

# Hazards of Lightning on Overhead Transmission Lines and its Protection

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**Abstract:** 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 due to natural cause of lightning is not yet reduced. Lightning is one of the most natural and serious cause of over voltage. The effects lightening on overhead transmission line have always been a matter of concern in studies of power distribution, transmission line and up gradation of transmission system. General transmission lines get very much affected by lightening thunder (leader stroke), the magnitude and shape of the lightening on overhead transmission line will be in undetermined and unpredictable form. It takes place for some microseconds to milliseconds and as it arises (immerses on object), it causes an serious damage to the system where it immerses. In this paper, we obtain analysis of 330kV and 132kV overhead transmission line structure and lightning protection to reduce the potential damage to Electric Power System.

**Keywords:** Lightning hazard, power transmission line, Surge arrester, flash over, Lightning strokes, lightning protection.

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## 1. INTRODUCTION

Lightning is one of the main causes of electric power system fault. The entire power system consisting of power plants, substations, transmission lines, distribution feeders and power consumers. All components of the power system form an organic whole and maintenance the dynamic balance in operation. The system frequency, voltage, tie-line flows, line currents and equipment loading must be controlled and kept with limits determined to be safe. [Chong.Tong and Mingguang.Tong,2006]. Lightning is an electrical discharge between cloud and the earth, between clouds or between the charge centers of the same cloud. Lightning is a huge spark and that take place when clouds are charged to at a high potential with respect to earth object (e.g. overhead lines) or neighboring cloud that the dielectric strength of the neighboring air is destroyed. [Rahul N. Nandeshwar, 2014].

Lightning, especially Cloud-to-Ground (CG) lightning could damage power transmission lines, distribution lines, substations and power plants. Furthermore, such hazard may lead to loss of the system stability and uncontrolled separation of power network even threatens the whole electric power grid. When lightning strikes a phase conductor of transmission line, the current of the lightning stroke will encounter the surge impedance of the conductor so that overvoltage will be built up and propagate to the substation along the transmission line in wave form. This lightning incoming wave would do damage to electrical equipments and facilities in substation. For example, if the SPD (Surge Protection Device) on the incoming lines did not sensitive or reliable enough, the whole station would be at risk of lost the inside precision devices, control systems or information network, even lost all of its power.

Similarly, the lightning hazards to power system could cause the proper voltage profile of the power grid, load shedding, abnormal oscillation, and frequency collapse or power network separation. Not only harm the individual components of system, indeed the main damaging effect of lightning is they destroy the dynamic balance of power system, harm to the stability of power grid indirectly and cause the serious effect subsequent. [Chong.Tong and Mingguang.Tong, 2006].

## 2. LIGHTNING HAZARDS TO TRANSMISSION LINES

The negative charges at the bottom of the cloud induce 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 transmission line.

(a) In the first discharge path (induced voltage), 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.

(b) The second discharge path (flashover) 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 (shielding failure) 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. [Swati Agrawal and Manoj Kumar Nigam, 2014].

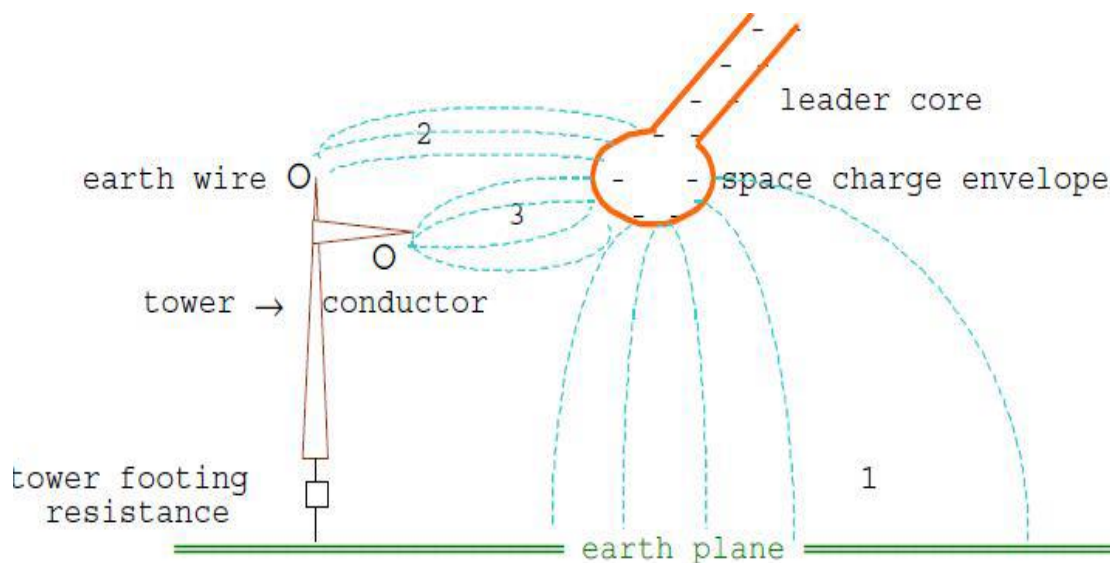


Figure 1: Lightning leader stroke and transmission line. [Swati Agrawal and Manoj Kumar Nigam, 2014].

## 3. LIGHTNING STROKES TO A PHASE-CONDUCTOR

A direct lightning strike on a conductor of a power line causes extremely high voltage pulses at the strike point, which are propagated as traveling waves in either direction from the point of strike, it is clear that such a pulse will cause failure of insulating components along the line. Therefore it's necessary that no direct strike must be permitted on the overhead power lines phase conductors. This is achieved by stringing one or more shield wires along the phase conductors sufficiently above them so that the shield wires attract direct strikes and not the phase conductors. The shield wire is earthed at each transmission tower and thus the lightning current safely passes into the groundmass. The clearance between the phase conductors and the shield wire must be selected so that air space between them does not breakdown by

the high impulse voltage generated in the shield wires. This is easily achievable in systems of 132 kV and 330 kV (Nigeria network). The flow of the pulse of lightning current in the shield wire causes an induced voltage pulse in the phase conductors. These being much smaller in value than the direct pulse safely pass along the line without causing any insulation failure. To protect the equipment at the termination point of the overhead lines (such as circuit breakers, transformers, measuring devices, etc.) The discharge current splits itself equally on contact with the phase conductor, giving travelling waves of magnitude  $e$

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

Where,  $Z$  is the surge impedance of the phase conductor.

#### 4. LIGHTNING HAZARDS TO SUBSTATIONS

When lightning strikes a phase conductor of transmission line, the current of the lightning stroke will encounter the surge impedance of the conductor so that overvoltage will be built up and propagate to the substation along the transmission line in wave form. This lightning incoming wave would damage the electrical equipments and facilities in substation such as transmission line, communication lines, and buses bar etc. [Rahul N. Nandeshwar, 2014]. 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 arrester could divert to earth such a powerful discharge, without allowing a part to be transmitted to the terminal apparatus.

#### 5. LIGHTNING STROKES TO A TOWER WITH NO EARTH WIRE

If lightning stroke direct 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, a steel tower (inductance  $L$ ) of a transmission line with no earth wire. If the earthing resistance of the tower is  $R$  (5-100 $\Omega$ ), and it is struck by lightning, then the potential build up on the tower top would be

$$R_i + L di/dt$$

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

$$e = R_i + L di/dt + e_i$$

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. [Swati Agrawal and Manoj Kumar Nigam, 2014].

#### 6. MODES OF LIGHTENING FLASHOVER

It is important to identify three modes or mechanism by which the lightning strokes can cause insulation flashover.

1. The induction (IN) mode is operative for strokes to earth near the line but not in contact with any element of it. Generally induction mode considered harmless to the transmission lines as a result in flashover on steel-tower lines and massive structural damage on wooden pole lines.
2. The shielding failure (SF) mode is operative for strokes directly to the phase conductor.
3. The back flashover (BF) mode is operative for strokes directly to the shield wire or supporting structure.

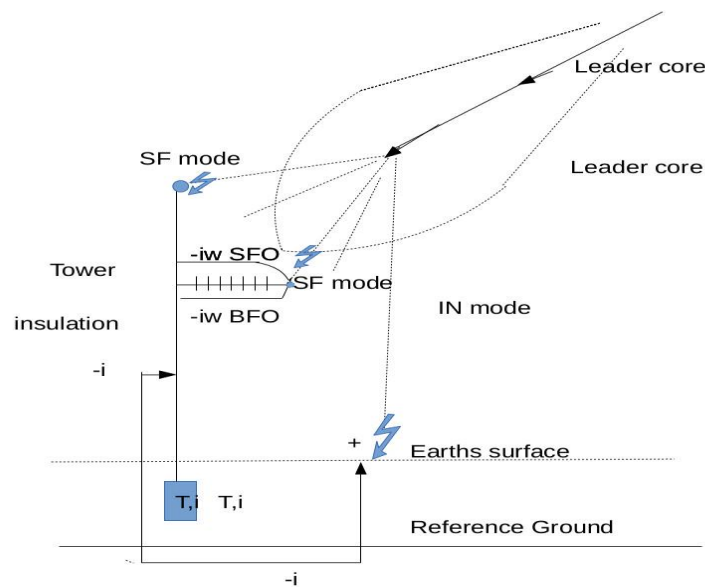


Figure 2: The lightning modes of flashovers on the transmission lines. [Rahul N. Nandeshwar, 2014].

## 7. LIGHTNING SURGES

If lightning strikes on or near overhead electric power or telephone line, a large current will be injected into or induced in the wires, and the current can do considerable damage both to the power and telecommunications equipment and to anything else that is connected to the system. Surges can have many effects on equipment, ranging from no detectable effect to complete destruction electronic devices can have their operation upset before hard failure occurs.

## 8. SURGE ARRESTER PROTECTION

Lightning surge arrestors are provided at the point of termination. These arrestors absorb any surges in the line and prevent them from traveling into the substation equipment. Lightning arresters are installed on transmission lines between phase and earth is connected to the substation grounding system through short ground conductors of adequate cross-sectional area in order to protect or improve the lightning performance and reduce the failure rate.

Surge arresters installed today are all metal-oxide (MO) arresters without gaps, which are the semiconductors; they function as high impedances at normal operating voltages and become low impedances during surge conditions. They are designed to break down at voltages above the highest system operating voltage (but lower than the basic insulation level of the system) thereby becoming good conductors and pass the energy of the lightning impulse to the ground. Once the voltage comes down (after the discharge of the pulse is over) the arrestors return to their original high-impedance state. An ideal lightning arrester should:

- (i) Conduct electric current at a certain voltage above the rated voltage;
- (ii) Hold the voltage with little change for the duration of overvoltage; and
- (iii) Substantially cease conduction at very nearly the same voltage at which conduction started.

The lightning energy  $E$  (in Joules) absorbed by an arrester is computed by the relation:

$$E = \int_{t_0}^t u(t) \cdot i(t) dt$$

Where:

$u(t)$  is the residual voltage of the arrester in kV and

$i(t)$  is the value of the discharge current through the arrester in Ka.

When the absorbed energy by the arresters exceeds their maximum acceptable level of energy, then they will fail (damage). Assuming that surge arresters are the last protection measure of a transmission line, an arrester failure is considered as a line fault. The arresters failure rate is given as:

$$FR = N_g L \left[ \left( \int_{T_t}^{\infty} \int_{I_{A,t}}^{\infty} f(I_p \times h_A) d(I_p) y(t) d(T_A) \right) + \left( \int_{T_t}^{\infty} \int_{I_{B,t}}^{\infty} f(I_p \times h_B) d(I_p) y(t) d(T_B) \right) \right]$$

Where:

$I_A(T, t)$  is the minimum stroke peak current in kA required to damage the arrester, when lightning hits on a phase conductor, depending on each time-to-half value,

$I_B(T, t)$  is the minimum stroke peak current in kA required to damage the arrester, when lightning hits on the overhead ground wire, depending on each time-to-half value,

$f(I_P)$  is the probability density function of the lightning current peak value,

$g(Tt)$  is the probability density function of the time-to-half value of the lightning current,

FR is the arrester total failure rate,  $N_g$  is the ground flash density in flashes per km<sup>2</sup> per year and L is the line length in km. [Rahul N. Nandeshwar, 2014], [Christodoulou C.A, Gonos I.F and Stalhopolos I.A, 2008)

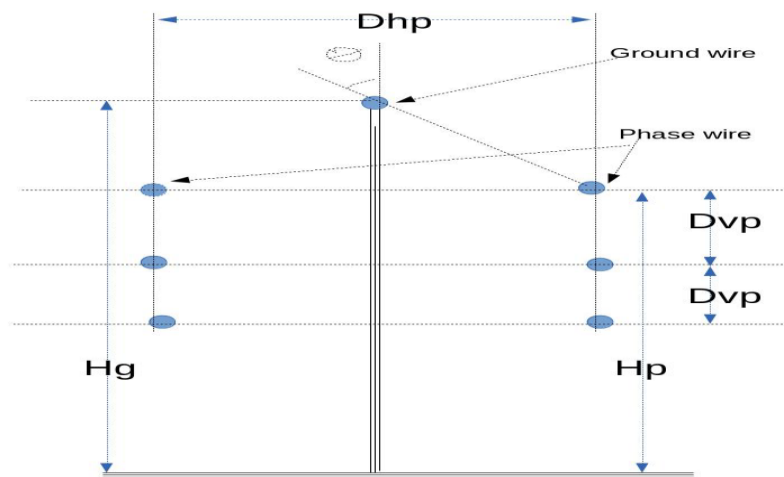


Figure 3: 330kV transmission line. [Rahul N. Nandeshwar, 2014]

The complete analytical model consist of geometry together with an associated set of basic assumptions and mathematical relations.

The mean conductor height can  $H_g$  can be computed from the fig 3

$$H_g = H_{gt} - \left(\frac{2}{3}\right)(Sc)$$

$H_{gt}$ = height of conductor at the tower,

Sc= sag of the conductor;

$$H_g = H_p + \Delta$$

$H_g$  = Height of ground wire from earth

$H_p$  = Height of phase conductor from earth

Dvp= Phase to phase vertical distance

Dhp= Phase to phase horizontal distance

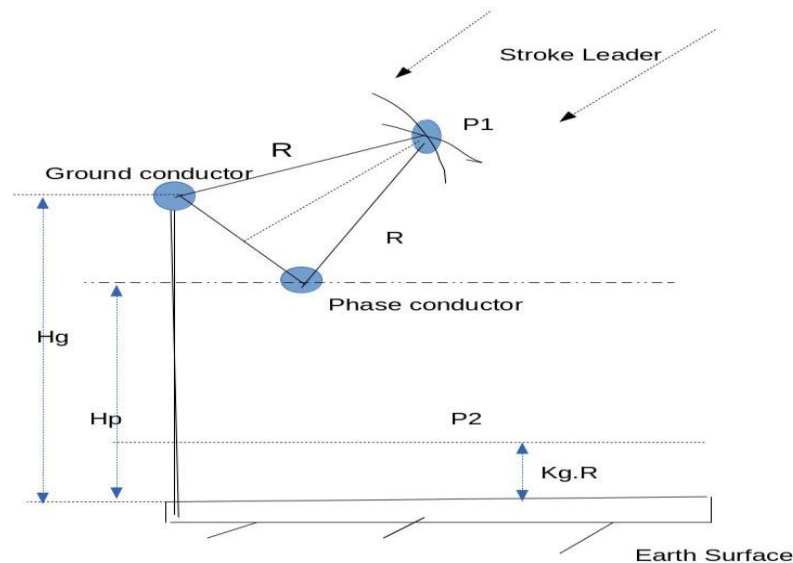


Figure 4: Analytical model of transmission line. [Rahul N. Nandeshwar, 2014].

Hgt = height of the shield wire at the tower

Ss = sag of the shield wire

The striking distances are given by

$$R = aI_p^b + C \quad \dots \text{(According to the standard IEEE model of Transmission line were } a = 10, \\ b = 0.65 \text{ and } c = 0)$$

$$R = 10i_p^{0.65}$$

And for Height dependent model (Rizk Model)

$$a = 4027Hg^{0.41}$$

As leader immerges to transmission line protective theory says that the Both Ground wire and Phase conductor produces protective arc around them. This protective arcs cuts each other in space at a point terminating point. The termination point of a lightning stroke to a transmission line can be a ground wire, a phase conductor, a metal tower or even the ground. According to the electro-geometrical model theory, it is able to determine the termination point, when the striking distance is known.

The striking distance, r is give as:

$$r = A \cdot i^b$$

Where A and b are constants. The striking distance is depending on the peak current amplitude of the leader stroke, if a lightning strike on transmission line from point P1 and P2 position from fig 5, the following points should be considered;

- (i) If lightning strokes disappear before point P, will goes to ground wire i.e. the transmission line has been saved.
- (ii) If lightning strokes goes between points P1 and P2 then it will strike directly to the phase conductor i.e. it will cause damage to the transmission line and can harm to useful equipments.
- (iii) If lightning stroke strike after point P2 then it will goes to ground and transmission line will be saved.

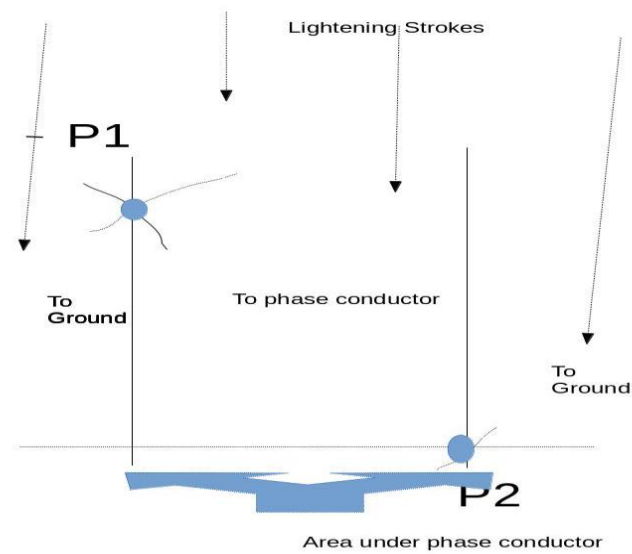


Figure 5: Area of region showing immerging lightning stroke. [Rahul N. Nandeshwar, 2014].

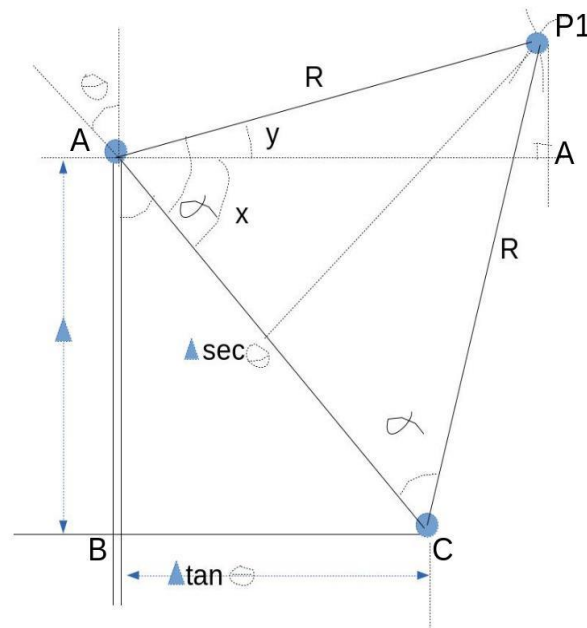


Figure 6: for calculating co-ordinate of P1. [Rahul N. Nandeshwar, 2014].

The analytical model structures of 330kV transmission tower as shown in fig 6 in this paper, with various physical parameters are as follows:

$H_g$  = Height of ground wire from earth

$H_p$  = Height of phase conductor from earth

$\Delta = H_g - H_p$

$R$  = radius of protective arc produced by both conductor during lightning  $\theta$  Shielding angle between Ground wire and phase conductor now considering fig 6



Applying geometrical method for calculating co-ordinates in triangle ABC

$$AB = H_g - H_p \text{ and } \theta$$

Shielding angle is  $BC = \Delta \tan(\theta)$

Applying Pythagoras theorem from fig 6;

$$AC = \sqrt{\Delta^2 + (\Delta^2 \tan^2(\theta))} = \Delta \sec(\theta)$$

$$A(0, H_g) \text{ and } C(\Delta \tan(\theta), H_g)$$

For triangle ACP1  $\alpha = \angle y + \angle X$

$$\cos(\alpha) = \frac{\left(\frac{\Delta}{2} \times \sec(\theta)\right)}{R}, \text{ i.e.; } \alpha = \cos^{-1} \left[ \frac{\left(\frac{\Delta}{2} \times \sec(\theta)\right)}{R} \right]$$

$$\alpha = y + x \quad \alpha = 90 - (\theta - y)$$

$$\alpha = \cos^{-1} \left[ \frac{\left(\frac{\Delta}{2} \times \sec(\theta)\right)}{R} \right] = [90 - (\theta - y)] \left[ \frac{\left(\frac{\Delta}{2} \times \sec(\theta)\right)}{R} \right] = \cos^{-1} [90 - (\theta - y)]$$

$$\left[ \frac{\left(\frac{\Delta}{2} \times \sec(\theta)\right)}{R} \right] = \sin(\theta - y) \quad \sin^{-1} \left[ \frac{\left(\frac{\Delta}{2} \times \sec(\theta)\right)}{R} \right] = (\theta - y)$$

$$y = \left[ \theta - \sin^{-1} \left[ \frac{\left(\frac{\Delta}{2} \times \sec(\theta)\right)}{R} \right] \right]$$

Therefore, the co-ordinates of the point P1 will be

$$P1(R \cos(\theta), H_p + R \sin(\theta))$$

And for finding co-ordinates of point P2 we can use generalized circle equation

$$(x - x_1)^2 + (y - y_1)^2 = R^2$$

$$y = K_g R \quad y_1 = H_p \quad x_1 = (\Delta \tan(\theta))$$

Applying the co-ordinate of P2 equation we have;

$$P2 \left( \sqrt{R^2 - (K_g R - H_p)^2} \right) + (\Delta \tan(\theta), K_g R)$$

Transmission line with area of 100km can be simply calculating use following formula

$$a = \frac{(P2 - P1) \times 100}{100} \quad [\text{Rahul N. Nandeshwar, 2014}].$$



## 9. PROTECTION OF TRANSMISSION LINE AGAINST LIGHTNING

Protecting overhead transmission lines against lightning strokes is one of the most important tasks to safeguard electric power system and to prevent the disturbing energy from reaching sensitive equipment, since lightning is a usual cause of faults in overhead lines. The protection of the lines is achieved with the following;

### 1. Reduce the tower grounding resistance:

Transmission lines of grounding resistance is inversely proportional to the lightning resisting level, according to each of the soil resistivity tower, as far as possible to reduce the grounding resistance of tower, which is to improve the lightning resisting level of high voltage transmission lines, is the most economic and effective method.

### 2. Add ground coupling:

Due to the coupling between the ground can make the wire and cable coupling coefficient increases, and through the thunder and lightning tower flow on both sides of the shunt, thus improve the lightning resisting level of the transmission lines. And coupling ground installation is generally applicable to the hills or mountains across, can lead to play an effective shielding protection, use and strike from the principle is also reduced exposure segment of the wire. But the strength of the tower, the safe distance, cross and lines at the bottom of the transportation, the influence of such factors as so erect coupling ground for the old line is not easy to implement.

### 3. Strengthen the insulation level of transmission line:

Insulation level and lightning withstand level is proportional to the power transmission line, to strengthen the detection of faulty insulators, ensure the transmission line with sufficient insulation strength is an important factor to improve the lightning withstand level of transmission line. As the commonly used to increase insulators or replacement for large climbing distance method of synthetic insulator to improve line insulation, to prevent the lightning strikes the tower lightning voltage effect is good, but to prevent the shielding effect is poor, and the increase of insulators by the tower head insulation gap and the guide line of safety distance constraints, so the line insulation of the enhancement is limited

### 4. The proper use of transmission line lightning arrester:

Because lightning arrester installation tower and conductor is potential difference over the action of lightning arrester voltage, lightning arrester join shunt, ensure insulator flashover is not. According to actual operation experience, the lightning trip-out more frequently on the high voltage transmission lines of selective installed lightning arrester can achieve very good lightning protection effect. Across the country have already been used a certain number of transmission line lightning arrester, reflect the good operation. Figure 7 shows the transmission line lightning arrester. [Wang Qinghao, Ge Changxin, Xue Zhicheng, Sun Fengwei, Wu Shaoyong, Li Zhixuan, 2011].



Figure 7: the transmission line lightning arrester

## 10. CONCLUSIONS

Lightning is one of the main causes of electric power system fault. Not only damage the single part, the lightning also destroy the dynamic balance of the electric power system, lead to loss of system stability and uncontrolled separation of power network even threatens the whole electric power grid which would cause large area outages. Overhead transmission line structure should be protected against lightening strokes at certain high level which will be beneficial for saving nations economy.

## REFERENCES

- [1] Wang Qinghao, Ge Changxin, Xue Zhicheng, Sun Fengwei, Wu Shaoyong, Li Zhixuan, Shi Dongpeng, Ren Hao, Li Jinye, Ma Hui, Cao Feiyi (2011); Lightning on Transmission lines hazards and Prevention Measures; Liaoning Electric Power Company Limited, State Grid, China,
- [2] Chong.Tong and Mingguang.Tong 2006 The Application of Lightning Detection on Power Grid Dispatching Mingming Co.,Ltd
- [3] Swati Agrawal and Manoj Kumar Nigam;(2014): Lightning phenomena and its effect on Transmission line Recent Research in Science and Technology 2014, Vol 6(1): pp.183-187 Raipur, India.
- [4] A. Xémard, S. Dennetière, I. Uglesic, V. Milardic, B. Milesevic, P. Grand, F. Sauvegrain, P. Stevenin, M. Mesic(2009): The protection against lightning of an overhead line uprated from 225 kV to 400kV International Conference on Power Systems Transients (IPST2009) in Kyoto, Japan June 3-6.
- [5] Christodoulou .C.A, Gones .I.F, and Stathopulos I.A.(2008): Lightning performance of high voltage Transmission lines protected by surge arresters. A simulation for the Hellenic transmission Network, 29th International conference on lightning protection, Uppsala, Sweden.
- [6] Rahul Narendra Nandeshwar (2014): Lightning and Lightning Protection of Overhead Transmission Line, Abha Gaikwad Patil College of Engineering, Nagpur, Maharashtra Indian Institute of Science
- [7] Richard L. Cohen, Doug Dorr, James Funke, Chuck Jensen and S. Frank Waterer (2005): IEEE Guide for Surge Protection of Equipment Connected to AC Power and Communication Circuits