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Numerical Simulation Results and Laws of Transmission Lines Ice-melting

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Abstract

Based on the numerical simulation model of icing, the impact on icing of the current was further investigated. The critical current value with the meteorological conditions of foreign objects, as well as the physical parameters of the aerial cable itself change the law. The calculation results showed that the critical current value depends on the external weather conditions and the aerial cable itself, the physical parameters, and the critical current and the ambient temperature, wind speed, relatively good linear relationship.

*Keywords:*aerial cable; ice - melting；deicing;critical current；Numerical simulation

1. Foreword

The phenomenon that water accumulated on surface of the object becomes ice (frost) because of freezing is one nature phenomenon which is extensively distributed. Icing on the power transmission line is one phase transformation nature random process which is related with meteorology, thermodynamics, heat transfer, hydrodynamics etc and is controlled by local meteorology (micrometeorology), topography (Micro-topography) and surface condition of power transmission line etc. When serious ice disaster continuously comes, icing on the power transmission line isn't avoided. The researchers have developed several de-icing technology [1-], a part of technology gets into practice phase, there is still some difficulty when some technologies are applied in the grid system, such as electric pulse de-icing method, it is difficult to remove icing on line with sufficient length because applicable excitation source can't be found. Basic ideas on de-icing in the grid system consists of three categories [1-5]：

—— Electric energy is converted into thermal energy to deice；

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—— Electric energy is converted into mechanical energy to destruct physical structure of icing on the power transmission line, so as to realize purpose of icing fall;

—— mechanical de-icing methods which directly destruct physical structure, such as install remote de-ice equipment.

De-icing technology that electric energy is converted into thermal energy shall calculate de-icing current and action time for the icing conductor, there is mature de-icing calculation mathematic model of icing conductor on this aspect [6-7]. Value simulation method of icing process and mechanism of the power transmission line starts from 1980s, foreign experts start to study various factors affecting icing of the power transmission line through establishing mathematic model for icing increment in power transmission line, such as wind speed, temperature, humidity, height and geometrical size of power transmission line etc, the established engineering model has strong theoretical meanings and engineering applicable value [8]. The author of this paper forwards one two dimensions value simulation method [10] for soft rime icing process on surface of the power transmission line based on Lagrangian method in document [9].This paper will fatherly observes influence of current on icing on basis of soft rime icing value method of the power transmission line. Give out change rules of critical current following change of external meteorological condition and change of physical parameters of the conductor. Which provides instruction for icing of the cable.

2. De-icing mechanism and mathematic model

2.1. Calculation of critical current

Each heat flux density in the surface heat balance equation can be calculated with the expression formula given in first chapter. After above influence factors are integrated, following formula is generally applied to calculate anti-icing critical current of the conductor:

$$I_c = \left(\frac{D}{\mu}\right)^{0.5} [(t_s - t) \bullet (\pi h + 4\pi\varepsilon\sigma t^3 + 2Ev_a LWCc_w) + 2Ev_a w_E L_e]^{0.5} \tag{1}$$

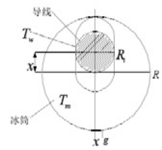
Where μ—— resistance of conductor in unit length (Ω/m); h in the formula is heat exchange coefficient between surface and air flow (generally called as heat transfer coefficient). ts is air flow temperature at location where is sufficiently far from surface of the power transmission line, i.e. edge of the boundary layer, it isn't affected by surface temperature of solid; t is surface temperature of the conductor. ε is total radiation coefficient of relative black body on surface of ice, it approximately equals to ; is Stefan-Boltzman constant, its value is 5.567×10-8(J/m2•K4•t). E is general collision rate, LWC humidity ratio of wet air ( ),cw is constant pressure specific heat of water , cw=4.18(kJ/kg•K); We is water evaporation capacity of the unit area in unit time, unit in (kg/m2•s). Le is evaporation potential heat. Chang of Le following temperature isn't great, when surface temperature is about 0℃, Le=2500(kJ/kg), it is approximately considered as unchanged during calculation.

Seen from above formula, critical current value mainly depends on external meteorological condition and physical parameters of the conductor. Generally speaking, type of the conductor will not be changed when the line is routed, so critical current value will be determined when meteorological condition of the conductor is known during icing.

2.2. Mathematic model for de-icing

When large current is applied to de-ice, it is necessary to calculate de-icing current and de-icing time in order to ensure that the conductor isn't overheat.

Assume radius of the conductor is Ri and the conductor is horizontally placed, icing on the conductor is even ice at cylinder shape, radius is R, temperature of ice is Tm, temperature of conductor is Tw, ice will not deflect during de-icing process. Refer to figure 1 and figure 2 for schematic figure of de-icing process.



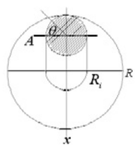


Figure 1 First phase Figure 2 Second phase

De-icing process of icing on the conductor consists of two phases, i.e. first phase that ice cylinder completely wraps surface of the conductor, the demanded de-icing time is t1, refer to figure 1, second phase is from conductor exposing after de-icing to complete falling of ice shell from the conductor, the demanded time is t2, refer to figure 2.

When surface heat flux density of the conductor is constant (equivalent large current de-icing), assume radius of the conductor is Ri and the conductor is horizontally placed, icing on the conductor is ice at cylinder shape, radius is R0, it means ice thickness is R0-R, , section area of melt ice is calculated as approximation:

Set air temperature as Ta, length of conductor for de-icing is l(m), temperature of ice on the conductor before de-icing is Tw=Ta, heat energy for de-icing is:

$$\phi_F = c_i \rho_i A_m l(273.15 - T_a) + \rho_i A_m l L_F \tag{2}$$

ci in the formula is specific heat of ice.

Time for de-icing t is:

$$t = \frac{[c_i(273.15 - T_a) + L_F]\rho_i R_i (2R_0 - \frac{\pi}{2} R_i)}{I^2 R_e} \tag{3}$$

Where, Re is resistance of the conductor in unit length at 0℃ (Ω /m).

3. Research result and analysis of icing on conductor

Research and observation show icing on the conductor in same channel is different under same climate condition, the general condition is that icing on heavy load line is light or no icing, and icing on no load line is heavy; icing on the arrestor line is heavy and icing on the conductor is relatively light. It is obvious that this phenomenon is related with Joule heat, Joule heat makes temperature at surface of the conductor different to ambient temperature, which causes change of the icing condition on surface of the conductor, and this change is controlled by heat transfer loop during icing process of the conductor. Minimum current which flows without icing on the conductor is called as critical current for anti-icing of the conductor. Factors affecting critical current include: wind speed, air temperature, air pressure, geometrical size and resistance of conductor, black degree etc. The method that critical current is applied to prevent icing on the conductor mainly depends on science coordination, it can change tidal current distribution of grid on section liable to be iced in advance, increase load of the light load line or make power generation of the peak regulation power plant in advance and make current passed in line reach value above critical value through analysis and forecast of micrometeorology and micro-topography.

This subject team fatherly investigates influence of current on icing on basis of the value simulation model of icing. This paper gives out change rule of critical current following external meteorological conditions (air temperature, wind speed, liquid water content in air, air pressure, humidity) and change of physical parameters of the conductor (diameter and layout etc). Give calculation sample with icing on the conductor when current is less than critical current.

3.1. Air temperature influence

Select 6 working conditions during calculation, temperatures are -15℃, -10℃, -7℃, -5℃, -3℃ and -2℃ from high to low. Type of conductor is LGJ-240/30, other parameters shall be selected according to following table.

Table 1 Other parameters for de-icing of conductor under different air temperature

Diameter of conductor (mm)	21.6
Wind speed (m/s)	5
Diameter of water droplet (μm)	25
Content of liquid water (g/m^3)	0.6

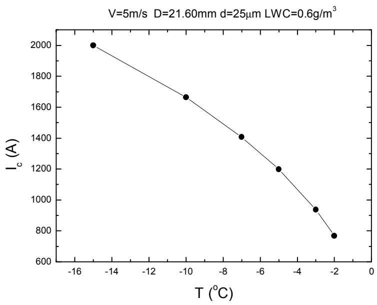


Fig 3 Relationship between critical current and ambient temperature

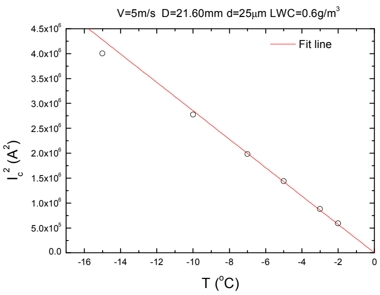


Fig 4 Relationship between square of critical current and ambient temperature

Seen from figure 3, lower is temperature, greater is critical current, this point is obviously obtained from theoretical formula for calculation of critical current. Even through critical current is related to release of evaporation potential heat. Factor of evaporation potential heat doesn't act as dominant factor when ambient temperature is very low because of influence factor of crossed air temperature. Theoretical formula for calculation of critical current is fatherly approximated as:

$$I_c \approx \left(\frac{D}{\mu}\right)^{0.5} [(t_s - t)\bullet(\pi h + 4\pi\varepsilon\sigma t^3 + 2Ev_a LWCc_w)]^{0.5} \cdots\cdots\cdots \qquad \cdots\cdots\cdots(4)$$

I.e.:

$$I_c^2 \approx \left(\frac{D}{\mu}\right)(t_s - t)\bullet(\pi h + 4\pi\varepsilon\sigma t^3 + 2Ev_a LWCc_w) \propto t_s - t \ \cdots\cdots \qquad \cdots\cdots\cdots\cdots(5)$$

It is learnt square of critical current is in direct proportion to ambient temperature. Shown as following figure, we find square of critical current has good direct proportion relationship with ambient temperature under this working condition (fit curve is straight line passing through origin point).

3.2. Diameter influence of conductor

The calculation selects 6 diameters of single conductor and grounding wire in total, specifications of the conductors are LGJ-185/30, LGJ-240/30, LGJ-400/35 and JL/G3A-900/40 respectively; specifications of grounding wires are 1×7-11.4-1370-B(GJ-80) and JLB20A-150 -19(JLB20A-150) respectively. Diameters of conductors are 18.88mm, 21.60mm, 26.82mm and 31.90mm respectively. Diameters of grounding wires are 11.40mm and 15.75mm respectively.

Calculation result shows ambient temperature plays evitable function on type of icing. We observes influence of different conductor diameter on icing under soft rime icing (-15℃) and glaze icing (-2℃) conditions.

When temperature is -15℃, selection of other parameters are shown as following table.

Table 2 Other parameters for de-icing of the conductor under different conductor diameter at -15℃.

Wind speed (m/s)	10
Air temperature (℃)	-15
Diameter of water droplet (μm)	20
Content of liquid water (g/m3)	0.1

Table 3 Other parameters for de-icing of the conductor under different conductor diameter at -2℃.

Wind speed (m/s)	5
Air temperature (℃)	-2
Diameter of water droplet (μm)	25
Content of liquid water (g/m3)	0.6

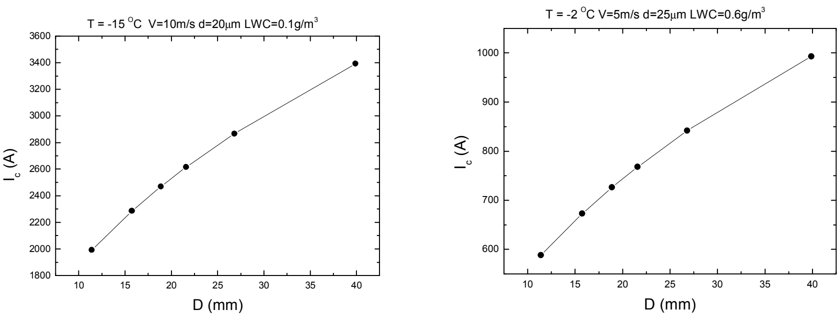


Figure 5 Relationship between critical current and diameter of conductor

Learn from above two icing conditions, more is diameter of the conductor, greater is critical current. Learn from ,when temperature rising doesn't play as dominant factor in surface heat balance influence of the cable, in particular when change of collision rate of water droplet isn't great, square of critical current is in direct proportion to diameter of the conductor. Because change of the conductor diameter is key factor affecting collision rate of water droplet, square of critical current isn't completely in direct proportion with diameter of the conductor, it is found in the result that this rule is linear and not in direct proportion relationship (fit curve is a straight line not passing the origin point).

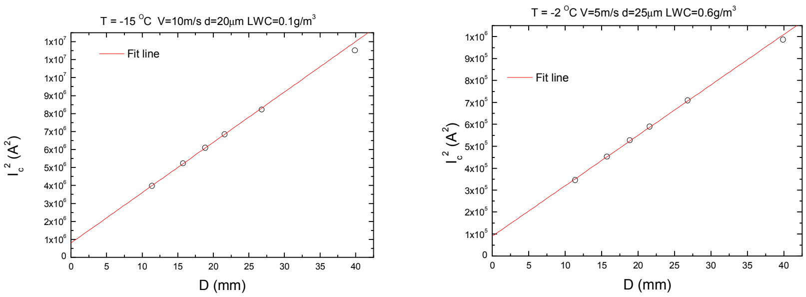


Figure 6 Relationship between square of critical current and diameter of conductor

3.3. Influence of wind speed

Because wind speed is an important factor affecting icing of the power transmission line, features of icing under different temperature aren’t same. Three different air temperatures (-15℃, -12℃ and -2℃) are considered during calculation, wind speeds are 3, 5, 6 or 8, 10, 15 and 20m/s, so as to observe change rule of icing following wind speed.

When temperature is -15℃, selection of other parameters are shown as following:

Table 4 Other parameters for de-icing of the conductor under different wind speed at -15℃.

Diameter of conductor (mm)	21.6
Air temperature (℃)	-15
Diameter of water droplet (μm)	15
Content of liquid water (g/m3)	0.3

Table 5 Other parameters for de-icing of the conductor under different wind speed at -12℃.

Diameter of conductor (mm)	21.6
Air temperature (℃)	-12
Diameter of water droplet (μm)	20
Content of liquid water (g/m3)	0.3

Table 6 Other parameters for de-icing of the conductor under different wind speed at -2℃.

Diameter of conductor (mm)	21.6
Air temperature (℃)	-2
Diameter of water droplet (μm)	25
Content of liquid water (g/m3)	0.6

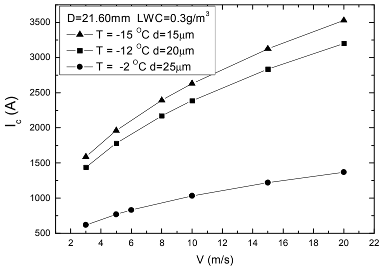


Figure 7 Relationship between critical current and wind speed

It is found that critical current increases following increment of wind speed. When it is fatherly approximated according to deduce formula of critical current, there is

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots I_c^2 = \left(\frac{D}{\mu}\right)(t_s - t)\bullet(\pi h + 4\pi\varepsilon\sigma t^3) + (2ELWCc_w + 2Ew_E L_e)v_a \tag{6}$$

Learn from above formula, square of critical current is in linear relationship with wind speed when ambient temperature is approximate to zero degree; because collision rate is also related to wind speed, so square of critical current isn't completely in direct relationship with wind speed, it is found in the result that this rule is linear and not in direct proportion relationship (fit curve is a straight line not passing origin point).

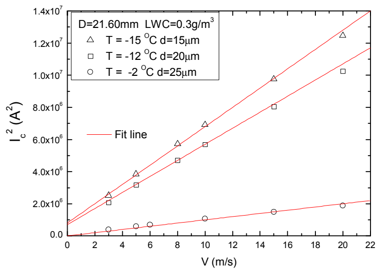


Figure 8 Relationship between square of critical current and wind speed under different ambient temperature

4. Calculation sample of icing

Conductor specification type for calculation selection is LGJ-240/30 and diameter is 21.6mm. Icing thickness is 19.95mm. Current is 1800A. Selection of other parameters is shown as following table.

Table 9 Other parameters table for icing calculation sample

Wind speed (m/s)	10
Air temperature (℃)	-15
Diameter of water droplet (μm)	40
Content of liquid water (g/m3)	0.3

Following figures are conductor, ice surface and calculation grid at t=0, 30min, 40min respectively. It is seen that conductor will be exposed after de-icing at t=40 min.Metal process for first phase calculated according to is 43 min, which is highly coincided with the calculation result.

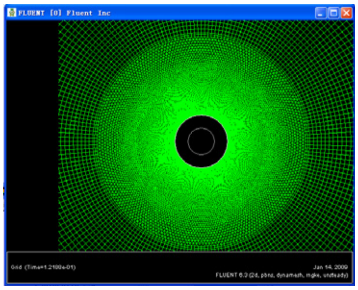


Figure 9: Surface grid schematic figure of conductor at t=0 min

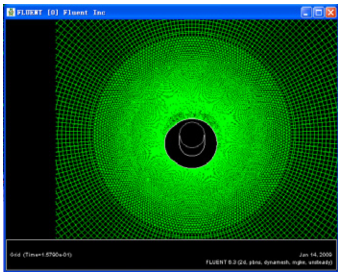


Figure 10: Surface grid schematic figure of conductor at t=30 min

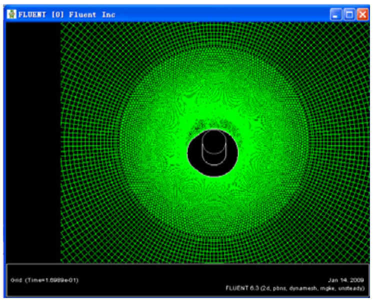


Figure 11 Surface grid schematic figure of conductor at t=40 min

5. Summary

1) Obtain change rule of critical current following external meteorological conditions (air temperature, wind speed, liquid water content in air, air pressure, humidity) and change of physical parameters of the conductor (diameter and layout etc.).

2) Critical current value mainly depends on external meteorological conditions and physical parameters of the conductor. Only meteorological conditions of the conductor during icing are known, critical current values can be determined.

3) Potential heat and convection have great contribution during surface heat balance calculation of the cable, good linear relationships between critical current and ambient temperature, wind speed of inflow etc are deduced.

References

[1] High voltage research institute of Water Resource and Electric Power Ministry, Comprehensive study on de-icing method of power transmission line (Volume one) High voltage technology, 1986,3

[2] Wuhan high voltage research institute of Energy Resource Ministry, Comprehensive study on de-icing method of power transmission line (Volume two) High voltage technology, 1988,3

[3] Wuhan high voltage research institute of Energy Resource Ministry, Comprehensive study on de-icing method of power transmission line (Volume three) High voltage technology, 1990,1

[4] Jiang Xingliang, Zhang Lihua, Summary on de-icing and anti-icing technology of power transmission line, High voltage technology, 1997,1

[5] Yuan Jihe, Jiang Xingliang, Yi Hui etc. Current foreign and domestic stats of conductor icing in power transmission line [J]．High voltage technology, 2004,3o(1)：6-9．

[6] LIU He—yun．Heat Transfer Analysis on Wire Icing and the Current Preventing from Icing,Doctoral Dissertation[D]．Wuhan：Huazhong University of Science and Technology,2001．

[7] LIU He—yun,ZHOU Di,FU Jun—ping,et a1．Heat Transfer Investigation on Critical Current to Prevent Wires from Icing[J]．Electric Power,2001,34(3)：42-44．

[8] Makkonen, L. , 1984, "Modelling of Ice Accretion on Wires," Journal of Climate and Applied Meteorology, Vol. 23, No.6, pp. 929-939

[9] Guo H. et.al., "Two-dimensional numerical simulation of the rime accretion process on transition lines ", Engineering Mechanics, (accepted)

[10] GUO Hao , LIU Pei-qing , QU Qiu-lin,et al,two-dimensional numerical simulation of the rime accretion process on transition lines, engineering mechanics. 2011,Vol.28 No.5,p212-218