Recent Research in Science and Technology 2014, 6(1): 183-187
ISSN: 2076-5061
Available Online: http://recent-science.com/

Lightning phenomena and its effect on transmission line

Swati Agrawal and Manoj Kumar Nigam

Department of Electrical Engineering, R.I.T, Raipur, India.

Abstract

As we know that Lightning is one of the most natural and serious cause of over voltage .So, my this paper describes about the lightning phenomena, the way it is caused and in the manner it effects the power equipments, building frames, transmission lines, etc It is matter of great surprise to know that over the whole world ,more than 40,000 lightning strokes per day and less than 100 lightning strokes per second takes place. Transmission lines functions as arteries that carry electricity from power stations to regions where the power is needed. Therefore, it is vital to control the construction and maintenance costs of these lines because while the frequency of transmission line faults resulting in power loss has decreased year by year yet the trouble due to natural cause lightning is not yet reduced The main object of this paper is to study the effect of lightning strokes on transmission lines which cause great damage due to traveling waves to the electrical equipments installed in open air and insulators, etc. Frequently lightning problems do not receive consideration during the design stage. It remains then for the lightning safety engineer to analyze the effect of thelightning during operations and to provide rational for safety through modification to the Assets, Facilities and Structures.

Keywords: Pilot leader, streamer, Back flash over.

INTRODUCTION

There are many theories which reveals statement of the acquiring charges by the clouds but main concept behind the occurrence of the lightning stroke is that the positive and negative ions in all attach to the dust particles and forms small droplets of water which gets suspended in air and due to polarization by induction they get charged to certain potential value under storm condition. When the clouds get charged with either positive or negative ions and has opposite charge is induced on the earth surface[2].

Suppose if the cloud gets charged with positive ions then opposite charge that is negative ions induced on the earth surface. When the charges acquired by the cloud increases the potential between earth and cloudpotential gradient reaches about 5KV to 10 KV/cm it breaks down the surrounding air, as a result of which streamer, which is also known as flash of lightning or initial flash is developed.[7]. This streamer starts from cloud and carries accumulated charges along with it. This streamer or initial flash is also known as Pilot Leader. This pilot leader will move in downward direction and if the potential gradient of the pilot leader is less than that of break down voltage of air then this initial flash / streamer will break in the middle and speed of Pilot leader so formed is about 30cm/ µsec. When the pilot leader reaches near the earth surface the electrostatic field is increased and Streamer strikes the earth surface resulting into a sudden spark and the contact of cloud and earth surface together produces an action similar to that of switch between cloud and earth that is between positive and negative charges. Now, the entire charges from cloud enter the earth surface and neutralizes. Now, as we know that every action has an equal and opposite reaction then this action of cloud is being opposed by the earth surface as a result of which a high reverse current travels at high rate from earth to cloud (at a speed of about 2.5mA/ µsec) but still the speed of reverse current is notmaximum enough to reach the cloud as a result of which it startsdecreasing. The Cloud being positively charged and earth being negatively charged with air acting as a dielectric form a charged condenser.[8]

Consider a negative charged cloud which induces positive charges on the earth. As the Streamer propagates downwards it is in the form of inverted tree and only part of it strikes the earth and as soon as the earth opposes it a high reverse current with positive charge starts flowing from earth to cloud and meet the scattered streamer carrying on thenegative charge from cloud as a result streamer gets neutralizes and path gets completed.

MECHANISM OF LIGHTNING

Lightning is an electric discharge in the form of a spark or flash originating in a charged cloud. It has now been known for a long time that thunder clouds are charged, and that the negative charge centre is located in the lower part of the cloud where the temperature is about - 50˚C, and that the main positive charge centre is located several kilometres higher up, where the temperature is usually below - 200˚C. In the majority of storm clouds, there is also a localised positively charged region near the base of the cloud where the temperature is 0˚C. Fields of about 1000 V/m exist near the centre of a single bipolar cloud in which charges of about 20˚ C are separated by distances of about 3 km, and indicate the total potential difference between the main charge centres to be between 100 and 1000 MV. The energy dissipated in a lightning flash is therefore of the order of 1000 to 10,000 MJ, much of which is spent in heating up

*Corresponding Author

Swati Agrawal
Department of Electrical Engineering, R.I.T, Raipur, India.

a narrow air column surrounding the discharge, the temperature rising to about 15,000 ˚C in a few tens of microseconds. Vertical separation of the positive and negative charge centres is about 2 - 5 km. The average current dissipated by lightning is of the order of kilo-amperes. During an average lightning storm, a total of the order of kilo-coulombs of charge would be generated, between the 0˚C and the -40 ˚C levels, in a volume of about 50 km^{3}.

BREAKDOWN PROCESS

Under the influence of sufficiently strong fields, large water drops become elongated in the direction of the field and become unstable, and streamers develop at their ends with the onset of corona discharges. Drops of radius 2 mm develop streamers in fields exceeding a 9 kV/cm - much less than the 30 kV/cm required to initiate the breakdown of dry air. The high field need only be much localised, because a streamer starting from one drop may propagate itself from drop to drop under a much weaker field. When the electric field in the vicinity of one of the negative charge centres builds up to the critical value (about 10 kV/cm), an ionised channel (or streamer) is formed, which propagates from the cloud to earth with a velocity that might be as high as one-tenth the speed of light. Usually this streamer is extinguished when only a short distance from the cloud. Forty micro-seconds or so after the first streamer, a second streamer occurs, closely following the path of the first, and propagating the ionised channel a little further before it is also spent. This process continues a number of times, each step increasing the channel length by 10 to 200 m. Because of the step like sequence in which this streamer travels to earth, this process is termed the stepped leader stroke.

When eventually the stepped leader has approached to within 15 to 50 m of the earth, the field intensity at earth is sufficient for an upward streamer to develop and bridge the remaining gap. A large neutralisingcurrent flows along the ionised path, produced by the stepped leader, to neutralise the charge. This current flow is termed the return stroke and may carry currents as high as 200 kA, although the average current is about 20 kA. The luminescence of the stepped leader decreases towards the cloud and in one instances it appears to vanish some distance below the cloud. This would suggest that the current is confined to the stepped leader itself. Following the first, or main stroke and after about 40 ms, a second leader stroke propagates to earth in a continuous and rapid manner and again a return stroke follows. This second and subsequent leader strokes which travel along the already energised channel are termed dart leaders.

What appears as a single flash of lightning usually consist of a number of successive strokes, following the same track in space, at intervals of a few hundredths of a second. The average number of strokes in a multiple stroke is four, but as many as 40 have been reported. The time interval between strokes ranges from 20 to 700 ms, but is most frequently 40-50 ms. The average duration of a complete flash being about 250 ms. The approximate time durations of the various components of a lightning stroke are summarised as follows.

Stepped leader = 10 ms
Return stroke = 40 µs
Period between strokes = 40 ms
Duration of dart leader = 1 ms

For the purpose of surge calculations, it is only the heavy current flow during the return stroke that is of importance. During this period it has been found that the waveform can be represented by a double exponential of the form

$$i = I\,(e^{-\alpha t} - e^{-\beta t})$$

with wave front times of 0.5-10 µs, and wave tail times of 30-200 µs (An average lightning current waveform would have a wave front of the order of 6 µs and wave tail of the order of 25 µs). The standard voltage waveform used in high voltage testing has a 1.2/50 µs waveform to take into account the most severe conditions. For the standard waveform, the coefficients α & β in the double exponential have values of $\alpha = 1.426 \times 10^{4}\ s^{-1}$ and $\beta = 4.877 \times 10^{6}\ s^{-1}$.

FREQUENCY OF OCCURRENCE OF LIGHTNING FLASHES

A knowledge of the frequency of occurrence of lightning strokes is of utmost importance in the design of protection against lightning. The frequency of occurrence is defined as the flashes occurring per unit area per year. However, this cannot be measured very easily, and without very sophisticated equipment. This information is difficult to obtain. However, the keraunic level at any location can be quite easily determined. The keraunic level is defined as the number of days in the year on which thunder is heard. It does not even distinguish between whether lightning was heard only once during the day or whether there was a long thunderstorm. Fortunately, it has been found by experience that the keraunic level is linearly related to the number of flashes per unit area per year. In fact it happens to be about twice thenumber of flashes/square mile/year. By assuming this relationship to hold good throughout the world, it is now possible to obtain the frequency of occurrence of lightning in any given region quite easily.

LIGHTNING PROBLEM FOR TRANSMISSION LINES

The negative charges at the bottom of the cloud induces charges of opposite polarity on the transmission line. These are held in place in the capacitances between the cloud and the line and the line and earth, until the cloud discharges due to a lightning stroke. There are three possible discharge paths that can cause surges on the line.

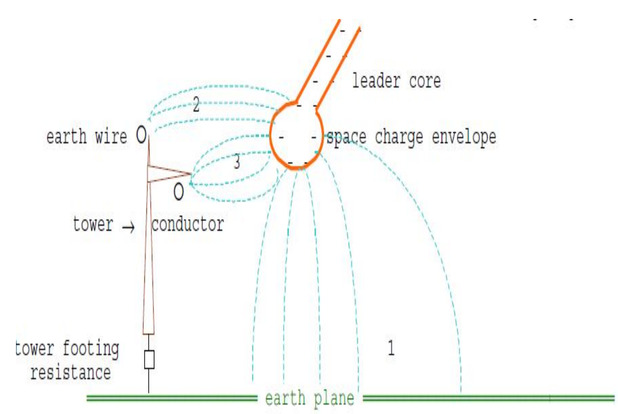


Fig 1. Geometry of lightning leader stroke and transmission line

(a) In the first discharge path (1), which is from the leader core of the lightning stroke to the earth, the capacitance between the leader and earth is discharged promptly, and the capacitances from the leader head to the earth wire and the phase conductor are discharged ultimately by travelling wave action, so that a voltage is developed across the insulator string. This is known as the induced voltage due to a lightning stroke to nearby ground. It is not a significant factor in the lightning performance.

(b) The second discharge path (2) is between the lightning head and the earth conductor. It discharges the capacitance between these two. The resulting travelling wave comes down the tower and, acting through its effective impedance, raises the potential of the tower top to a point where the difference in voltage across the insulation is sufficient to cause flashover from the tower back to the conductor. This is the so-called back-flashover mode.

(c) The third mode of discharge (3) is between the leader core and the phase conductor. This discharges the capacitance between these two and injects the main discharge current into the phase conductor, so developing a surge impedance voltage across the insulator string. At relatively low current, the insulation strength is exceeded and the discharge path is completed to earth via the tower. This is the shielding failure or direct stroke to the phase conductor. The protection of structures and equipment from the last mode of discharge by the application of lightning conductors and/or earth wires is one of the oldest aspects of lightning investigations, and continue to do so.

EFFECT OF THE LIGHTNING PERFORMANCE ON A TRANSMISSION LINE

1. Generation of random numbers of lightning strokesto obtain the parameters of the lightning strokes and three overhead lines of the random nature [3]
2. Application of the model to realize the point of impact of every lightning stroke.
3. Calculation of the over voltage generated by each stroke depending on the point of impact.
4. Calculation of the flash over rate[6].

Since transmission lines are usually shielded by several wires, lightning over voltage can be caused by strokesto either a shielded wire or aphase conductor. This type of stroke produces a flash over if the back flash over voltage exceeds the insulator strength. Over voltages caused by a Shielding failure that is a by a stroke to a phase conductor, are more dangerous there frequency is very low due to shielding provided by sky wires[6]

6.1 Strokes to a Phase-conductor:

The charged cloud could discharge directly onto the line. If the line is struck a long distance from a station or substation, the surge will flow along the line in both directions, shattering insulators and sometimes even wrecking poles until all the energy of the surge is spent. If it strikes the line immediately adjacent to a station, then the damage to plant is almost certain, since it is doubtful whether the ordinary lightning arrestor could divert to earth such a powerful discharge, without allowing a part to be transmitted to the terminal apparatus. When lightning strikes an overhead phase-conductor, the magnitude of the current and the high frequency nature of the stroke causes voltage surges to be propagated in both directions from the point of the strike .The waveshape of these voltage surges is similar to that of the current in the lightning discharge. The discharge current splits itself equally on contact with the phase conductor, giving travelling waves of magnitude e

$$e = \frac{1}{2} Zi\,(e^{-\alpha t} - e^{-\beta t})$$

where,
Z is the surge impedance of the phase conductor.

Strokes to a tower with no earth wire

Fortunately, direct strokes to the line are infrequent in occurrence compared to side strokes, the effects of which are not so severe. If there is a direct stroke to the tower, a current would be discharged through the metal work of the tower and there would be a potential difference between the top and bottom of the tower. Fig 2.2 shows a steel tower (inductance L) of a transmission line with no earth wire. If the earthing resistance of the tower is R (=5-100Ω), and it is struck by lightning, then the potential build up on the tower top would be

$$Ri + L\,di/dt$$

If e_i is the induced voltage on the conductor due to the lightning, then the potential difference built up across the tower and the conductor is given by

$$e = Ri + L\,di/dt + e_i.$$

If the value of e exceeds the line insulation strength, then a flashover occurs from the tower to the line and this is termed a backflashover.

Lightning Overvoltages

Lightning can produce overvoltages when it hits either the line conductors (direct strokes) or a point in the vicinity of the distribution network (indirect strokes). Overvoltages can be impressed upon a power system by atmospheric discharges, in which case they are called 'lightning overvoltages', or they can be generated within the system by the connection or disconnection of circuit elements or the initiation or interruption of faults. The latter type are classified as 'temporary overvoltages' if they are of power or harmonic frequency and sustained or weakly damped, or as 'switching overvoltages' if they are highly damped and of short duration. Because of their common origin, temporary overvoltages and switching surges occur together, and their combined effect is relevant to insulation design. The probability of coincidence of lightning and switching surges, on the other hand, is small, and can be neglected.

The prospective magnitudes of lightning surges appearing on transmission lines are not much affected by line design; hence lightning performance tends to improve with increasing insulation level, i.e. system voltage. The magnitudes of switching surges, on the other hand, are substantially proportional to operating voltage. As a consequence, here is a system voltage at which the emphasis changes from lightning to switching surge design; this point is reached at approximately 300 kV. In the 'extra-high voltage' range, up to the highest existing system voltage of 765 kV, both lightning and switching overvoltages have to be considered.

Temporary Overvoltages

The significance of temporary overvoltages in respect to insulation co-ordination lies in the requirement that surge diverters (lightning arresters) must be able to reseal against sustained voltages, or risk destruction. Since the protective level of any kind of surge diverter is proportional to the reseal voltage, the insulation level and cost of equipment depends indirectly on the magnitudes of temporary overvoltages. In the extra high voltage range, temporary overvoltages cum switching surges determine the insulation of transmission lines and consequently their dimensions and cost.

The main causes of power frequency overvoltages are: sudden loss of load; disconnection of inductive loads or connection of capacitive loads; Ferranti effect; and unbalanced ground faults. The duration of temporary overvoltages may vary from a few cycles, if inter tripping or voltage-dependent relay protection is provided, or a few seconds, if reduction depends on automatic voltage regulators, to much longer periods if human intervention is relied upon.

A single line-to-ground fault causes a rise in the voltages to ground of the healthy phases, which depends mainly on the effectiveness of neutral earthing. For isolated neutral or suppressed coil systems, the potentials of the healthy phases can exceed the line-to-line voltage; for solidly grounded systems they will increase above their normal values but remain below line-to-line voltage. Double line-to-ground faults may also produce increases in line-to-ground voltages.

A measure of the voltage rise caused by single line-to-ground faults is the 'earth fault factor', defined as the ratio of the higher of the two sound-phase voltages to the line-to-neutral voltage at the same point of the system, with the fault removed.

Switching Overvoltages

It has already been pointed out that switching overvoltages are the criterion by which the insulation of extra high voltage systems has to be designed. The reduction of switching surges is therefore an economic necessity.

In the past, circuit-breaker design was directed towards reducing the overvoltages caused by the interruption process. As these efforts were successful, it was found that surges arising on energizing extra high voltage transmission lines became more critical, and circuit-breakers were developed to control these closing surges. Indications are that in the future, overvoltages accompanying the initiation of short-circuits, which are uncontrollable, may establish the next lower limit. The continuing reduction in switching surge magnitudes may result in lightning performance again increasing in relative importance. The absolute lower limit, as far as insulation exposed to the atmosphere is concerned, will probably be set by insulator pollution.

The peak magnitude of a phase-to-ground switching overvoltage can be expressed in 'per unit', relating it to the peak voltage to ground. A phase-to-phase overvoltage is also expressed in terms of the highest voltage peak to ground. Quite often the term 'overvoltage factor' is used to indicate the ratio of the overvoltage to the peak of the system voltage prior to or after the transient. This voltage may of course differ considerably from the highest voltage for equipment, and to avoid misunderstandings, the reference voltage and the conditions of the case ought to be clearly stated.

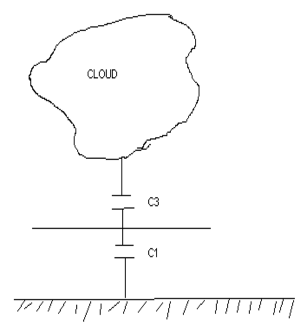
PROTECTION OF TRANSMISSION LINE AGAINST LIGHTNING

In order to protect the transmission line against lightning stroke let us consider two case:

CASE: I: Suppose if we are using an unprotected transmission line then in that case, consider a cloud over an unprotected conductor than a capacitance C_3 will come in existence between cloud and line conductor and C_1 between line conductor and earth. Induced voltage on line conductor will be V_{Li}, then,

$$V_{Li} = (C_3 / C1 + C_3.)\ E_c$$

where E_c=Voltage of cloud.

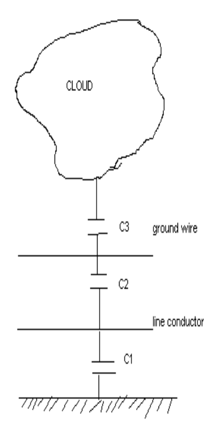


CASE: II: Suppose if we are using protected transmission line then in that case , ground wire is placed between capacitor C_3 and C_2 and line conductor between capacitance C_2 and C_1 than voltage induced will be equal to

$$V_1 = (C_3 / \quad C_1 + C_2)\ E_c$$

where ,

E_c = Voltage of cloud.



If the ground wire is present it increases the capacitance between conductor and earth, thus decreasing the induced voltage on line conductor, if the number of ground wires are used , induced voltage can be reduced further because presence of one earth wire reduces the induced voltage on the line to half.

REFERENCE

[1]Lightning likes land, http: //science. msfc. nasa. gov/ newhome /headlines/essd1 9may98 htm.

[2]Karthick Srinivasan & Jason Gu, 2006." Lightning as Atmospheric Electricity ", IEEE transactions on CCECE/CCGEI, Ottawa,.pp- 2258-2261.

[3]I.B.Johnson&A.J.Schultz, 1958."A Hypothesis Concerning Lightning Phenomena and Transmission Line Flashover", IEEE transactions,February pp- 1470-1477

[4]Liew, MIEEE &Thum, 1993. " Comparative Studies Of Lightning Performance Of A Quadruple- Circuit Dual Voltage 275/132KV Transmission Line Design With Wooden Crossarms ",IEEE Transactions on Power Delivery,Vol.8, No.4, pp- 1973-1980.

[5]Longo & Hickman, 1998. "Lightning Research Update Including New Uses Of Lightning Data", IEEE transactions.pp- 1285-1286.

[6]W.W. Lewis, C.M.Foust 1940. "Lightning Investigation On Transmission Lines",VII, Ibid,vol.59, pp.227-34.

[7]Martin A Uman, " Lightning", Dover ISBN O-486 –64575-4,1969.

[8]ZavisaJ, "How Lightning works", http://science.howstuffworks.com/lightning.htm.