Study on Diameter Correction Coefficient of the Icing Thickness of the Conductors

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***Abstract*—**while the transmission lines under the construction to improve the anti-icing performance, if the design ice thickness selection is too thin, it is hard for the conductors keep safe and stable operation under icing conditions; and if the design ice thickness selection is too large, the investment of the construction or reconstruction can be multiple improved. Therefore, how to determine the reasonable design ice thickness and make it meet the economy and safe demands of the conductors is an important problem to the construction and reconstruction project of the transmission lines. The influence mechanism of the diameter on the conductors icing is analyzed. According to analysis the icing data observed in field in recent years, the diameter correction coefficient Kφ of the transmission lines icing thickness is proposed. The Kφ proposed in this paper can met the demand of the ice thickness design of the transmission lines in the field measured areas very well.

1. INTRODUCTION

Electric power industry is the mainstays of our nation's economy, while the safe and stable operation of power grid determined the reliability of the power supply. In sleet and freezing weather, the ice thickness greatly exceed the design standard of transmission line, which results in the serious transmission line icing, and cause the frequent occurrences of many serious accidence such as transmission line broken, electrical wire pole/tower falling down and so on.

2. SECTION SHAPE OF ICING CONDUCTOR

According to field observations and laboratory studies, conductor icing is generally uneven, which is approximately oval. And it is thicker on the windward side than that on the leeward side.

3. THE INFLUENCE MECHANISM OF THE DIAMETER ON THE CONDUCTORS ICING

According to analysis the icing data observed in field in recent years, the diameter correction coefficient Kφ of the transmission lines icing thickness is proposed. The Kφ proposed in this paper can met the demand of the ice thickness design of the transmission lines in the field measured areas very well. We can describe the diameter correction coefficient as fallow:

$$K_{\phi} = 1 - a\ln(\phi/\phi_0)$$

4. CONCLUSION

In natural icing environment, the contour of icing conductor is not uniform, which is approximately oval. The thickest part of ice often exists in the windward side, while the thinnest part always locates in the leeward side of the conductor. According to the DL/T 5158-2002 diameter correction coefficient, the calculated value deviates from the ice thickness measured in field in Tab.2. The calculated value is more than the field measurement with the mean relative error of year at 22.35~42.3%.While by the diameter correction coefficient in this paper, the mean relative error of year is only 4.5%~6.8% between the calculated value and the ice thickness measured in field in Tab.2. Which is more effective to the actual requirements for regional ice thickness design.

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Abstract—**While the transmission lines under the construction to improve the anti-icing performance, if the design ice thickness selection is too thin, it is hard for the conductors keep safe and stable operation under icing conditions; and if the design ice thickness selection is too large, the investment of the construction or reconstruction can be multiple improved. Therefore, how to determine the reasonable design ice thickness and make it meet the economy and safe demands of the conductors is an important problem to the construction and reconstruction project of the transmission lines. The influence mechanism of the diameter on the conductors icing is analyzed. According to analysis the icing data observed in field in recent years, the diameter correction coefficient Kφ of the transmission lines icing thickness is proposed. The Kφ proposed in this paper can met the demand of the ice thickness design of the transmission lines in the field measured areas very well.**

Key words-conductor; icing; design; measured in field; ice thickness; diameter correction coefficient

I. INTRODUCTION

Electric power industry is the mainstays of our nation's economy, while the safe and stable operation of power grid determined the reliability of the power supply[1]. The first record transmission line icing disaster happened in America in 1932[2,3], while 1954 the first record to transmission line icing disaster happened in our country[4]. In North America, Europe, east Asia and other regions, the transmission line icing disasters have repeatedly occurred, and cause the frequent occurrences of many serious accidence such as tower collapse, transmission line disconnection, galloping, ice flashover and even large area blackout accidents. The extreme weather that caused the serious ice disaster in southwest Quebec and the eastern Ontario[5,6] in January 1998 and caused serious damage to the equipment in power grid. In early 2008, many provinces of Southern China encounter the rare sleet and freezing weather, which results in the serious transmission line icing, and cause the frequent occurrences of many serious accidence. The stable operation of power systems and reliable power supply are faced with huge challenges.

In sleet and freezing weather, the ice thickness greatly exceed the design standard of transmission line, which results in the serious transmission line icing, and cause the frequent occurrences of many serious accidence such as transmission line broken, electrical wire pole/tower falling down and so on. In 2008 south area icing disaster, many transmission lines icing reached 30-60mm in central and east China area, and the ice thickness greatly exceed the local icing records. Compared with the original design standards, meteorological conditions return period has undergone a fundamental change, far more than procedures stipulated in the 30 years in a value. Then the frost-recovery countermeasure of reinforcing and rebuilding was put forward, including reinforcing transmission line, improving construction standard of new building lines. In view of early fortification standards are not meet the requirements against the line ice storm. After the ice disaster, both the state grid and southern power grid have revised the line design procedure specification. The revised standard has been applied in reinforcing and rebuilding of the transmission lines where the ice disaster appeared easily. Although increasing the construction standards can greatly enhance the anti-ice performance of network equipment, the investment of the construction or reconstruction can be multiple improved. Only the National Grid plans which upgrade the anti-ice resilience of transmission network have the amount of investment as high as 500 billion yuan. Namely ice thickness doubled, the investment will also increase double. For 500 kV line, when ice thickness increased from 10 mm to 20 mm, 30 mm, the corresponding amount of tower supplies per kilometer becomes 2.2 times, 3.4 times, while the cost will become 1.8 times 2.6 times[9]. China power grids experienced rapid development, the total length of the national circuit 220kV and above transmission line is 399,400 km at the end of 2009, namely the scale has been ranked first in the world. Even the implementation of different design, if the ice thickness design is inappropriate, the investment of transformation line will increase exponentially. Therefore, how to determine the reasonable design ice thickness of the conductors is an important problem to the construction and reconstruction project of the transmission lines.

Based on the ice data measured by Chongqing University in Liupan Mountain of Guizhou province, Chongqing Wulong, Huaihua and enshi and other sites, the relationship between the equivalent ice thickness of conductors with different diameter and the reference wire is analyzed in this paper, and the diameter correction coefficient of the transmission lines icing thickness is proposed, which can provide the reference to construct the anti-disaster transmission network in local areas.

II. Section Shape Of Icing Conductor

Since the eighties of last century, Chongqing University has been committed to research the mechanism of conductor icing in natural environment, and established natural icing observation stations in Liupan Mountain and Xuefeng Mountain as shown in Figure1. The physical process of the conductor icing is observed, and a large number of valuable experimental data is accumulated.

Figure 1. Xuefeng Mountain icing observation station

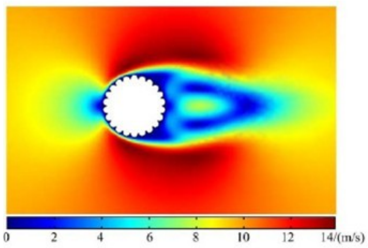


Figure 2. The airflow field around the conductor

According to field observations and laboratory studies, conductor icing is generally uneven, and it is thicker on the windward side than that on the leeward side. When the cooling water droplets carried by the air flow around the wires, the air flow in the windward side is blocked, while the leeward side form a turbulent vortex because of the air viscosity, the flow velocity distribution shown in Figure 2. The momentum of supercooled water droplets is larger than the air flow, so the cooling water droplets and the flow separate after the collision in the windward side of the wire, and lead to windward conductors icing[10, 11].

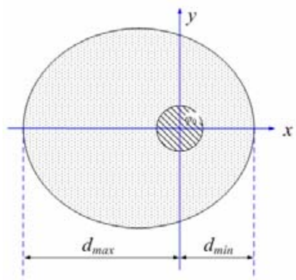
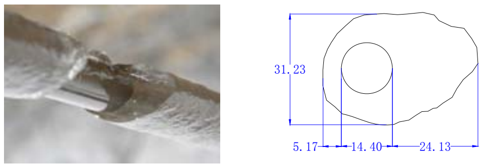
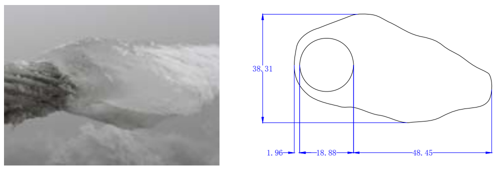


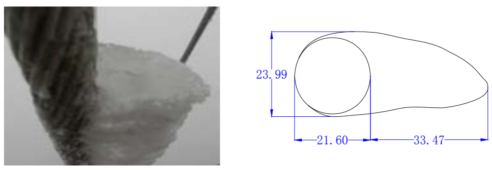
Figure 3. Elliptic icing conductor



(a) conductor model：CTMH150, temperature：-3~0℃，humidity：98%，wind velocity：3~7m/swind direction: horizontal axis and the wire into 60 ° ~ 90 °.



(b) conductor model：LGJ-185，temperature：-5~0℃，humidity：97%，wind velocity：3~9m/s，wind direction: horizontal axis and the wire into 60 ° ~ 90 °.



(c) conductor model：LGJ-240，temperature：-5~0℃，humidity：97%，wind velocity：3~9m/s，wind direction: horizontal axis and the wire into 60 ° ~ 90 °.

Figure 4. Section shape of glaze icing conductor observed in Xuefeng Mountain icing observation station

By analyzing the data of nearly 20years observed at Liupan Mountain and Xuefeng mountain natural icing observation stations, the section shape of the icing conductor is related to the wind velocity, the size of the cooling water droplets, conductor torsional stiffness and other factors, and the torsional stiffness play a decisive role. For the relatively small stiffness, wire section shape of icing conductor is much closer to circular, while for large ones, the section shape generally is oval-shaped or wing. Wire stiffness related to its own span. If the wire far from the tower, it is general likely to twist after the icing because of low stiffness and the section shape of icing conductors is approximately circular. On the contrary, for the wire close to the tower difficult to twist, the section shape of icing generally is oval shape or wing, as shown in Figure 3. Some section shape of the icing wire observed at January 6, 2010 to February18, 2010 period in Hunan Xuefeng Mountain natural icing observation station is shown in Figure4. Based on the Figure 4, in the natural icing environment, the glaze section shape mostly is wing which can be approximated by oval. And it is thicker on the windward side than that on the leeward side.

According to field observations, this paper confirmed the conclusions obtained by Poots, Makkonen and Farzaneh and other researchers though simulation and laboratory studies[12-17].

III. The Influence Mechanism Of The Diameter On The Conductors Icing

Conductor icing is the physical phenomena occurred when the wire capture the cooled water droplets in the air and release the latent heat of freezing. The process can be described by collision rate, the capture rate and the freezing rate and other parameters. Collision rate can be defined as the ratio of the magnitude of the cooling water droplets in the airflow collision with the object to the diameter of icing object. Assumed to be in the airflow, a is a water droplet from the target object at infinity and its vertical coordinates is y_0, as shown in Figure 5. This droplet with the airflow movement from a to b along the cylinder, and at the point b its speed direction just along the tangent of the target cylinder, so in this flow field the collision rate of the cooling water droplets on the target cylinder can be expressed as :

$$E = \frac{y_0}{R} \tag{1}$$

The droplets in the flow line ab and the x-axis will collide with the target object. Without consideration the capture rate and freezing rate on the ice surface, the cooling water droplets and the collision rate directly affect the growth of the ice thickness.

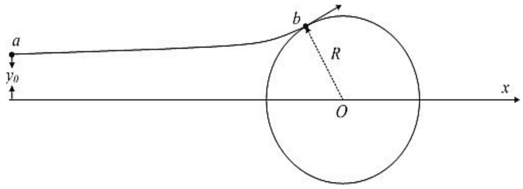


Figure 5. Moving trajectories of the droplet

By fitting the collision coefficient of the data studied by Langmuir and Blodgett[15,16], Finstad and Lozowski put forward the mathematical expression about the collision coefficient which is more recognized by scholars at home and abroad.

$$E = A - C(B - 0.0454) - 0.028 \tag{2}$$

where：

$$\left.\begin{aligned} A &= 1.066K^{-0.00616}\exp\left(-1.103K^{-0.688}\right) \\ B &= 3.641K^{-0.498}\exp\left(-1.497K^{-0.694}\right) \\ C &= 0.00637(\beta - 100)^{0.381} \end{aligned}\right\} \tag{3}$$

Where, K and β are dimensionless, $K=\rho_w d^2/9\mu D$，$\beta=Re^2/K$，$Re=\rho_a dv/\mu$, *d is diameter of the droplet, D is the conductor diameter, v is free flow speed, μ is the absolute viscosity of air,* ρ_w *and* ρ_a *is respectively the density of droplets and air .*

According to the conclusion in the bibliography[17-22], the collision rate of the cooling water droplets over the wire is affected by the conductor diameter. The smaller diameter of icing object, the damping influence on droplets is smaller, and the collision rate is bigger. The collision rate decreases with the increasing of the conductor diameter. Therefore, with the increasing of the conductor diameter, the ice thickness will decrease. With the conclusion in the bibliography[10], the diameter correction coefficient $K\varphi$ can be described as:

$$K_\phi = \frac{d_\phi}{d_0} = \frac{E_\phi}{E_0} \tag{4}$$

Where, dφ and d0 is respectively the ice thickness of the design wire and reference conductors；Eφ is the collision rate as the wire diameter at φ. E0 is the collision rate of the reference conductors.

Based on the equations (2) and (4), the diameter correction coefficient of the icing conductor is not equal to one, when choose the relatively smaller diameter cladding ice body as the reference wires, and it will decrease with the increasing of the design wires. Therefore, in the same weather conditions, the diameter correction coefficient calculated by the equation (4) can be simplified as fallow:

$$K_{\phi} = 1 - \zeta \tag{5}$$

Where, ζ is a function related to ratio of the design wire diameter and the reference line diameter(φ/φ_0).

Combined with the expression about the diameter correction coefficient in DL/T 5158-2002[23], the relationship of ζ and φ/φ_0 can be described as fallow:

$$\zeta = a\ln(\phi/\phi_0) \tag{6}$$

Where, a is a constant related to water droplets diameter, wind speed, liquid water content and other meteorological parameters.

Substitute equation (6) into equation (5), and we can describe the diameter correction coefficient as fallow:

$$K_{\phi} = 1 - a\ln(\phi/\phi_0) \tag{7}$$

IV. TEST RESULTS AND ANALYSIS

A. The field measured results

The measured sites are located along the "west-east power transmission, mutual supply between north and south" transmission line corridor in this paper, and the field measured sites shown in Figure 6. In the figure, the black curve shows the flow of the river systems in our country, and dark gray areas indicate the mountains in our country. The altitude and waters in which the field measured sites is shown in Table1.

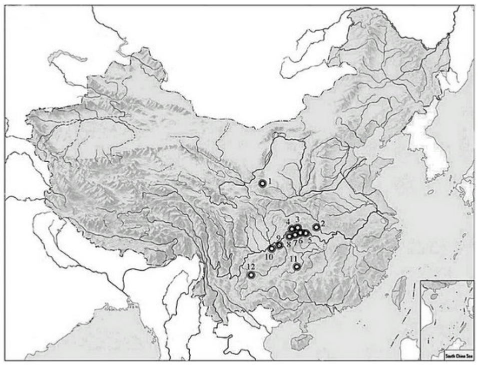


Figure 6. distribution of field measurement location

TABLE 1 . field measurement areas

NO.	Site	Altitude /km	The waters
1	Guyuan	1900	Jing river
2	Jinmen	300	Han river
3	Wushan	1700	Yangtze river
4	Fengjie	1500	Yangtze river
5	Zigui	1300	Yangtze river
6	Padang	1820	Yangtze river
7	Jianshi	1000	Qing river
8	Icheon	1680	Yangtze river
9	Wulong	1300	Wu river
10	Qijiang	1300	Qi jiang
11	Huaihua	1400	Yuanjiang
12	LiupanMountain	1500	KilnReservoir

Most of the measured sites with special landscape geographical environment pattern are near the waters. Micro-meteorology and micro-topography conditions can appear easily, which can lead to serious transmission line icing. Among them, the Three Gorges region is more typical which located in the Yangtze River distribute many north-south mountain ranges, mostly in the mountain height of 500m-1800m, and many north to south flows along the sides. With the implementation of “west-east power transmission, nationwide power networking” in China, these transmission lines need span the complex environment areas where severe icing accidents occur easily. Because the geomorphology fluctuation in this region is great disparity, forming a wide and complex range of micro-meteorology and micro-topography, so in some areas transmission lines appear the phenomenon of severe icing. Therefore, Chongqing University choose nine field measurement location along the Yangtze River ,such as Jinmen, Wushan, Fengjie, Zigui, Padang, Jianshi, Icheon, Wulong, Qijiang. According to the field measurement results, the icing phenomenon is in-cloud icing mainly in Three Gorges districts which is characterized with micro-meteorology and micro-topography. And the glaze and mixed ice are more usual in Padang, Icheon.

According to the length and the density of the icing by the field measurement, some data calculated and conversed in accordance with the DL / T 5158-2002 standard is shown in Table2, where GL, SR, HR, ML are glaze ,soft rime, hard rime and mixed ice, respectively. Some icing shapes observed in field are shown in Figure 7. And the height of the measured conductors above ground is 2.0m.

In order to be simple and get more data easily, this paper choose the 5mm icing object as the reference wire diameter. By Michael Marquardt (Levenberg-Marquardt) general global optimization method, the data in Table 2 is simulated according to the equation(7). The relationship of the diameter correction coefficient and the ratio of measured wire and reference wire can be described by equation(8), and the entire square of the correlation coefficient R2 are more than 0.99.

$$K_{\phi} = 1 - 0.200\ln(\phi/\phi_0) \tag{8}$$

Where, φ_0 is the diameter of the reference wire in mm; φ is the diameter of the measured wire in mm;

(a) Huaihua (rime ice) (b) Liupan Mountain (glaze) (c)Wulong (glaze)

Figure 7. Icing shape observed in field

TABLE 1 . Standard ice thickness of conductors with different diameters measured in field

year	**φ/φ_0**	**Standard ice thickness /mm**												
1996	***sites***	***Liupan Mountain***				***Padang***			***Jianshi***		***Icheon***		***Qijiang***	
	Icing type	***GL***	***SR***	***HR***	***MI***	***GL***	***SR***	***HR***	***GL***	***SR***	***MI***	***HR***	***GL***	***SR***
	1	8.3	37.2	23.5	30.2	11.0	13.2	20.7	6.7	27	34.2	15.7	5.3	4.1
	2	5.7	33.1	19.6	25.9	8.0	9.6	17.4	4.4	23.3	30.2	12.2	3.1	2.2
	3	4.6	30.8	17.5	24.1	6.7	8.7	15.5	3.5	21.1	28.1	10.7	2.3	1.7
	4	4.0	28.7	16.4	22.6	6.0	7.6	14.1	2.8	19.5	26.3	9.8	1.9	1.3
	5	3.7	27.6	15.6	21.3	5.4	7.0	13.3	2.7	18.6	25.0	9.1	1.8	1.1
1997	*sites*	*Liupan Mountain*			*Guyuan*			*Padang*				*Wulong*		
	Icing type	*GL*	*SR*	*MI*	*GL*	*SR*	*HR*	*GL*	*SR*	*HR*	*MI*	*GL*	*SR*	*HR*
	1	8.8	39.8	31.0	7.3	5.4	24.3	11.7	13.4	21.5	34.4	6.3	28.6	16.5
	2	6.6	35.1	27.6	5.2	3.2	21.3	9.8	11.2	19.1	29.7	4.4	25.2	13.7
	3	5.7	32.3	24.7	4.4	2.7	19.7	8.2	9.7	16.8	27.5	3.9	22.6	12.1
	4	5.2	28.1	22.9	3.7	2.1	17.8	6.9	8.3	15.5	25.7	3.5	20.2	10.9
	5	4.5	27.4	21.5	3.3	1.7	16.6	6.6	7.8	14.3	25.1	3.1	19.8	10.1
2006	***sites***	***Liupan Mountain***			***Huaihua***		***Wushan***		***Zigui***		***Padang***		***Icheon***	
	Icing type	***GL***	***SR***	***MI***	***GL***	***SR***	***SR***	***HR***	***SR***	***HR***	***GL***	***HR***	***GL***	***MI***
	1	10.9	46.2	37.9	7.9	34.3	6.5	20.1	18.7	29.3	9.6	32.7	15.5	41.5
	2	8.1	40.3	33.6	6.2	30.1	4.1	16.7	15.1	25.3	7.4	28.1	12.5	36.2
	3	7.6	36.4	30.4	5.7	27.6	3.1	15.2	13.7	22.7	6.1	25.7	10.6	32.9
	4	7.2	33.7	28.2	5.1	26.1	2.9	13.4	12.2	21.2	6.0	23.3	10.2	30.5
	5	6.5	31.9	26.5	4.8	24.5	2.5	12.6	11.3	19.9	5.3	21.1	9.7	29.1
2009	***sites***	***Huaihua***			***Wushan***			***Qijiang***			***Icheon***		***Padang***	
	Icing type	***GL***	***SR***	***MI***	***GL***	***SR***	***HR***	***GL***	***SR***	***HR***	***GL***	***MI***	***SR***	***HR***
	1	10.5	35.6	31.8	5.1	3.8	13.2	6.5	11.2	17.3	6.9	27.9	25.4	22.7
	2	7.3	31.6	28.3	3.4	1.7	10.2	4.9	8.8	14.4	4.7	24.4	21.7	18.9
	3	6.2	29.2	26.5	2.2	1.5	8.9	3.7	6.8	12.9	4.0	21.9	19.8	17.4
	4	5.8	27.7	23.9	1.9	1.3	8.1	2.9	6.4	11.6	3.6	20.6	18.5	16.1
	5	5.1	26.1	22.8	1.7	0.9	7.7	2.7	5.9	10.9	3.1	19.1	17.6	15.5
2010	***sites***	***Huaihua***			***Wushan***		***Qijiang***		***Wulong***		***Icheon***		***Padang***	
	Icing type	***GL***	***SR***	***MI***	***SR***	***HR***	***SR***	***HR***	***GL***	***SR***	***GL***	***MI***	***GL***	***HR***
	1	8.6	39.4	36.7	5.7	17.8	16.1	25.2	6.1	29.1	13.2	32.8	9.3	26.7
	2	6.9	34.7	32.4	3.7	14.6	13.5	22.1	4.7	25.8	10.6	29.1	6.8	22.5
	3	5.4	31.2	28.9	2.8	12.8	11.7	19.2	4.3	22.6	9.3	25.9	5.9	20.8
	4	4.8	29.8	26.7	2.4	11.9	10.8	18.4	3.8	21.4	8.4	24.2	5.4	19.7
	5	4.4	27.2	25.3	1.9	11.3	10.4	16.8	2.9	19.3	8.1	22.6	5.3	18.4

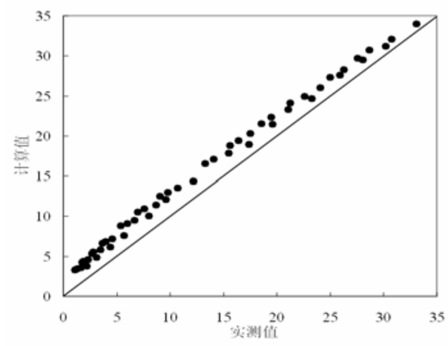
B. Compared to the diameter correction coefficient of the DL/T 5158-2002

The recommended diameter correction coefficient of the DL/T 5158-2002 is:

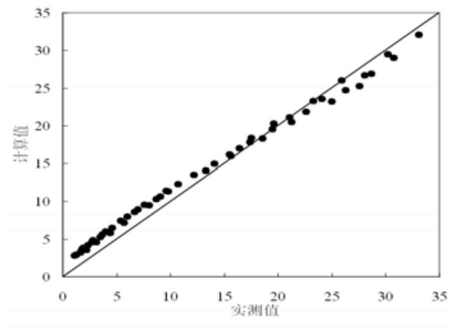
$$K_{\phi} = 1 - 0.126\ln(\phi/\phi_0) \quad (9)$$

Compare the equation(3) with the equation (4), Comparison of the correction coefficient between DL/T5158-2002 and this paper, it was found that significant differences in the constant factor a. When choose the same reference diameter, the correction coefficient curve gained by equation (8) and (9) is shown in Figure8. By the Figure8, with the increasing of the wire diameter, the difference of the correction coefficient obtained by equation (8) and (9) is increasing.

By using the equation(9) and (4), the standard ice thickness of conductors with different diameters can be calculated when the reference diameter is 5mm. Compared it with the field measurement results in table2, deviation between the calculated value and the ice thickness measured in field can be gained, as shown in Figure9(a). The relationship of the ice thickness and measured in field can be gained by equation (8) and (4), as shown in Figure((b).



(a) Deviation between the calculated value and the ice thickness measured in field by equation (9) and (4)



(b) Deviation between the calculated value and the ice thickness measured in field by equation (8) and (4)

Figure 9. Deviation between the calculated value and the ice thickness measured in field

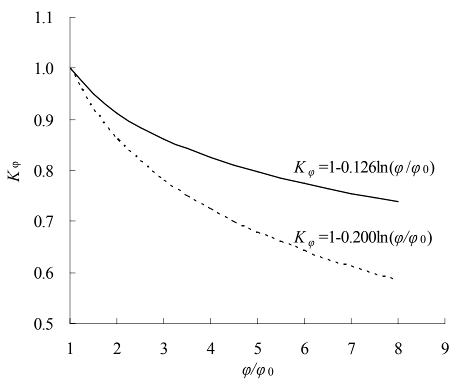


Figure 8. Comparison of the correction coefficient between DL/T 5158-2002 and this paper

According to table2, Figure8 ,9 it is known that:

1) The correction coefficient of the icing-wire diameter decreases with the increase of the design line diameter. When the design line diameter is small, the influence of $\varphi/\varphi 0$ on $K\varphi$ is strong, and this decreasing became gentle with the increase of the design line diameter.

2) The $K\varphi$ gained by the DL/T 5158-2002 recommended formula is more than the $K\varphi$ obtained by fitting the measured data. The difference is small when the diameter is small, but the difference increases with the increase of the design diameter.

3) When choose the icing object at 5mm, according to the DL/T 5158-2002 diameter correction coefficient, the calculated value deviates from the ice thickness measured in field in table2. When calculated by the equation(9), the mean relative error of year is 22.35~42.3%; while by the equation(8), the mean relative error of year is only

4.5%~6.8%. Both of them are smaller in error when icing serious, and the error is larger when icing light.

4) According to the DL/T 5158-2002 diameter correction coefficient, the deviation between the calculated value and the data measured in field increases along the positive direction with the increase of the design line diameter. Namely the value calculated according to DL/T 5158-2002 diameter correction coefficient tends to be bigger than the data measured in field in table2. With the increase of the design line diameter, the ice thickness calculated with the diameter correction coefficient gained by the equation(8) is smaller than the field measurement.

V. CONCLUSIONS

(1) In natural icing environment, the contour of icing conductor is not uniform, which is approximately oval. The thickest part of ice often exists in the windward side, while the thinnest part always locates in the leeward side of the conductor.

(2) According to the DL/T 5158-2002 diameter correction coefficient, the calculated value deviates from the ice thickness measured in field in Tab.2. The calculated value is more than the field measurement with the mean relative error of year at 22.35~42.3%.

(3) According to the diameter correction coefficient in this paper, the mean relative error of year is only 4.5%~6.8% between the calculated value and the ice thickness measured in field in Tab.2, Which is more effective to the actual requirements for regional ice thickness design. But it need further more research to verify whether it meet the requirement in the large regions or not.

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