ISSN : 0974 - 7435 Volume 10 Issue 15

2014

BioTechnology
An Indian Journal

FULL PAPER

BTAIJ, 10(15), 2014 [8787-8794]

Research on grounding technique used in lightning protection of transmission line

Le Luo
Department of Communication Engineering, Chengdu Technological University, Chengdu, 611730, (CHINA)

ABSTRACT

Since reform and opening up, all walks of life enter rapid economic development, demanding for electricity is in the rising trend, so it is very necessary for stable and reliable supply of electricity. Power grid construction is accelerated constantly in recent years, which also lead to the speed of the construction of the transmission lines. As an important component of the power grid, due to its long-term exposure to outdoor harsh environment, it is easy for transmission lines to be damaged by external forces, so lightning protection and grounding of the transmission line is very necessary. Power grid transmission line has a wide coverage and they are set in the complex environment conditions, any failure will affect the whole system. Therefore, in the process of power grid stability, maintenance and management is an important link. Transmission line lightning protection is an important content in line work. In order to prevent damage due to lightning strike, the design of the lightning protection grounding for transmission lines is necessary. The reason and harm of the transmission line lightning, lightning protection and the kinds of main technical measures are analyzed in the paper. This paper further introduced the transmission line lightning protection grounding technology, as well as the existing problems and modification methods of grounding systems located in soil.

KEYWORDS

Transmission lines; Lightning strip-out; Lateral rod; Line lightning protection; Distribution network.

PRINCIPLE OF TRANSMISSION LINE LIGHTNING DISCHARGE

Formation of lightning

Lightning discharge is discharge phenomenon caused by the thunder clouds. Under the condition of some sort of atmosphere and the earth, damp heat flow into the atmosphere condensation to form a thunder clouds, thunder clouds in the atmosphere at the bottom of most negatively charged, it induced on the ground out a lot of positive charge, so ray has formed a strong electric field between cloud and the earth, with the development of thunder clouds and movement, when the space electric field intensity exceeds the critical electric field intensity of the atmospheric free discharge, occurs between thundercloud or thundercloud to ground discharge, thunder and lightning.

Lightning is of a high voltage and the instantaneous current strength is very large. Therefore, although only a lightning discharge time is only about 0.01 s, but the release of energy is staggering[1]. Workers of our country electric power industry after decades of research, according to actual data collected summarizes China's lightning distribution features are: summer more than spring and autumn, land more than the ocean, mountainous area more than plain, the south more than the north.

Lightning parameters

(a) Thunderstorm and thunderstorm hours

In the design of lightning and the lightning protection measures, we must consider the lightning activities in the region. The activity of thunder in a region frequency can use thunderstorm or thunderstorm hours in the region to say[2]. Thunderstorm is a thunder and lightning days in a year. Thunderstorms hours a year have hours of thunder and lightning. Within an hour a day or as long as you hear the thunder (whether heard several times), write it as a thunderstorm or thunderstorm hours. Because in each of the thunderstorm (or thunderstorm hours) change is bigger, so should be used for many years the average.

Can be seen from TABLE 1, thunderstorm hours and the ratio of the thunderstorm days increased with the increase of thunderstorm days. In general, the ratio of the two is about 3. The annual average thunderstorm generally not more than 15 area is a minefield, less more than 40 days of call minefield, more than 90 days of call strong minefield, to adjust measures to local conditions to discriminate on lightning protection design.

TABLE 1: Ratio of thunderstorm and thunderstorm hours in China

Annual average thunderstorm days	Thunderstorms hours/days
20-25	2.2-3
30-40	2.5-3.5
50-60	3-4
Above 70-80	3.3-4.3

(b) Lightning density on the ground

Thunderstorm or thunderstorm hours reflect the frequency of lightning activities in the region, but it failed to reflect its discharge is cloud or the cloud of discharge[3]. Test showed that the discharge between clouds is more than to ground discharge. We care about most is the cloud to ground discharge, namely lightning on the ground. The ground lightning density is γ . It says each thunderstorm, per square kilometer ground lightning ground. Our country generally take γ = 0.015.

Lightning current and voltage

The essence of thundercloud to ground discharge is thundercloud charge to the sudden release of the earth. Despite high initial thundercloud to potential could make the atmospheric breakdown, forming the guide electricity, but the ground was hit potential is not depends on the initial potential of the object, but depends on the product of lightning current and impedance by a strike object. So, from the nature of the power supply, it is the equivalent of the effect of a current source process[4]. Lightning phenomena are complex but from the perspective of the analysis of the consequences of can still see it as a along a fixed wave impedance of the lightning channel to the ground for the spread of electromagnetic wave process, on the basis of calculation model is established.

In lightning discharge process, people can measure power, mainly current I through the strike objects when lightning strikes the ground, and then deduced the parameters of the waves according to the calculating model. By the current source equivalent circuit of Figure 1, get the type:

$$i = 2i_o \frac{Z_o}{Z_o + Z_c} \quad (1)$$

Lightning current is single polarity of the pulse wave. In general, our current standard recommends the probability of lightning current amplitude distribution is as follows:

$$\lg P = -\frac{I}{108} \quad (2)$$

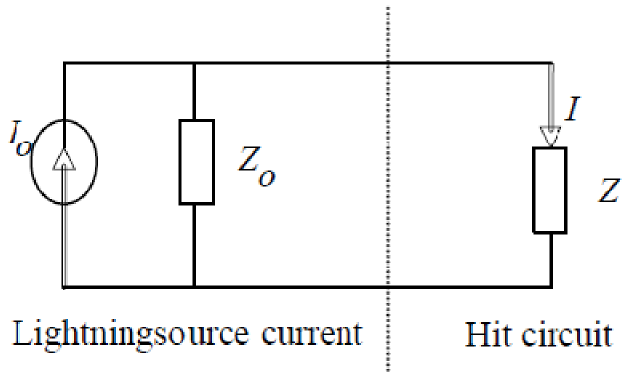

Figure 1: Equivalent circuit of lightning source current

(a) Induction lightning overvoltage

(A) No wire when the induction lightning overvoltage

When thunder clouds close over transmission lines, according to the principle of electrostatic induction, the online induction out on the road a thundercloud charge equal but opposite polarity charge, this is the bound charge, charge and with thunder clouds, by line grounded neutral escape into the earth, and the neutral point insulation lines, charge will be made by the same number line leak and escape into the earth. At this point, such as thunder clouds near the ground) (transmission line to discharge, or lightning tower but didn't happen back (the difference between them is that the latter only replace the part with tower lightning channels), due to the fast discharge speed, thunder clouds in charge quickly disappear, then the bound charge on the transmission line becomes the free charge, respectively to the line spread around.

Set induced voltage for U, when lightning strike administrative electricity, electrostatic field caused by thundercloud suddenly disappeared, resulting in a wave[5]. According to initial conditions of the wave equation, we known that wave will be split in two, to spread around. Induced over-voltage is produced by the thundercloud electrostatic induction.

When overhead line S > 65 m, if thundercloud discharge to ground, over-voltage on a line can be calculated by:

$$U = 25 \times I \times h_d / S(kV) \quad (3)$$

More lightning are attracted by line and click on the line itself. When ray direct or line near the ground wire in the Eiffel Tower, rapid changes in the surrounding electromagnetic field will be induced in wire overvoltage instead symbols. In the absence of ground wire, for the average height of the line, a maximum of the induced over-voltage can be calculated by the next type:

$$U = a \times h_d (kV) \quad (4)$$

(B) Induction lightning overvoltage with conducting wire

If there is wire lines, due to its shielding effect, induced over-voltage on the conductor will drop. Actually ground wire is grounded; its potential is zero, which is in a reverse polarity, superimposed on the amplitude equal voltage (U), the voltage is the voltage generated in the lotus root cooperation on conductor fork[6]. Conductor, therefore, the induced over-voltage on the amplitude of the combination, in contrast to the lightning current polarity.

(b) Direct lightning overvoltage

(A) Lightning overvoltage with no ground wire

Under the condition of ground wire are not set up, lightning line has only two parts, one is struck by lightning conductor, and the second is lightning tower.

When a lightning directly strikes on the conductor, lightning current flow on both sides along the conductor, assume Z to be the lightning channel wave impedance, Z / 2 for the lightning strike point on both sides of wires parallel wave impedance. The lightning overvoltage is:

$$U_a = (I/2) \times (Z/2) = I \times Z/4 = 100I \quad (5)$$

Lightning conductor of the over voltage is proportional to the size of the lightning current. If the voltage exceeds line insulation withstand voltage, impulse flashover will occur. The lightning resisting level of available route is:

$$I = U_{50\%}100(kA) \quad (6)$$

When lightning line strike on the top, I will pass through the tower lightning current and the grounding resistance into the earth[7]. Assuming that tower inductance is L_{gt}, the impact of the tower resistance R_{ch}, wire suspension point height of H_d, lightning current for bevel flat wave, wave head 2.6 μs, and engineering calculation function in the voltage on the insulator string is:

$$U_j = I \times (R_{ch} + L_{gt}/2.6 + H_d/2.6)(kV) \quad (7)$$

(B) Direct lightning overvoltage with a ground wire

A wire line there has three parts: the first is the lightning stroke pass by ground wire and directly strike at wire, the second is lightning tower; the third is a lightning ground wire in the middle of span.

Lightning bypass the lightning resisting level of ground wire strike in wire overvoltage and must draw around the P_a [8]. The so-called around rate refers to bypass the ground wire and hit probability of the wire; it drops rapidly with the decrease of the angle of protection. According to simulation test and experience for many years in field operation, bypass rate is associated with protection angle a of ground wire to lateral wire, tower height h and terrain conditions, suggest use the type calculation:

The plain lines:

$$\lg P_a = a\sqrt{h}/86 - 3.9 \quad (8)$$

The mountain route: $\lg P_a = a\sqrt{h}/86 - 3.35$ **(9)**

ANALYSIS OF THE ACCIDENT AND AFFECTING FACTORS

Lightning is a kind of event of small probability. It is impossible to accurately measure and capture the line of every lightning parameter, even it is difficult to accurately distinguish each type of flashover line lightning failures, such as back or detour lightning problem, and cause on the lightning protection measures of pertinence is not strong[9]. Transmission line lightning protection research by investigation and observation in order to further clarify the characteristics, find out the problem, develop targeted lightning protection measures. In this paper, starting from the principle of transmission line lightning over-voltage, combined with field investigation data and laboratory test results, at last the simulation analysis, the computation of the related factors influencing the lightning resisting level of line are analyzed, and the grid 110 kV lines typical ray harm accident made a concrete analysis.

Calculation model and activity characteristics of lightning discharge

Lightning discharge in meteorology, landscape and other natural conditions, the randomness is very big, about so the various factors of lightning properties is the nature of the statistics, by a large number of measurement is needed to determine, lightning protection design based on the measured data. Understand the equivalent calculation model of lightning current and lightning current amplitude distribution of lightning protection design is of prime importance.

(a) Lightning equivalent circuit calculation

The essence of thundercloud to ground discharge is thundercloud charge to the sudden release of the earth. Although thunder clouds have a high initial potential (up to hundreds of megabytes v) could make the atmospheric breakdown, forming the guide, administrative electricity, but the ground was hit potential is not depends on the initial potential of the object, but depends on the product of lightning current and impedance by a strike object (the object impedance refers to be hit points and the impedance between the earth zero potential reference point). So, from the nature of the power supply, this is equivalent of a current source process.

Although the physical process of lightning discharge is very complicated, but the practical effect of feel from the ground and lightning protection engineering point of view, still can look at it as a along a fixed wave impedance of the lightning channel to the ground propagation of electromagnetic wave process, on the basis of calculation model is established.

In lightning discharge process, people can measure power, mainly current through the strike objects when lightning strikes the ground, and then deduced according to the calculating model of the parameters of the waves. By the current source equivalent circuit:

$$i = 2i_o \frac{Z_o}{Z_o + Z_c} \tag{10}$$

(b) Lightning current amplitude

Lightning current is single polarity of the pulse wave. In general, our current standard recommends the probability of lightning current amplitude distribution as shown in the type :

$$\lg P = -\frac{1}{88} \tag{11}$$

The research of the influential factors of lightning resisting level of line

From the survey of statistical data analysis, high lightning accidents and lightning trip-out rate of 110 kV transmission line in a mountainous area, main affected by factors such as location, environment, and cause the loss of transmission line electrical insulation level and higher ground resistance, this section on the influencing factors of lightning resisting level of line calculation for the simulation analysis, the analysis process is as follows:

(a) Relationship between tower grounding resistance and the lightning resisting level

Due to the complexity of terrain and topography, mountain transmission line is difficult to construct, and soil resistivity is high, tower grounding resistance is mostly on the high side[10]. The greater line tower grounding resistance is, the lower lightning resisting level is; the higher the lightning resisting level of vice.

$$I = \frac{U_{50\%}}{(1-k)[\beta(R_{ch} + \frac{L_{gt}}{2.6}) + \frac{h_d}{2.6}]} \tag{12}$$

TABLE 2: Lightning resisting level of110 kV transmission line under different grounding resistance value

Power frequency grounding resistance/Ω	corresponding grounding resistance/Ω	lightning resisting level/kV
15	11.25	42.76
22	16.50	34.30
28	21	29.31
35	26.25	25.05
46	34.50	20.41
67	50.25	15.07
88	66	11.95
120	90	9.08

(b) Relationship between single and double wire protection and lightning resisting level

Separately calculated the resisting level and lightning trip-out rate when two tower in the impact grounding resistance of 7 Ω and 15 Ω, and list it in TABLE 2. The calculation formula of lightning resisting level of TABLE 4.2 for (4.16), the calculation formula of lightning trip-out rate as follows:

$$n = 0.6h_b\eta(gp_{I1} + p_a p_{I2}) \tag{13}$$

It can be seen from TABLE 4.2 data that when the tower grounding resistance value is 7 Ω, compared with single wire, the lightning resisting level of double wire increased by 28.3%, and lightning trip-out rate is reduced by 40%. Also found that when the tower grounding resistance value is 15 Ω, compared with single wire, the lightning resisting level of double wire is only increased by 11.1%, only reduce lightning trip-out rate of 32.2% [11]. This means that different protection modes of transmission lines under the same grounding resistance, the lightning protection effect is different, the double effect of lightning protection of conducting wire is better than single wire. In addition, the line of the lightning protection effect is related to the size of the tower grounding resistance, with the increase of tower grounding resistance, single or double wire lightning resisting level will reduce, and lightning resisting level of single wire and double wire will incline to the same lightning resisting level. That is to say, with the increase of tower grounding resistance wire of lightning protection effect will be less and less obvious. Therefore, for mountain transmission line, reduce the tower grounding resistance is one of the effective measures to improve the level of transmission line lightning resisting.

(c) Affect of coupling ground wire on line lightning resisting level

Coupling ground is as follows. Firstly, it has the effect of shunt effect and increases the conductivity, the coupling coefficient between the grounds and reduced the equivalent impedance, makes the wire on the lightning Bob get effective control, makes the voltage on the insulators decreases, and the flashover circuit not easy, so as to improve the level of resistance to ray. Secondly, the lightning rod tare current shunts effect increase, reduce the tower potential. Thirdly, it can improve the potential at alignment pole place, reduce tower effective height corresponding, and induced voltage on the lightning conductor when the tower component decreases,.

Assume that lightning current is oblique wave 2.6/50 μs , then:

$$i_1 = \frac{I_1}{2.6} t \tag{14}$$

$$i_L = \frac{I_L}{2.6} t \tag{15}$$

$$\beta = \frac{I_1}{I_L} = \frac{2L_{b1}L_{b2}}{2.6R_{ch}(L_{gt}^a + L_{b1} + L_{b2}) + 2L_{b2}L_{gt}^b + 2(L_{gt}^a + L_{b1})(L_{gt}^a + L_{b2})} \tag{16}$$

Through the above analysis we can get the potential of coupling ground are as follows:

$$U_o = i_1 R_{ch} + L_{gt}^b \frac{di_1}{dt} = \beta i_L R_{ch} + \beta L_{gt}^b \frac{di_L}{dt} \tag{17}$$

According to: $u_o = L_{b2}(\frac{di_3}{dt} - \frac{di_1}{dt})$ **(18)**

We can get: $\frac{di_3}{dt} = \frac{u_o + L_{b2}\frac{di_1}{dt}}{L_{b2}}$ **(19)**

Potential at the top of the tower is:

$$U_1 = (1 + L_{gt}^a)(R_{ch} + \frac{L_{gt}^b}{t_f}) + L_{gt}^b \frac{\beta I_L}{2.6} \tag{20}$$

Line lightning resisting level after adding coupling ground is:

$$I_1 = \frac{U_{50\%}}{\beta(1 - C_1)(R_{ch} + \frac{L_{gt}^a}{t_f}) - C_2\beta(R_{ch} + \frac{L_{gt}^b}{t_f}) + \frac{h_d}{t_f}(1 - k)} \tag{21}$$

ACCURATE MODELING OF TRANSMISSION LINE GROUNDING DEVICE

Introduction

Figure 2 is the typical 500 kV line tower grounding device, grounding body adopts Φ 12 round steel, ray length is 4 x 5 meters, ground total of 48 m long, a fixed depth of 0.8 m, single homogeneous soil structure, its resistivity is 100 Ω • m

Basic principle of method of moments

This paper uses international famous Canadian security engineering company development package CDEGS to study the impact of the grounding device features. CDEGS packages are a powerful integrated software tool, which can be used for accurate analysis of grounding, electromagnetic field, electromagnetic interference etc. CDEGS can be calculated by embedding or any network structure of electric conductor above the ground in the normal and fault, under transient conditions, such as lightning current and electromagnetic field[12]. CDEGS can simulate simple conductor and composite conductors, such as the bare wire, coated pipe or embedded in the structure of complex soil pipe with electric cable system.

CDEGS can provide solutions from simple grounding network design to complex problems caused by lightning and other embedded systems or ground system.

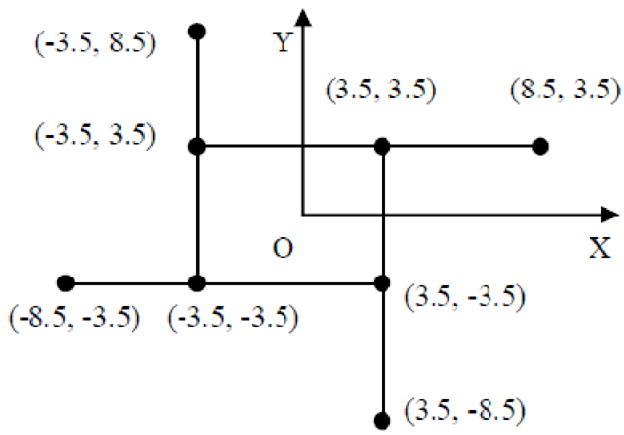

Figure 2: Typical 500kV tower grounding device

Frequency response of grounding device

(a) Impact resistance of grounding device

Lightning current injection point potential v (t) can be writing form as follows:

$$v(t)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}V(\varpi)e^{jct}d\varpi \\ =\frac{1}{2\pi}\int_{-\infty}^{+\infty}Z(\varpi)I(\varpi)e^{jct}d\varpi \quad (22)$$

(b) Acquisition of grounding device of frequency response

Experiments or the simulation calculation can usually be used for frequency domain characteristics of grounding device. There are many different kinds of tower grounding device, through the experiment for frequency domain characteristics of grounding device tend to be very laborious. Must first experience, more importantly, power transmission and transformation project design phase, wiring and grounding device has not yet started building, could not through the experiment of heavy and complicated to determine the frequency domain characteristics of grounding device. Therefore, this article adopts the CDEGS MALZ modules, namely by fast Fourier transformation (fast Fourier transform and FFT) and the method of moments method, the simulation calculation for the frequency domain response of grounding device.

Establishment of the equivalent circuit model for grounding device

(a) Vector fitting method frequency domain the impedance function feature

Vector Fitting is a stable and effective mathematical Fitting method, it USES first-order rational fraction and the frequency domain in the form of function approximation, especially suitable for power system frequency varying effects modeling, this paper use this method for Fitting frequency domain characteristics of grounding device, check with domestic and foreign literature have not been reported the application of this method in the field of earth. Compared with other fitting method, vector matching method has the following advantages:

1) Search for optimal fitting directly by solving two linear least square equations, less number of iterations, convergence speed is fast.

2) Usually, general fitting method using higher order rational function over a very wide frequency range for numerical problems is proposed to fit the measured frequency response of the will, and vector matching is not affected.

3) Do not need to estimate the zero and pole, both real pole smooth curve fitting are available, and also can use the plural pole curve fitting resonance properties.

The method uses rational function approximation fitting of the frequency domain response z (s), the partial fraction form is:

$$\delta(s)=\sum_{i=1}^{N}\frac{r_1}{s-a_1}+d+es \quad (23)$$

(b) Transformation of rational function approximation type to the equivalent circuit

After getting the grounding device impedance function of rational function approximation, we can convert rational approximation expressions of frequency domain to time domain of the circuit model, thus getting the equivalent circuit grounding device. Considering the grounding device impedance function of frequency characteristic curve is smooth, so the general residue r_i, pole a_i are real numbers; Parameter d and e is the set of real numbers. Assuming that $r_i < 0, I = 1, 2, \dots, K$; $r_i > 0$, I = K + 1, K + 2,..., N. The type (4-14) can be written as:

$$\delta(s) = \sum_{i=1}^{N} \frac{r_1}{s - a_1} + \sum_{i=K=1}^{N} \frac{r_1}{s - a_1} d + es \quad \textbf{(24)}$$

CONCLUSION

Around computation is one of the key links of transmission line lightning protection performance evaluation. In this paper, on the basis of predecessors' research, it is concluded that a more complete set of hammer computation model, namely the improved electrical geometric model through strict mathematical deduction. With foreign authoritative literature comparative analysis, it shows that using this model, the calculation result is accurate. In addition, with the comparison of operating experience shows that the improved model in calculating smaller or negative protection angle lines around the hit rate, it has a clear advantage.

Counter calculation is one of the key links of transmission line lightning protection performance evaluation. This paper analysis the three calculation models, namely the regulation method, simplified back calculation method based on the single wave impedance model and standard back calculation method based on ATP/EMTP. Calculation shows that the ATP/EMTP method can accurately modeling on the wire - tower - insulator - wire - grounding device and the complex system, so the result of calculation is more in line with expectations.

Lightning protection focus on grounding. Grounding research at home and abroad have made great progress, but in lightning protection calculation, especially in back calculation, failed to fully absorb the domestic and foreign research results, and still continue to use the concept of the grounding resistance in the past, the grounding device simply replace with impact grounding resistance, is used for lightning protection calculation. In this paper, on the basis of predecessors' research, first pioneering with five order equivalent circuit to replace the previous impact resistance, as grounding device model of ATP/EMTP time-domain calculating program. Compared with international authoritative grounding analysis software CDEGS calculation results, it show that the equivalent circuit model of time domain features is more close to actual real impact characteristics of grounding device than impact resistance model, which can improve the accuracy of the results in lightning protection calculation.

REFERENCES

[1] S. Grant, J. G. Anderson, et al.; A Simplified Method for Estimating Lightning Performance of Transmission Lines [J], IEEE Trans. on Power Apparatus and Systems, **104(4)**, 919-927 **(1985)**.

[2] James T. Whitehead, W. A. Chisholm; IEEE Working Group Report, Estimating.

[3] Lightning Performance of Transmission Lines Ⅱ - Updates to Analytical Models [J], IEEE Trans. on Power Delivery, **8(3)**, 1254-1267 **(1993)**.

[4] A.J.Eriksson; An Improved Electro-geometric Model for Transmission Line Shielding Analysis [J], IEEE Trans. on Power Delivery, **2(3)**, 859-870 **(1987)**.

[5] Wen Yuanfang; High Voltage Technology [M], Wuhan: Huazhong University of science and technology press **(2006)**.

[6] Ma Wenxia, xiao Lili, Yuan Tao; Analysis of Gground Soil Impact Characteristic Method that Considering Nonlinear Characteristics [J], Proceedings of the csee, **29(16)**, 127-132 **(2009)**.

[7] D Deschrijver, M Mrozowski, T Dhaene, D De Zutter; Macro Modeling of Multiport Systems Using A Fast Implementation of the Vector Fitting Method [J], IEEE Microwave and Wireless Components Letters, **18(6)**, 383-385 **(2008)**.

[8] B Gustavsen; Computer Code for Rational Approximation of Frequency Dependent Admittance Matrices [J], IEEE Trans. on Power Delivery, **17(4)**, 1093-1098 **(2002)**.

[9] Takuro Shigeno; Experience and effectiveness of application transmission line arresters, Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES, **1**, 636-639 **(2002)**.

[10] Wangjian, Zhang Xuepeng; Study of the transmission line lightning protection measures, North China electric power technology, **10**, 1-5 **(1998)**.

[11] Cheng xueqi, Yang Chunlei; Application of the Line Arrester in the Lightning Protection for Transmission Line, China electric power, **32(8)**, 66-67 **(1999)**.

[12] Yang Maohui, Tan Jianmin; The Application Effect of Line Surge Arrester on Line Lightning Protection, Guangdong electric power, **4**, 53-55 **(2003)**.