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Study on the Lightning Protection Differentiation Technology of Power Distribution Lines

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Abstract:

With the continuous improvement of China's economy, the current construction of China's power grid has been continuously optimized and improved, and the structure of the power system has become more professional and advanced. At the same time, the operation of distribution and transmission lines has become more complicated, which also poses new requirements and challenges for the operation management and maintenance of daily distribution and transmission lines. Therefore, this article will focus on the daily operation and maintenance measures of distribution and transmission lines. This article analyzes the various faults in the operation of daily distribution and transmission lines, calculates the lightning strike rate based on the topography of the line, and finds the line. The lightning protection point is weak. Then propose feasible measures to promote the operation management and maintenance work. Based on the research and summary of the operation mode of the distribution line system, this paper points out the power distribution line maintenance technology commonly used in the current system operation, and on this basis, explores the construction method of the lightning protection technology system. So that the security level of the entire system can be maximized.

Keywords: *Lightning risk, Topography, The improved analytic hierarchy process, Differential lightning protection.*

I. INTRODUCTION

In the context of the continuous development of society, China's power industry has a broader space for improvement, but the various problems still existing in the operation of daily distribution lines need to be improved. The purpose of the distribution line operation and maintenance technology is to adopt the offline control and online control modes through real-time monitoring of daily operation status to ensure that the entire power distribution system is in the most normal and stable operation state, and the electrical equipment of the entire power

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distribution system and the user terminal is prevented. Suffered from damage. In the process of using lightning protection technology, the purpose is to prevent common direct lightning strikes and inductive lightning from interfering with the power parameters of the system, and transmitting this fault information to the entire power system.

Distribution lines is characterized by wide distribution and relatively low insulation level, which is easy to cause insulation accidents due to overvoltage. For distribution lines, lightning strikes are a factor that cannot be ignored [1]. Due to the weak structure and complex operating environment of the distribution line, it is prone to lightning accidents. During thunderstorm season, distribution transformers, leakage switches and other power distribution equipments are easily burned. Therefore, it is necessary to find out the defects and shortcomings of the distribution network line and improve its lightning protection capability, which is the key to ensuring the safe operation of the distribution network [2,3].

Because the terrain and geomorphology of the distribution network are different and meteorological conditions vary widely, the characteristics of lightning strikes in different areas, different sections and different towers of the same line are different [4]. To this end, it is necessary to comprehensively consider the terrain, geomorphology, lightning distribution characteristics, tower structure and line parameters of the distribution line [5]. Do some research on an accurate lightning strike risk calculation for the distribution line, and find out the severe lightning damage area of the distribution line [6]. Further, selecting appropriate lightning protection measures for severely damaged areas to achieve differentiated lightning protection of distribution lines, which is important to lightning protection research of distribution lines. Therefore, lightning protection research on distribution lines is mainly divided into two steps: Firstly, it is necessary to clarify the severe lightning damage area of the distribution line, secondly, appropriate lightning protection measures should be taken for different areas to reach the target of differentiated lightning protection of the distribution line.

II. MATERIAL AND METHODS

The lightning strike rate is taken to measure lightning risk of the distribution line. When considering the topography, lightning distribution characteristics, tower structure and other factors of the line, the lightning tripping rate calculation of each tower of the distribution line is shown as follows.

2.1 Lightning Parameters

Statistical distribution of lightning distribution in the located area of the distribution line are required in computing the tripping rate of lightning of a distribution line. The statistical data of the lightning location system is processed based on the grid method: the number of lightning strikes in each grid area over the years is counted, and then the ground lightning density Ng is calculated, which means the mean value of lightning strikes per square kilometer per lightning day. Figure 1 shows the ground drop density map of a certain area as measured by the lightning location system:

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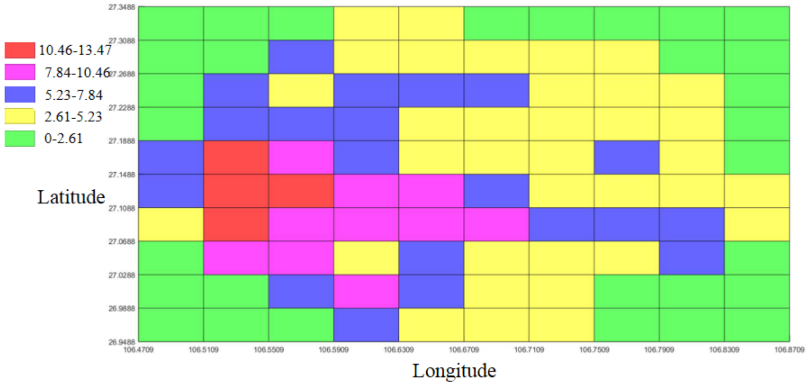

Fig 1: The ground lightning density map

In addition to the ground lightning density-Ng, the measured value of the lightning positioning system can compute the lightning current amplitude, too. DL/T 6201997 “Overvoltage Protection and Insulation Coordination of AC Electrical installations” stipulates that: by calculating the probability that the greatest value of the lightning current exceeds I_m:

$$P = \frac{1}{1 + (I_m / 36.641)^{2.782}} \tag{1}$$

2.2 Induction Lightning Tripping Rate

When there is no lightning shield line overhead the transmission lines, the induction lightning tripping rate is calculated below: it begins with computing the induced overvoltage on the line; usually, the calculation of the induced overvoltage is based on the formula of the peak value of the induced lightning voltage; after that, on the basis of the determination of the induced overvoltage Umax, the range of the induced overvoltage to make the line trip is determined. Voltage causes line tripping range. If Umax>U50%, the insulator flashes, so with U50% of the insulator, the critical flashover distance Smax can be obtained when the peak lightning current is I. If the distance between the line and the lightning strike point is smaller than Smax, the insulating flashover occurs.

Calculate the tripping rate TRI of induction lightning stroke as below [6]:

$$TR_I = 0.2 N_g \left(\int_{I_L}^{\infty} P(I)(S_{max} - S_{min}) dI \right) \cdot \eta \tag{2}$$

η-are rate [7]

Smin-critical distance of lightning striking lines, m [8]

IL-critical current value of lightning striking shield line, kA [9]

$$\eta = [4.5 \cdot (\frac{U_e}{2l_j + l_m})^{0.75} - 14]\% \tag{3}$$

$$S_{min} = 10 I^{0.74} h^{0.6} \tag{4}$$

$$I_L = \frac{U_{50\%}}{100} \tag{5}$$

Ue -rated line voltage, kV

Lj-the length of insulator string, m

lm-the distance between the poles and towers (lm =0 for iron and reinforced concrete lines), m

h-the height of the tower, m.

When lightning shield line exists over distribution lines, [10]

$$TR_I' = 0.2N_g(\int_{I_L}^{\infty} P(I)(S_{max}' - S_{min})dI) \cdot \eta \tag{6}$$

The shielding effect of lightning arrester has been taken into account for the solution of S_{max}'. Because of lightning shield line, the induced overvoltage on the distribution lines will decrease. Its induced overvoltage is calculated by U = (1-K) Umax, and K is the product of the coupling coefficient and the impact coefficient between lightning arrester and shield line. When the induced overvoltage U>U50% on the shield line, the insulator flashes, so as the U50% of the insulator, the critical flashover distance S_{max}' and S_{max}' can be obtained when the peak lightning current is I. If the distance between the line and the lightning strike point is smaller than S_{max}', the insulating flashover occurs.

2.3 Direct Lightning Tripping Rate

If the distribution line is not tripped caused by inductive lightning, other lightning trips are attributed to the direct lightning trip. When there is no lightning protection line on the distribution line, the lightning will only hit the distribution line directly, and the resulting trip rate is calculated as follows (the meaning of each parameter is the same as the calculation of the induced lightning tripping rate) [11]:

$$TR_{ST} = 0.2N_g(\int_{I_L}^{\infty} P(I)S_{min}dI) \cdot \eta \tag{7}$$

When installing the lightning protection line over the line, in addition to the lightning strike to hit the distribution line, the trip rate resulting from the lightning strike of the tower is also considered. The lightning tripping rate TRR of the lightning bypass distribution line is as follows [12]:

$$TR_R = 0.2N_g(\int_{I_L}^{\infty} P(I)S_{min}dI) \cdot \eta \cdot P_\alpha \tag{8}$$

Pa-shielding failure rate

For mountain lines [13]:

$$\lg P_\alpha = \frac{\alpha\sqrt{h}}{86} - 3.35 \tag{9}$$

α-the protection angle of the line

The trip rate TRT caused by lightning strikes the tower is shown below [14]:

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$$TR_T = 0.2N_g(\int_{I_T}^{\infty} P(I)S_{min}dI) \cdot \eta \cdot g \quad (10)$$

$$I_T = \frac{U_{50\%}}{R_{ch} + L_t / 2.6 + h_d / 2.6} \quad (11)$$

Rch-tower grounding resistance, Ω

I_T is lightning resistant level, kA

Lt-tower equivalent inductance, uH

hd-height of line, m

Therefore, when there is a lightning protection line on the distribution line, the direct lightning tripping rate of the line is:

$$TR_{ST}' = TR_R + TR_T \quad (12)$$

The total trip rate of the line is:

When the lightning protection line is not installed over the lines:

$$TR = TR_I + TR_{ST} \quad (13)$$

When there is lightning protection line over the lines:

$$TR' = TR_I' + TR_{ST}' \quad (14)$$

2.4 Influence of Topography

Lightning strikes on distribution lines vary in different topography and landforms. According to the GPS positioning system and satellite photos, we can know the geographical situation of the tower and obtain the risk factor f through statistical analysis. The value of f is shown in TABLE I.

TABLE I. The value process technology points

Topography	Risk factor
Peak, mountain edge	1.3
Large span on both sides of the tower	1.3
Smooth rolling mountains	1.5
Mid-mountain, side mountain	1.2

Based on the calculation of the lightning tripping rate, considering the impact of topography and geomorphology, the risk of mountains distribution network is calculated as follows:

$$RISK = f \cdot TR \quad (15)$$

III. RESULTS

The lightning tripping rate TR of each base tower of the line has been calculated, then compare the towers with severe lightning damage. Measures are taken to decrease the lightning tripping rate of the tower and the efficiency of the lightning tripping rate reduction after each lightning protection measure is implemented. The economic efficiency and implementation

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difficulty of the lightning protection measures are considered, and the optimized lightning protection scheme is determined.

The importance parameters of the lightning strike rate reduction effect, engineering cost, and engineering difficulty are calculated. The improved analytic hierarchy process can be used to calculate the weight coefficient. The steps are shown as below:

3.1 Determine the Comparison Matrix Ann

The form of the comparison matrix Ann is shown as below:

$$A_{nn} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \cdots & & \cdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{16}$$

In matrix Ann, the value of element aij is 0, 1 or 2, which reflects the importance of the influencing factor Ai with respect to Aj. The value of aij is 0, indicating that Ai is not important with respect to Aj. aij's value of 1 indicates that Ai and Aj are of equal importance. A value of 2 indicates that Ai is more important than Aj.

3.2 Constructing a Judgment Matrix

Assume that the comparison matrix A33 is shown as below:

$$A_{33} = \begin{bmatrix} 1 & 0 & 0 \\ 2 & 1 & 2 \\ 2 & 0 & 1 \end{bmatrix} \tag{17}$$

For each set of factors, construct a judgment matrix, and obtain a matrix B33

$$B_{33} = \begin{bmatrix} 1 & 1/5 & 1/3 \\ 3 & 1 & 3 \\ 3 & 1/3 & 1 \end{bmatrix} \tag{18}$$

3.3 Calculate the Transfer Matrix of the Judgment Matrix

The elements of the transfer matrix $c_{ij} = \lg b_{ij}$, get C33 with:

$$C_{33} = \begin{bmatrix} 0 & -0.669 & -0.447 \\ 0.669 & 0 & 0.447 \\ 0.447 & -0.447 & 0 \end{bmatrix} \tag{19}$$

Calculate the element of the optimal transfer matrix of transfer matrix

$$d_{ij} = \frac{1}{n}\sum_{k=1}^{n}(c_{ik} - c_{jk})$$

D33 has:

$$D_{33} = \begin{bmatrix} 0 & -0.784 & -0.392 \\ 0.784 & 0 & 0.392 \\ 0.392 & -0.392 & 0 \end{bmatrix} \tag{20}$$

3.4 Calculate the Quasi-Uniformity Matrix of the Judgment Matrix

The quasi-uniformity matrix $b'_{ij} = 10^{d_{ij}}$, B'33 has the elements that are obtained:

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$$B_{33}' = \begin{bmatrix} 1 & 0.164 & 0.406 \\ 6.081 & 1 & 2.466 \\ 2.466 & 0.406 & 1 \end{bmatrix} \quad (21)$$

Each row of the quasi-uniformity matrix has the elements that are multiplied by an n-dimensional column to [0.067, 14.996, 1.001]T, and the vector element is processed by n-th root (where n is 3) to get [0.405, 2.466, 1.000]T, then normalized to obtain the vector ω = [ω1,ω2,ω3]T = [0.105,0.637,0.258]T, where ω1,ω2,ω3 are the influencing factors A1, A2, A3 respectively weights.

Calculate the weights of the three measurement factors ω1, ω2, ω3 and multiply the values of the three factors themselves to obtain the comprehensive values of different lightning protection measures, and determine the more beneficial lightning protection scheme.

IV. DISCUSSION

The 35kV distribution line has been taken (hereinafter referred to as the A line) as an example to explain the lightning protection of the distribution line. Information of the line is shown in Figure 2.

NO. of Tower	h(m)	lj(m)	U50%(kV)	Rch(Ω)	Logitude	latitude	f	b(With or without lightning lines; with b=1; without:b=0)	blq(With or without lightning arrester; with blq=1; without:blq=0)
35001001	26	1.18	400	9.6	106.71919	27.14998	1.5	1	1
35001002	18	0.885	300	6.8	106.72105	27.14841	1.5	0	0
35001003	18	0.885	300	7.4	106.72251	27.14401	1.5	0	0
35001004	16.5	0.885	300	9	106.7209	27.14084	1.5	0	0
35001005	16.5	1.28	250	7.5	106.72341	27.13695	1.5	0	0
35001006	15	1.28	250	7.5	106.72514	27.13292	1.5	0	0
35001007	15	1.28	250	7.5	106.72595	27.13127	1.5	0	0
35001008	15	1.28	250	7.5	106.72773	27.12679	1.5	0	0
35001009	15	1.28	250	7.5	106.72794	27.12622	1.5	0	0
35001010	16.5	0.885	300	7.5	106.73046	27.12144	1.2	0	0
35001011	16.5	0.885	300	7.5	106.73093	27.12065	1.3	0	0
35001012	16.5	0.885	300	7.5	106.73223	27.11893	1.3	0	0
35001013	12	0.885	300	7.5	106.73368	27.11852	1.5	0	0
35001014	15	0.885	300	9.2	106.73676	27.11099	1.5	0	0
35001015	12	0.885	300	12	106.73714	27.11034	1.5	0	0
35001016	16.5	0.885	300	10	106.73767	27.10966	1.5	0	0

Fig 2: The line information

After calculation, the risk value of each tower is shown as TABLE II:

TABLE II. Properties of raw materials

Tower No.	Risk	Tower No.	Risk
35001001	2.86	35001009	14.65
35001002	22.81	35001010	21.32
35001003	22.91	35001011	21.32
35001004	21.54	35001012	21.32
35001005	15.91	35001013	16.53
35001006	14.65	35001014	20.0
35001007	14.65	35001015	17.25
35001008	14.65	35001016	21.66

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The towers that need to be focused on are No. 3, No. 2, No. 16, No. 4, No. 12, No. 11, No. 10, No. 14, and the No. 3 tower is taken as an example. It is necessary to strengthen the lightning protection because the tower grounding resistance is already small. Therefore, it is not considered to reduce the grounding resistance. It can also take measures such as installing a lightning protection line, installing a lightning arrester, and increasing the number of insulators. The lightning risk reduction effect of No.3 tower with three measures is as follows in TABLE III.

TABLE III. The lightning risk reduction effect of No. 3 tower with three measures

Lightning protection measures	Risk	Risk reduction rate
Install lightning protection line	4.33	81.1%
Installation of lightning arrester	18.21	20.5%
Add a piece of insulator	13.26	42.1%

The engineering cost and engineering difficulty of different lightning protection measures should be taken into consideration to decide the final lightning protection measure. RISK reduction rate, the engineering cost and engineering difficulty are called A1, A2, A3. Considering the importance of A1, A2, A3, A1 is the most important and A3 is east important and analytic hierarchy process is applied to calculate ω1, ω2, ω3. Normalization A1, A2, A3 of three kinds of lightning protection measures, on the basis of the weight coefficient that is calculated by the analytic hierarchy process, the result is shown in TABLE IV. It can be seen that for Tower No.3, the appropriate lightning protection measure is the installation of lightning protection lines.

TABLE IV. Selection value of three lightning protection measures

Lightning protection measures	Selection value
Install lightning protection line	1
Installation of lightning arrester	0.37
Add a piece of insulator	0.41

V. CONCLUSION

When the traditional European light distribution protection technology is used for lightning protection, it has the problems of limited distribution range and low insulation level, which is easy to cause insulation accidents. Therefore, this paper studies the lightning protection of distribution lines. Because different protective measures have different protective effects, it is necessary to explore and select appropriate protective measures for mathematical methods. In the project, considering the effect of lightening rate reduction, project cost and project difficulty, different lightning protection schemes are selected. By processing the statistical data of lightning location system, more lightning information can be obtained. Based on the analytic hierarchy process that is improved, the weight coefficients of different influencing factors are calculated. On this basis, the risk caused by lightning to distribution lines is calculated, and the affection of tower topography is considered, the reinforcement degree of distribution line tower is defined, and the accurate evaluation of lightning is implemented. The results of the experiment indicate

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that this method can alleviate the problems of traditional European distribution network protection technology.

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