safe path to the charge accumulated in the cloud to the ground. During the past 250 years Franklin rod successfully protected the structures from the lightning-caused damage. That was the only requirement to the lightning protection against direct hits till last 40 - 50 years. In the recent 4 decades, due to the explosive progress in computers, electronics technology, the secondary effect of the lightning stroke became the major concern in many cases generated by lightning current, the strong magnetic field around the downward conductor connecting the lightning rod to the grounding system caused the induced voltages of such a magnitude that it permanently damaged or caused malfunction of sensitive electronic equipment located nearby. The prevention of the direct lightning strokes into the premise is one of the ways to eliminate the damaging consequences of the secondary effect. Such systems developed in recent years were Dissipation Array System (DAS), The Ion Plasma Generator (IPG), The Spline Ball lonizer (SBI) and Spline Ball Terminal (SBT) etc... All these system can be called by a common name as the Charge Transfer System (CTS).

Prevention of lightning strokes: The array is designed to dissipate the charge between cloud base and ground, therefore reduce the electric field intensity that will result, prevention of lightning strike on the site. This is generally known as "Charge Transfer". The direct stroke prevention ability of such a system is based on the physical phenomenon called point-discharge.

Point Discharge: Sharp edged objects such as leaves of trees, bushes, grass as well as pointed electrodes such as lightning rods, when exposed to the strong electric field, electrons are accelerated and collide with gas molecules will ionize the air surrounding the sharpened points. This small amount of ionized air is at the tip of the sharp point or water droplet start to emit current into the surrounding air [Mark, 1999]. This phenomenon passes through three stages as follows

Passive state: Which exists at electric fields lower than 10 Kv/meter, no activity is noted as shown in Fig 1.

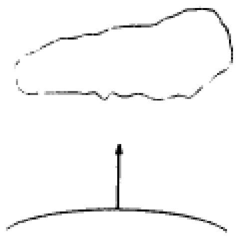

Figure 1. Passive State

Corona State: It is initiated at about 10Kv/meter. Ionization of the air molecules adjacent to the point is created when electrons are removed from these molecules. The ionization activity and the related current flow increase exponentially as the potential on that point is increased as shown in the Fig 2.

Streamer state: Visible channel starts when the ionization current from any one point exceeds the ability of the combination of wind and the electrostatic field to move *the new ions away from the point fast enough. The air then breaks down and forms the visible channel and they often become lightning collectors as shown in the Fig 3. CTS must never pass in to the streamer mode, conversely it must pass in to the corona mode quickly and remain there.*

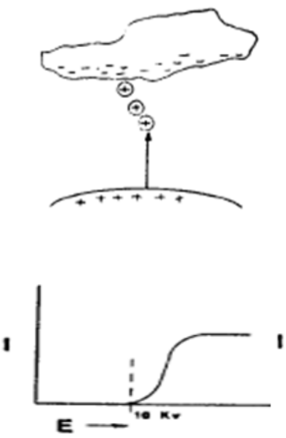

Figure 2. Corona State

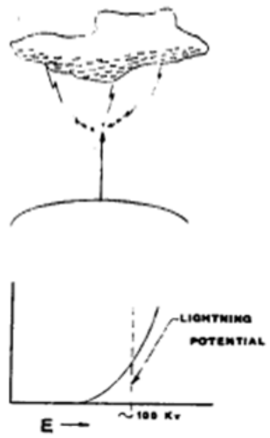

Figure 3. Streamer State

Space Charge: Because of electric field of the charged cloud overhead, a slow and continuous point discharge of charged ions will take place from any sharp point.

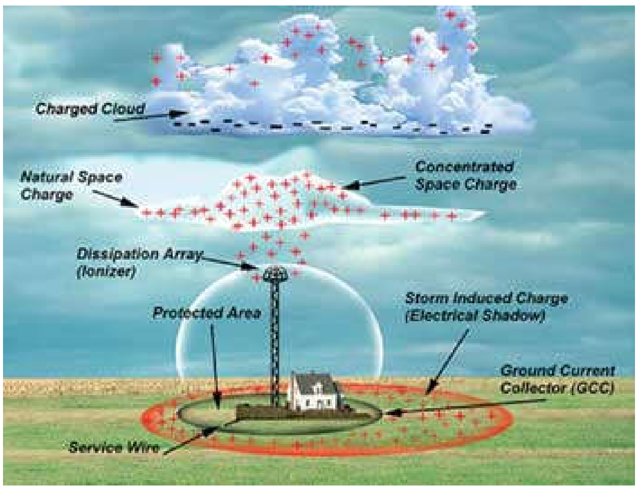

Figure 4. Charge Transfer System

This will leads to development of the opposite charge from the bottom of the cloud overhead around the sharpened points as shown in the Fig 4. The size of such a space charge depends on many factors, such as strength of the electric field, no of points on CTS, distance between cloud and CTS as well as wind velocity past the points, and barometric pressure.

Effective Electric Field: A relatively small space charge 'qsc' above the sharpened points, causes a significant reduction of the total electric field strength at the points. This is because the electric field is proportional to the size of the charge but inversely proportional to the square of the height of this charge. The magnitude of critical electric field can vary widely depending on factors like an availability of free electrons in that area, barometric pressure, temperature. The following empirical formula used frequently in power transmission and distribution engineering to determine the critical value of the electric field strength which will start a corona from the line conductors.

$$E_{cr} = 23.3\delta\left(1 + \frac{0.62}{\delta^{0.3} r_0^{0.38}}\right),$$

Where δ is the relative air density factor depending on temperature and pressure, and ro is the radius of the conductor. In calculations of the electric fields due to the lightning, the thunderstorm cloud is often represented by a simplified model of point charges located on one vertical line as shown in the Fig 5. The main positive charge is at the top of the cloud, the negative charge at the bottom of the cloud, and an additional local positive charge at some distance below the negative charge**.** The electric field at the ground level can then be calculated by the following equation

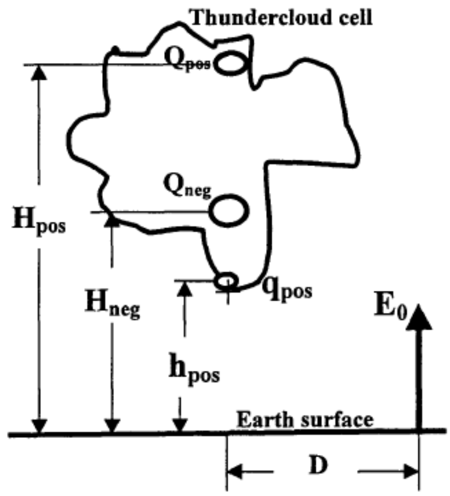

Figure 5. Simplified Model of a Thunder cloud cell

$$E_0 = \frac{2Q_{pos}H_{pos}}{4\pi\varepsilon_0(H_{pos}^2+D^2)^{3/2}} + \frac{2Q_{neg}H_{neg}}{4\pi\varepsilon_0(H_{neg}^2+D^2)^{3/2}} - \frac{2q_{pos}h_{pos}}{4\pi\varepsilon_0(h_{pos}^2+D^2)^{3/2}}$$

Where: Qpos and Qneg are the positive and negative charges of a thundercloud cell. qpos is a local positive charge below the thundercloud cell. Hpos and Hneg are the heights of the corresponding charges above the ground level. D is the horizontal distance of the point at the Earth's surface from the thundercloud cell charges.

Under influence of the rapidly increasing electric field, E the ionization of the air surrounding the sharpened points is intensified, leading to development of the positive space charge around the sharpened points. An increasing space charge will weaken the electric field at the points. The new value of the electric field strength with consideration of an additional positive charge qsc at the height hsc above the ground.

$$E_0 = -\frac{2Q_{pos}H_{pos}}{4\pi\varepsilon_0(H_{pos}^2+D^2)^{3/2}} + \frac{2Q_{neg}H_{neg}}{4\pi\varepsilon_0(H_{neg}^2+D^2)^{3/2}} - \frac{2q_{pos}h_{pos}}{4\pi\varepsilon_0(h_{pos}^2+D^2)^{3/2}} + \frac{2q_{sc}h_{sc}}{4\pi\varepsilon_0(h_{sc}^2+D^2)^{3/2}}$$

A relatively small space charge, qsc causes a significant reduction of the total electric field strength at the points. The more current that is flowing from the sharpened points into the air, and the longer duration of that current flow, the larger the space charge will be. An increasing space charge will weaken the electric field at the points. The point discharge current will continue to flow until the electric field strength drops below the level where the further ionization will cease to exist. At this particular phase of the lightning development process, the situation exists where the space charge above the sharpened points acts as a shield to the direct lightning.

Charge Transfer System: The CTS is designed to enhance the local electric field, providing an earlier initiating of the ion current. The multitude of the points of the CTS produces an ion current of such a magnitude that a resulting space charge will interact with the lightning channel reducing the electric field strength at the CTS location. As result of such a reduction of the electric field, the direct stroke into the CTS and the structure protected by the CTS becomes less and less possible. This is the stroke prevention mode of the CTS performance.

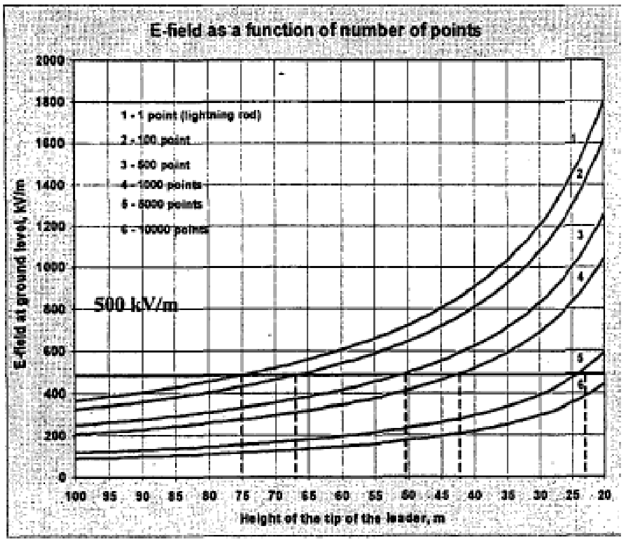

Figure 6. Electric field intensity as a function of number of Points

The CTS with limited numbers of points has a limited ability to prevent lightning stroke into itself but has also the better than lightning rod ability to collect lightning strokes because of the stronger and longer streamers produced much faster when interacting with lightning channel. Therefore, the protection zone of the CTS has to be larger than of the lightning rod of the same height. CTS with a large number of points reduce the electric field in the air gap between the tip of the leader and points of the CTS to the level below the breakdown value as shown in the Fig 6, preventing the occurrence of the direct lightning stroke into the structure protected by such a system.

Equipment

The CTS consists of three elements:

- The Ionizer or dissipater
- The ground current collector
- The conductors connecting the dissipater and the ground current collector.

Ionizer: The Ionizer consists of spiked wire, similar to barbed wire, either strung across rooftops like barbed wire or wound on a form. There are many shapes and forms for the Ionizer. One common form is shaped like a beach umbrella with the spikes closely wound around the top as shown in the Fig. 7.

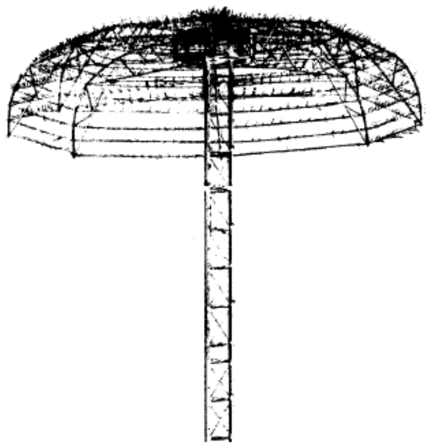

Fig 7 a) Umbrella Type Ionizer

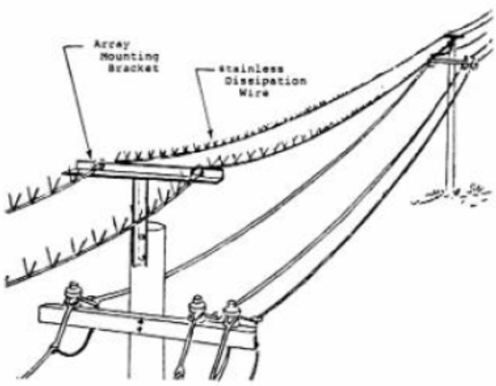

Figure 7. b) Ionizer on Transmission line

Ground Current Collector: Extensive testing of the soil resistivity is conducted before a system is installed. The earthing method used varies depending on the soil conditions. At one time, the earthing system consisted of ground rods about 1-m long (40 in). The ground rods are spaced about 10 m (33 ft) apart as shown in the Fig 4. Chemical ground rods were used sometimes, depending on the soil resistivity. If available, other grounding objects were interconnected, such as utility systems, building electrical ground systems. The object was to have an extremely low earth resistance connection.

Conductor: Previously, the earthing connection was connected to the ionizer by conductors buried 25 cm (9.8 in) deep. However, presently a unique method is used to interconnect the chemically activated grounding electrode system. A thin-wall soft copper tubing of at least 1.27 cm (1/2 in) diameter, consisting of 99% pure copper or 4/0 AWG bare stranded conductor is used to connect together the chemically activated grounding electrode system.

The electrodes are connected together in a single point connection to achieve a common point grounding (CPG) system. The object is to achieve low resistance to earth. Since a single-point distribution system is to be utilized, all runs from each rack of equipment, including surge protective devices, telephone lines, and all related equipment are to be run separately. They are to be connected to the single-point ground within the building.

Possibility of Controllining the Downward leader: The counter leader is initiated from the object under the influence of the equivalent electric field produced by the charges of a thundercloud cell and a downward lightning channel. The values of the electric field are quite different. The field is rising rapidly to the values exceeding by one or two orders of magnitude the field produced by a thunderstorm cell. Two problems have to be solved by developing the possible ways to control downward lightning. The first problem is the study of the non-stationary corona produced under influence of the fast rising electric field and the redistribution of the electric field near the electrode in the fast changing lightning environment [Edward, 2003].

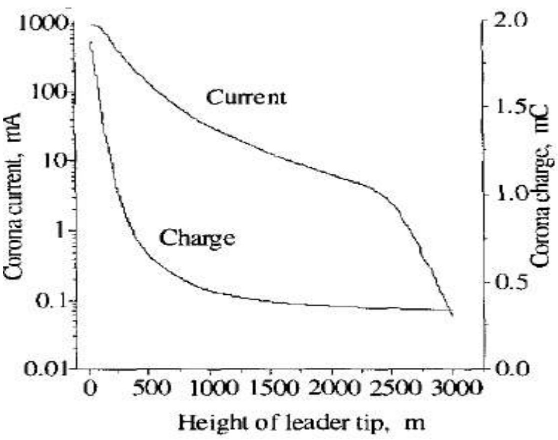

Figure 8. Corona current and injected space charge as functions of the tip height of the approaching downward leader

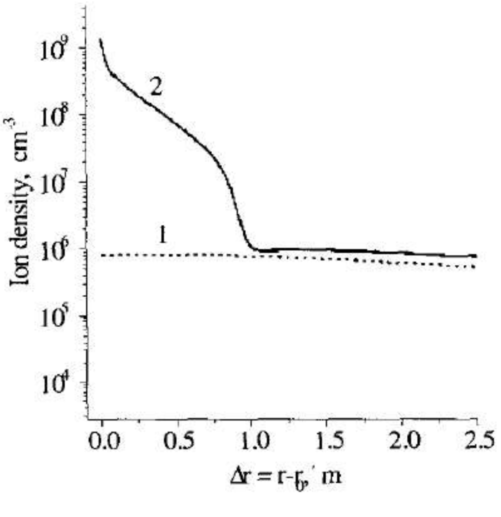

Figure 9. Ion density distribution of point rod

The corona current and space charge as a function of the height of the downward leader's tip. As can be seen from Figure 8, the intensification of the corona by the approaching lightning leader is so strong that the corona current increases almost four orders of magnitude. The peak of this strong electric field has to detach itself from the surface of the corona producing electrode and to move into the air gap.

The theoretical criterion obtained in [Edward M. Bazelyan, 2003] connects the initiation of the streamers with the critical value of the corona current as follows:

$$I_{cor.max} = 8\pi\epsilon_o\mu r_o E^2_{cor}$$

For the conventional lightning rod with radius of the tip equal to r_o = 1-10 cm and typical ion mobility, μ equal to 1.5 cm^2 /(Vs) the corona current of the transition to the streamer form is estimated to be equal to 3 - 30 mA. Such values are practically always produced under the influence of the electric field of the downward leader. In the case of the multi-point corona producing electrode with a large radius like the DAS the total corona current is distributed among the multitude of the points. Thus, it is relatively easy to control the corona current from the single point and limit its value below the critical current even in the case of the extremely large total corona current.

All that needs to be done is to increase the number of points to that slightly above 1000. The ability to limit corona current below the critical value underlines the second advantage of the large multi-point protection system - high probability of the stable existence of the streamer free corona discharge in close proximity of the rip of a downward leader. Reduction of the lightning strokes by the downward leader to the protection system is ensured by delaying the initiation of a counter leader caused by the corona space charge injected into the thin layer near the electrode during 10 -20 ms of the downward leader propagation.

Combination of both Collection and Prevention

The protective range of lightning rejector increases with the increase of rejector's height, but there is a limitation on critical height. If the rejector's height is over critical height, combining rejection with attraction must be used. For important protected objects, combining rejection with attraction should be used though rejector's height is not over critical height [Liu Xuanyi and Guan Shuilong]. When the protected object is higher, lightning rod is placed outside the device's protective range. This will guarantee the device and the objects in the device's protective range are not be struck. This is the combination of rejection with attraction. The devices of lightning rejection and combining rejection with attraction are widely used in Sub stations, group of oil tanks and warehouse of combustible things.

Conclusion

Collecting of lightning strokes may damage the sensitive electronic equipment due to secondary effect. The Prevention of lightning strokes into the premise is one of the ways to eliminate the damaging consequences of the secondary effect.

- CTS with a large number of points will reduce the electric field in the air gap between the tip of the leader and points of the CTS to the level below the breakdown value.
- It also prevents the occurrence of the direct lightning stroke on the structure protected by such a system and reduces the secondary effect of the lightning stroke.
- If the protected objects are higher than critical height of the rejecting device, it is necessary that the combination of rejection with attraction be used.

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