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METEOROLOGIC CHARACTERISTICS AND STANDARD THICKNESS CALCULATIONS OF WIRE ICING OVER THE NORTH REGION OF GUANGDONG PROVINCE

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Abstract: Based on the wire icing observational data and climate data of Lechang high-mountain weather station during 1972-1978, meteorological characteristics of wire icing over the north region of Guangdong province were analysised and the calculation model of standard ice thickness of wire icing was established. According to the history observational data of Lechang national weather station neraby,climate data of Lechang high-mountain weather station was corrected and extended, the long age serial of yearly maximum standard ice thickness was developed, and then, different return period of standard ice thicknesses at different height were calculated. The results show that, wire icing over the north region of Guangdong Province mostly occurs in Jan., the next in Feb. and Dec., the average icing period is about 90 days, the longest icing period reach 131 days more. Predominant wind direction, daily minimum air temperature and daily precipitation are the major meteorologic factors to influence wire icing thickness. The serial of yearly maximum standard ice thickness of Lechang high-mountain weather station is preferably obey extreme-I probability distribution. The maximum wire icing thickness occurred in Jan 26, 2008, standard ice thickness at 2 meters height was 64.4mm and 92.7mm at 15 meters height, which is close to 115mm obtained from the investigation about wire icing damage in 2008.

Key Words: wire icing; standard ice thickness; meteorologic characteristics; calculate; the north region of Guangdong Province

1 Introduction

Wire icing phenomena is very common both at home and abroad and our country is one of the most serious wire icing countries in the world [1-3].The north region of Guangdong located at the South China and mostly covered by mountains which make it the necessary way of cold surge south bound. Because of the blocking effect and uplift of Nanling Mountains to the airflow, the southward cold air often meets with the southward warm air and develops South China Stationary Front which causes the weather cold and damp for a long time and then wire icing appeared during winters and springs every year. The serious low temperature, rain and snow, frost disaster in 2008 was created by the South China Stationary Front which occupied the north region of Guangdong for a long time [4-5].The disaster caused 32 Guangdong transformer substations and 451 lines stopped working, 342 poles of cables with more than 110kv fell down, the heads of the transmission towers collapsed, 2541 columnfoots were spoilt and 393 wires were broken. Guangdong Electric Network received a heavy blow.

According to different cable lines (110-330kv, 500kv, 750kv), the exist code of China electric network construction applies the standard ice thickness of once in many years (The thickness of the ice evenly cover the wire while its density is $0.9g/cm^3$) in the ice resistance design [6-7].Due to the lack of systematic and regular icing observation and pertinent investigation results, the estimate of the design ice thickness parameter of most cable lines in actual operation are according to the local icing phenomenon collected occasionally which have large blindness and randomness. According to the analysis of the ice damage investigation data in early 2008, the design ice thicknesses of most electric transmission lines in the south provinces of our countries which are 10-15mm have significant differences from the actual condition.

The wire icing mechanism is very complicated in the natural condition. Lots of factors influence the icing phenomenon and weather condition is the main factor [1].Zhang et al. investigated the relationship of wire icing and the primary meteorological factors in Daban Mountain in Qinghai Province[8]; According to the icing observation data in Three Gorges Area, Xie summarized different kinds of meteorological condition which can cause icing and established quantitative relationship between ice weight and meteorological elements[9].According to the practical application of the wire icing parameters in the transmission engineering of Shanxi Province, Yan gave an index equation to indicate the variation of icing thickness with altitude[10].The work above is some preliminary study of the relationship between icing and meteorological elements, but their analysis method mainly depended on the regular surface meteorological observation elements and seldom calculated the parameters such as wire icing thickness according to the regular long time series. Due to the different climate backgrounds, the icing phenomenon of each place has distinctive local characteristic. The study of the icing phenomenon in the warmer and high humidity winter of South China is still blank.

The electricity from the western to the eastern regions supply occupied one-third of the Guangdong power consumption. The electric network in construction mainly applied 500kv above extra-high voltage power transmission lines which mostly need to pass the north region of Guangdong. Wire icing problem has a great effect on the construction cost of the electric network and operational safety. For the purpose of weather service for electric network and engineering design, based on the regular meteorological elements, an icing meteorological model is established to objectively calculate the wire icing thickness by extending the local annual extremum icing series.

2 Data and Method

2.1 Data

The data used in this paper includes: the wire icing observation data between Dec. 1975 and Mar. 1976 and daily meteorological observation data between Jan. 1 1972 and Dec. 31 1978 from Lechang high-mountain weather station; daily meteorological observation data between Jan. 1 1959 to Dec. 31 2008 obtained from Lechang national weather station.

Lechang high-mountain weather station which is 1023.8m above sealevel is located at the top of Yuanzhu Mountain in Lechang at the north of Guangdong. Standard meteorological observation included icing phenomenon was carried out from 1971 to 1979 at this weather station. The fairly complete wire icing observation was done from Dec. 1975 to Mar. 1976. Two wire icing observation stands were installed, one was oriented north and south and the other one was oriented east and west. An iron wire which is 100cm long and 4mm in diameter was set horizontally at 2m height under each stand.

Lechang national weather station is 28km south by east of Lechang high-mountain weather station, with an altitude of 102.8m. This weather station was built at end of 1958 and the observation items included air pressure, absolute humidity, relative humidity, wind speed, wind direction, air temperature, precipitation, sunshine, evaporation and so on.

2.2 Method

(1) standard ice thickness calculation method

The wire icing observation at Lechang high-mountain weather station recorded the diameter, thickness of icing and ice weight and so on. Due to the different shape and density of icing, icing diameter and thickness in the original records can not comparable, it is necessary to convert to the standard ice thickness[11]: The thickness of the ice evenly cover the wire with the density of 0.9 g/cm^3. Measured ice weight can convert to the standard ice thickness by the formula below:

$$B_0 = (\frac{G}{0.9\pi} + r^2)^{0.5} - r \quad (1)$$

In the equation：B_0——standard ice thickness, mm;

G ——ice weight, g/m;

r ——radiu of wire, mm.

(2) “choose the optimum variable subset” method[12]

Compare to the stepwise regression, this method can promise to choice the optimum variable subset to achieve globle optimum, its regression equation is also the best under some criterion.

3 Result and Analysis

3.1 Analysis of icing meteorological characteristic

According to the icing observation data from 1971 to 1978, icing weather was rather frequent in winter in this area. The annual average icing days was 31.3d and mainly appeared in Jan. and followed by Feb. and Dec..

We define the dates when the initial icing phenomenon appeared and the icing finished as icing initial date and end date, respectively, and the days between these two dates as the icing duration. The statistical data of Lechang high-mountain weather station showed that, the icing initial date usually appeared in mid-Nov. to late Dec. while the end date often happened in middle or late Feb. to late Mar., the annual average icing duration was 89.7d. The longest icing duration was 131d during the 7 years. (Table 1).

Table.1 icing days at Lechang high-mountain during 1971 to 1978 (d)

Month / Year	11	12	1	2	3	sum	Initial Dates (day/month)	End Date (day/month)	Icing Duration (d)
1971-1972			14	9	1	24		1/3	
1972-1973		10	12	2		24	12/12	20/2	71
1973-1974		5	11	17		33	22/12	28/2	69
1974-1975		12	6	4		22	6/12	10/2	67
1975-1976	2	17	9	5	5	38	23/11	24/3	120
1976-1977	6	8	28	17	2	61	14/11	24/3	131
1977-1978		2	12	10	1	25	26/12	14/3	80
Mean	0.9	5.9	14.1	9.3	1.1	31.3			89.7

According to the icing observation data of Lechang high-mountain weather station, the meteorological condition related to the icing forming can be summarize as follows: daily average temperature is -5.0~0.90°C, daily maximum temperature is -3.8~4.8°C, daily minimum temperature is -6.0~-1.0°C, daily average relative humidity is 94%~100%, daily average precipitation is 0.0~16.9mm, daily evaporation is 0.0~5.3mm, daily mean wind speed is 1.3~8.3m/s.

3.2 Calculation of standard ice thickness

3.2.1 Lechang high-mountain weather station standard ice thickness calculation model

Based on the icing observation data obtained from Lechang high-mountain weather station, the standard ice thickness is calculated as follows:

Table.2 wire icing data of Lechang high-mountain weather station from Dec. 1975 to Mar. 1976

Data	Oriented North And South				Oriented East And West				Prevailing Wind Direction
	Diameter (mm)	Thickness (mm)	Ice Weight (g/m)	Standard ice thickness (mm)	Diameter (mm)	Thickness (mm)	Ice Weight (g/m)	Standard ice thickness (mm)	

1975-12-09	113	25	1356	20.0	31	25	216	7.0	WNW
1975-12-10	130	35	1112	17.9	—	—	—	—	W
1975-12-11	105	38	1164	18.4	104	58	1348	19.9	W
1975-12-13	110	65	3060	31.0	75	55	1440	20.7	NW
1976-1-22	116	25	520	11.7	—	—	—	—	WNW
1976-1-23	104	23	540	12.0	118	55	1072	17.6	WNW
1976-1-30	102	23	480	11.2	—	—	—	—	W
1976-1-31	70	15	392	9.9	35	30	452	10.8	WNW
1976-2-19	148	84	2960	30.4	60	39	828	15.2	NW
1976-2-20	115	25	1472	20.9	50	30	680	13.6	NW
1976-3-01	21	9	92	4.0	6	5	—	—	W
1976-3-02	50	15	296	8.4	14	9	—	—	W
1976-3-20	138	26	1200	18.7	53	22	320	8.8	WNW

We can see from the 13 records that, all of the north-south wire was icing while only 10 of the east-west wire was icing. The wire icing frequency is larger for the run north and south wire compared to the east-west one. The average standard ice thickness for the north-south wire is 1.42 times thicker than the east-west one. This phenomenon is due to the prevailing westward wind under the icing weather. The north-south wire has a rather large windward angle with the prevailing wind direction and frontal area which can capture much more water vapor. But for the case of the east-west wire which is almost parallel with the dominant wind direction, both the frontal area and the water vapor captured are rather small.

Make a step forward to give the quantitative relationship of each meteorological element and the standard ice thickness. Tests of correlation significance among the daily maximum standard ice thickness and various meteorological factors are necessary. The test results are shown in table 3:

Table.3 results of the correlation significance test between daily maximum standardice thickness and each meteorological element at Lechang high-mountain weather station

meteorological factor	correlation coefficient	t-test value
daily average precipitation	0.82	4.82
daily minimum air temperature	0.50	1.92
daily average air temperature	0.50	1.89
daily average evaporation	0.39	1.40
daily maximum air temperature	0.23	0.77
daily average relative humidity	0.22	0.76
daily average wind speed	0.17	0.59
daily average air pressure	0.12	0.41

The correlations between daily maximum standard ice thickness and each meteorological factor range in order from strong to week: daily average precipitation > daily minimum air temperature > daily average air temperature > daily average evaporation > daily maximum air temperature > daily average relative humidity> daily average wind speed> daily average air pressure. For daily average precipitation, t-test value >$t_{0.05}$ is equal to 2.201 which is remarkable at level 0.05.The next is daily minimum air temperature, t-test value > $t_{0.1}$ is equal to 1.796 and the rest factors have no significant correlation with the ice thickness.

In winter and early spring, the rainfall is mainly in the form of light rain at north region of Guangdong. If the temperature and the wind speed are suitable for freezing, the light rain can easily become glaze. So during this period, the significant positive correlation between the daily precipitation and the ice thickness is reasonable.

When the humidity condition is satisfied, the lower the air temperature, the freeze is more serious and the icing thickness is thicker. Therefore, the negative correlation between the icing thickness and daily minimum/mean air temperature to some extent is reasonable too.

The low correlation between daily relative humidity and the ice thickness is because the relative humidity is close to saturation (The daily average relative humidity is 94% when the icing happened and above 99% at the other days) while the icing is forming. Due to the small amplitude of variation of the relative humidity, the linear relationship of relative humidity and icing thickness is not significant. But it also relates to the small number of sample. The low correlation between daily mean wind speed and icing thickness suggests the suitable wind speed is the essential requirement for icing forming, but not the decisive factor for icing increasing.

Obviously, icing forming results from several meteorological factors. The “choose the optimum variable subset” method is adopted to do the multiple regression analysis to obtain the regression equation for the local standard ice thickness:

$$Y=8.226-1.344X1+1.089X3 \qquad (2)$$

In the equation, Y is the standard ice thickness (mm), X1 is the daily minimum air temperature (℃) and X2 is the daily mean precipitation (mm).

The multiple correlation coefficient in equation 2 is equal to 0.90，F-test value is 22.05 which is larger than $F_{0.01}$=7.56, residual standard deviation SE is equal to 3.74 mm which is significant at the level of 0.01.The comparison of the regression calculation result and the observed standard ice thickness can be seen in Fig.1.

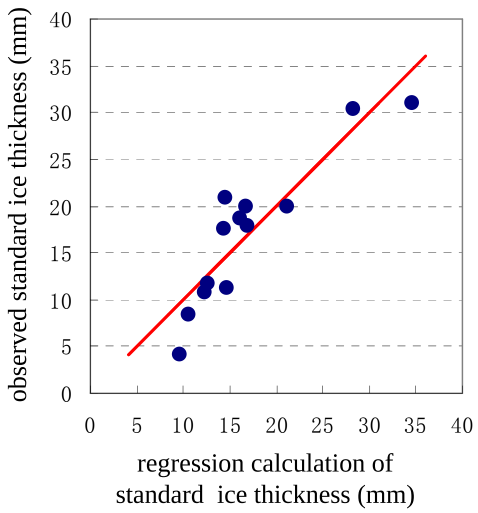

Figure.1 comparison of the regression calculation and observed standard ice thickness

3.2.2 Construction of the annual maximum standard ice thickness serial at Lechang high-mountain weather station

According to the probability and statistics theory, calculation of return period needs a long enough historical sequence. In other word, at least 30 years of yearly maximum ice thickness of Lechang high-mountain weather station is necessary. We chose the historical meteorological observation series from the nearest Lechang national weather station. Based on the correlation of each element, the historical series is obtained by the method of data correction and extension and is satisfied by the return period parameter calculation.

As required by equation 2, the daily minimum air temperature and daily mean precipitation of Lechang high-mountain weather station were corrected and extended. Firstly, examine the correlation between the daily minimum air temperature and the daily average precipitation from Lechang national weather station and from Lechang high-mountain weather station in Dec. to Mar. next year during 1972 to 1978. Figure 2 is the correlation diagram of daily minimum air temperature.

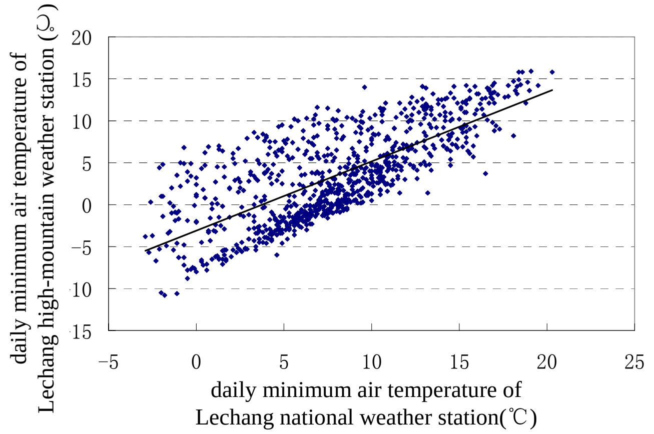

Figure.2 linear correlation of daily minimum air temperature

The examination results of the daily minimum air temperature from Lechang high-mountain weather station and Lechang national weather station are: sample size n=849, correlation coefficient R＝0.73, t-test value＝31.36>>$t_{0.01}$=2.617, positive correlation above 0.01 significance level.

Revise the daily minimum air temperature by differential method [13], based on the observed data, the correction equation is:

$$Td1 - Td2 = -4.4℃ \quad (3)$$

In the equation,Td1(℃) is the mean value of daily minimum air temperature samples of Lechang high-mountain weather station,Td2(℃) is the mean value of daily minimum air temperature samples of Lechang national weather station.

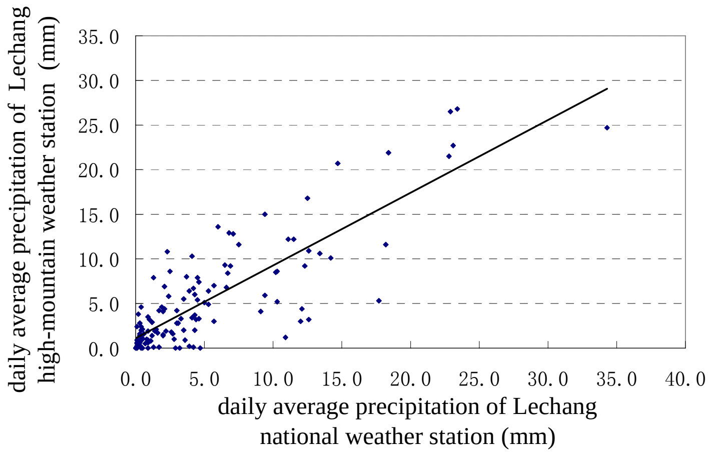

Figure.3 linear correlation of daily average precipitation

Figure.3 shows the correlation of the daily average precipitation between two weather stations. The test results are: n＝129, R＝0.84, t＝17.20>>$t_{0.01}$=2.617, positive correlation above 0.01 significance level.

Correct the daily mean precipitation by ratio method [13], according to the observed data，the relationship of these two station is ：

$$R1/R2=1.06 \quad (4)$$

In the equation, R1 (mm) is the mean value of the daily average precipitation samples of Lechang high-mountain weather station; R2 (mm) is the mean value of the daily average precipitation samples of Lechang national weather station.

The daily minimum air temperature and daily mean precipitation from Jan. to Mar. and Dec. each year during 1959 to 2008 at Lechang high-mountain weather station can be revised and obtained by utilizing equation 3 and 4 (the data during Jan. 1972 to Dec. 1978 is the observed data at Lechang high-mountain weather station). The data is satisfied with the requirements of standard ice thickness calculation by equation 2

Calculated the daily standard ice thickness from Jan. to Mar. and Dec. each year during 1959 to 2008 at Lechang high-mountain weather station by using equation 2 and chose the annual maximum to establish the annual maximum serial of standard ice thickness. Figure 4 gives the maximum standard ice thickness from 1959 to 2008 at Lechang high-mountain weather station. The historical maximum standard ice thickness during 50 years is 64.4mm appeared on Jan. 26 2008.

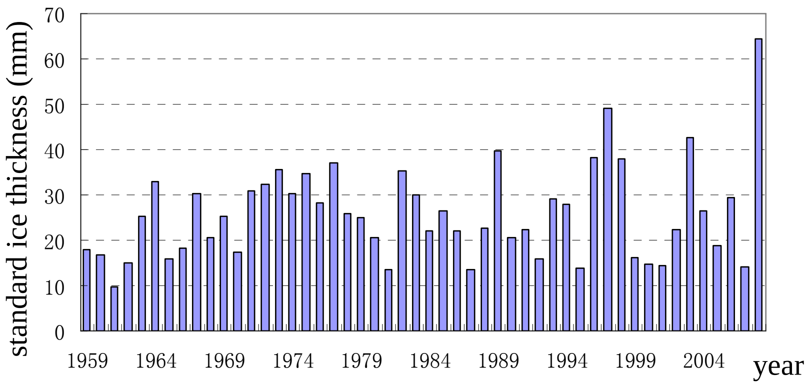

Figure.4 Histogram of the annual maximum standard ice thickness of Lechang high-mountain weather station

3.2.3 2m height standard ice thickness of each return period at Lechang high-mountain weather station

(1) parameter estimation and goodness of fit test of extreme-I probability distribution

To calculate the once in many years standard ice thickness by using the extreme-I probability distribution function [11], it is necessary to test the goodness of fit for the annual maximum standard ice thickness sequence firstly so as to judge whether it is satisfied with the extreme-I probability distribution.

extreme-I probability distribution function:：

$$F(x) = \exp(-\exp(-a(x-b))) \qquad (a > 0, -\infty < b < \infty) \tag{5}$$

In the equation, *a* is the scale parameter of the distribution, *b* is the location parameter of the distribution. Based on exist annual maximum standard ice thickness, estimate the parameters *a* and *b* reasonably and the F(x) can be identified uniquely.

Using the method of Gumber to estimate the parameter a and b[11]：

Assuming an ordered sequence of annual maximum standard ice thickness as:： $x_1 \le x_2 \le ... \le x_n$， then the empirical distribution function is：

$$F^*(x_i) = \frac{i}{n+1} \qquad i = 1,2,...,n \tag{6}$$

Establish a sequence as follows:

$$y_i = -\ln(-\ln(F^*(x_i))) \qquad i = 1,2,...,n$$

As a result：

$$a = \frac{\sigma(y)}{\sigma(x)} \qquad u = E(x) - \frac{E(y)}{a} \tag{7}$$

$\sigma(x)$ and $\sigma(y)$ is the mean square deviation of sequence x_i and $y_i, E(x)$ and $E(y)$ is the mathematical expectation of sequence x_i and y_i . The estimation of $E(x)$ and $\sigma(x)$ can be replace by the mean value and standard deviation of the limited samples in the practical calculation.

According to the annual maximum standard ice thickness at Lechang high-mountain weather station:

a=8.94, b=20.9.

Test index of the Kolmogorov fitting [13]：

$$K_f = D_n \sqrt{n} \tag{8}$$

n is the sample size，Dn is as follows:：

$$D_n = \max\{|F^*(x_i) - F(x_i)|\} \tag{9}$$

Dn represents the maximum difference between empirical distribution and the extreme-I distribution at each point. By calculation, we got K_f=0.422 above 0.05 significance level, look over tables and find $K_f < K_f$ (0.05)=1.35. As a result, the annual maximum ice thickness at Lechang high-mountain weather station is satisfied with extreme-I distribution. The fitting curve can be seen in Figure 5.

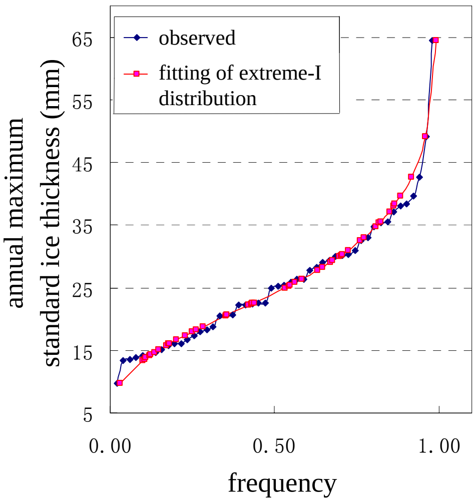

Figure.5 fitting curve of extreme-I probability distribution

(2) calculation of 2m height standard ice thickness of each return period

When return period is R（probability is $1/R$ ）,the standard ice thickness is：

$$x_R = b - \frac{1}{a}\ln\left[\ln\left(\frac{R}{R-1}\right)\right] \tag{10}$$

The 2m height standard ice thickness once of many years at Lechang high-mountain weather station in north Guangdong can be calculated and the results are given in table 4.

3.2.4 Calculation of standard ice thickness of each return period at different height

Design ice thickness of aerial transmission line is the standard ice thickness of given return period above the surface for some distance. According to exist design standard, the height above the surface and the return period is different for different lines [6-7,11] . Usually, the height is 15m or 20m and the return period is 15、30、50、100 years. The revise coefficient of the standard ice thickness at 15m and 20m height are 1.44 and 1.51 respectively compared with that at 2m height. The calculation results are shown in table 4.

Table.4 standard ice thickness of each return period at different height at Lechang high-mountain weather station

return period(year)	15	30	50	100
at 2m height standard ice thickness (mm)	44.8	51.2	55.8	62.0
at 15m height standard ice thickness (mm)	64.5	73.7	80.4	89.3

at 20m height standard ice thickness (mm)	67.6	77.3	84.3	93.6

The maximum standard ice thickness at the height of 2 meters at Lechang high-mountain weather station in 2008 is 64.4mm. According to the probability calculate by equation 10, this value is once in 130-year and would increase to 92.7mm at 15m height (height of 220kv aerial transmission line).It is very close to the icing thickness (115mm) of 220kv Pinglang line 786m above sealevel at Yunyan county in Lechang at north of Guangdong Province (47km away from Lechang high-mountain weather station) which is observed by electric department during the ice damage in 2008 [14].

4 Conclusion and Discussions

(1) Wire icing at north of Guangdong Province mainly happened in Jan., the next is Feb. and Dec.. Annual mean icing day is about 90 days at high altitude area represented by Lechang high-mountain weather station while the longest can reach more than 131 days.

(2) Icing thickness is affected by some meteorological factors, such as low air temperature, nearly saturation relative humidity, a bit of precipitation and suitable wind speed. Expect for the height above surface, icing thickness is also related to the angle between the wire and the prevailing wind direction. Icing more easily appears on the south-north wire than the east-west wire at Lechang high-mountain weather station and the mean standard ice thickness of south-north wire is 1.42 times thicker than that of the east-west wire.

(3) The revised and extended yearly maximum standard ice thickness sequence at Lechang high-mountain weather station is satisfied with the extreme-I probability distribution. According to the calculation, the historical maximum icing happened on Jan. 26 2008 and the standard ice thickness at 2m and 15m height are 64.4mm and 92.7mm, respectively which happened once in 130-year and very close to the icing thickness 115mm in the ice damage investigation of 2008.

(4) The above conclusion is obtained by analyzing a few ice observation data. Though based on probability and statistic theory, correlative code and strict correlation test, the return period ice thickness parameter required by the wire icing design which is obtained by the method of revising and extending still have some uncertainty. The exist ice observation data has some difference with the actual transmission lines, such as the diameter, length of the wire, the height above the surface and whether electrify which need to test after much more and more refined observation data is available. Expect for the meteorological factors mentioned in the paper, the icing thickness is also affected by the height above sea level and the lay of the mountain terrain. All the above questions will be discussed in the future.

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