NUMERICAL SIMULATION ON THE ICE-MELTING PROCESS FOR HIGH-CURRENT WIRES

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Abstract: The computational fluid dynamics (CFD) code FLUENT is employed to simulate the ice-melting process for high-current wires, which by means of a moving mesh technology that can be used to validly track the moving boundary of wires. The aim of study is to focus on the characteristics of the moving interface between the wire, ice and water during ice-melting process. Propagations of the temperature field and melting interface have been obtained. Moreover, the relationship of the ambient temperature, wind speed, ice thickness, ice-melting current and ice-melting time for high-current wires are studied, the ice-melting characteristic curves are obtained.

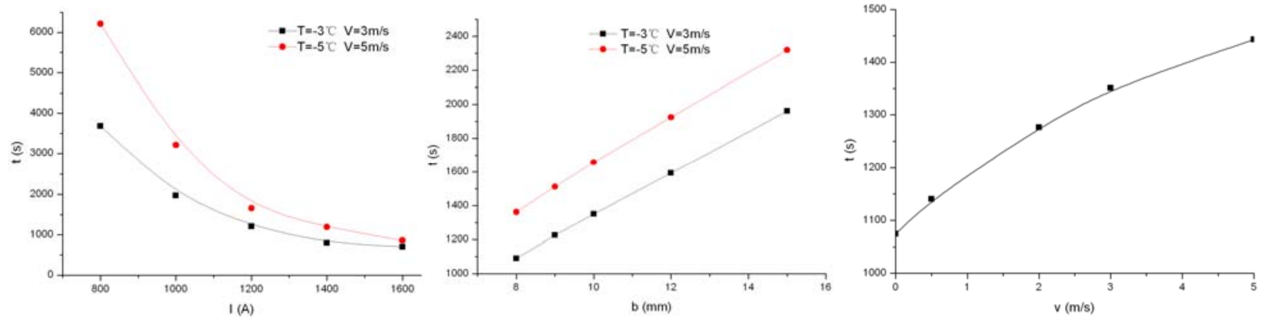
1. INTRODUCTION

Selection of ice-melting current and time is the key in the ice-melting process of transmission lines. Determination of ice-melting current and time and calculation of characteristic waves in accordance with different sizes of wires, ambient temperature and wind speed, would efficiently guide the field implementation of ice-melting[1]. In this paper, the computational fluid dynamics (CFD) code FLUENT is employed to simulate the ice-melting process for high-current wires, the computational domain is divided into two sub-domains------solid phase and liquid phase, moving mesh technology is applied to track the moving interface, and a whole-process numerical computation of the air circulation outside the ice zone, temperature changes in the ice zone, relative movements of the melting ice and the wire, and the phase change of the ice-water mixture in the ice zone is made.

2. RESULTS AND DISCUSSION

Numerical simulation employs the solidification and melting modules of the FLUENT software, divides the grids by triangular element and makes a grid refinement to the ice zone and the outer surface of the ice, so as to improve the accuracy of the solution. Movements of the wire in the ice zone are achieved through the moving mesh technology--- the UDF programming.

Take the LGJ400/50 wire as an example, make a computation of the characteristic curves of ambient temperature, wind speed, ice thickness, ice-melting current and time, shown in Fig.1.



(a) (b) (c)

Figure.1 The Characteristic Curve of Ice-Melting: (a) The Characteristic Curve of Ice-Melting Current and Time; (b) The Characteristic Curve of Ice Thickness and Ice-Melting Time; (c) The Characteristic Curve of Wind Speed and Ice-Melting Time.

3. CONCLUSION

(1)The physical model of the ice-melting of high current wires has been analyzed, assumptions of numerical simulation have been proposed, and the CFD computation model of the ice-melting of wires has been built. The accuracy of simulation computation has been improved by employing moving mesh technology to track the moving interface.

(2) In the ice-melting process: the temperature of the ice zone increases from the ambient temperature to the phase-change temperature, ice melts into water and accumulates in the bottom of the wire, re-solidification of water dose not occur, the ice-melting area is a rectangle with its width equal to the diameter of the wire. Ice-melting of the wire has no influence on the wind speed outside the ice zone.

(3) Ice-melting time decreases with the increase of the current; ice thickness is linear with ice-melting time, ice-melting time increases with the increase of ice thickness; ice-melting time increases with the increase of wind speed.

4. REFERENCE

[1] C L CA, J KANG. Study on ice-melting technology for 500kV power transmission line [J], Hubei Electric Power, 2005, 29:2-7.

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***Abstract*—The computational fluid dynamics (CFD) code FLUENT is employed to simulate the ice-melting process for high-current wires, which by means of a moving mesh technology that can be used to validly track the moving boundary of wires. The governing equations are discretized on collocated grids in a body fitted coordinate by using finite volume methods. The first order upwind scheme and central differencing schemes are used for the discretization of convectional term and diffusion terms respectively. The SIMPLE algorithm is employed to decouple velocities and pressure. The aim of study is to focus on the characteristics of the moving interface between the wire, ice and water during ice-melting process. Propagations of the temperature field and melting interface have been obtained. Moreover, the relationship of the ambient temperature, wind speed, ice thickness, ice-melting current and ice-melting time for high-current wires are studied, the ice-melting characteristic curves are obtained. The results demonstrate that the ice-melting time increases with the increase of wind speed and ice thickness, and it decreases with the increase of ice-melting current.**

Keywords-high-current ice-melting; numerical simulation; moving mesh technology; ice-melting characteristic curves; computational fluid dynamics

I. INTRODUCTION

Transmission line icing is one of the natural disasters for power system. Added ice load would cause a certain mechanical damage to wires, towers and fittings. The heavy ice cover would lead to the breaking wire, the collapse of tower, resulting in a large area of blackout accident. Thus, making researches on anti-icing and de-icing methods are of great importance to mitigate the effects of ice and snow storms [1-9]. More than 30 anti-icing and de-icing methods proposed home and broad can be categorized into thermal de-icing, mechanical de-icing and natural passive de-icing, among which the first one is widely applied. Ice-melting technology is a technology that melts ice on transmission lines by making use of the heat effect of high current on wires, with characteristics of high efficiency and large de-icing area.

Selection of ice-melting current and time is the key in the ice-melting process of transmission lines. Determination of ice-melting current and time and calculation of characteristic waves in accordance with different sizes of wires, ambient temperature and wind speed, would efficiently guide the field implementation of ice-melting [10-11]. Ice melting is a complex heat transfer process that coexists with phase change, heat conduction, convection and heat radiation at the same time. Ice melting process is combined with two parts: the process of phase change melting and heat conduction in the inner ice zone and that of convection and heat radiation in the outer ice zone. In this paper, the computational fluid dynamics code FLUENT is employed to simulate the ice-melting process for high-current wires[12-16], the computational domain is divided into two sub-domains---solid phase and liquid phase, moving mesh technology is applied to track the moving interface, and a whole-process numerical computation of the air circulation outside the ice zone, temperature changes in the ice zone, relative movements of the melting ice and the wire, and the phase change of the ice-water mixture in the ice zone is made.

II. PHYSICAL MODEL

The ice-melting process of the wire can be divided into two stages. The first stage is the complete enclosure of the wire from the ice, and the second stage is the enclosure of the wire from the ice until the complete separation of the wire and the ice. Due to the small ice-melting area and the short ice-melting time of the second stage, the broken ice tube would quickly separate itself from the wire when wind blows [17]. Ice-melting time is mainly determined by the first stage. In terms of the computation model of the first stage, some assumptions are made as follows:

① Ice melting occurs within a small range of temperatures, i.e. a phase change zone exists.

②Thermal physical parameters of ice melting such as the specific heat of the phase change zone, heat conductivity, density and so on are linear with the temperature.

③Latent heat of the phase change zone is not related to the temperature.

④Ice melts into water and the water flows to the bottom of the wire. The upper surface of the wire directly connects the ice. The heat transfer of the boundary is not considered.

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⑤The air outside the ice dose not contain droplets, that is, ice accretion and the heat exchange from the impact of droplets on the ice surface are not considered.

Phase change melting employs enthalpy---porous media technology [18-20]. The enthalpy value of the material is the sum of sensible enthalpy and latent heat.

$$H = h + \Delta H \tag{1}$$

$$h = h_{ref} + \int_{T_{ref}}^{T} c_p dT \tag{2}$$

where H represents the enthalpy value, h represents the sensible enthalpy, ΔH represents the latent heat, h_{ref} is the reference enthalpy value, c_p is the specific heat capacity.

$$\Delta H = \beta L \tag{3}$$

Where L represents the latent heat value; β is the liquid fraction, which is defined as:

$$\beta = \begin{cases} 0 & T < T_{solidus} \\ 1 & T > T_{liquidus} \\ \dfrac{T - T_{solidus}}{T_{liquidus} - T_{solidus}} & T_{solidus} < T < T_{liquidus} \end{cases} \tag{4}$$

Where T represents the temperature of the phase changes zone, $T_{solidus}$ represents the solidus temperature, $T_{liquidus}$ represents the liquidus temperature.

$$\frac{\partial(\rho \mathrm{H})}{\partial t} + div\left(\rho \vec{v} \mathrm{H}\right) = div\left(kgrad\ \mathrm{T}\right) + S \tag{5}$$

Thus, energy equation:where ρ represents the density, t represents the time, k is the heat transfer coefficient of the fluid, T is the temperature, $\vec{v}$ is the velocity vector and S is the heat source which is composed of the heat source of the fluid and the heat transformed from the mechanical energy of the fluid due to viscous interaction.

Momentum equation:

$$S = \frac{(1-\beta)^2}{(\beta^2 + \varepsilon)} \mathrm{A}_{mush} (\vec{v} - \vec{v}_p) \tag{6}$$

Where ε is a number less than 0.001, avoiding being divided by 0; A_{mush} is a constant in the phase change zone; $\vec{v}_p$ is the speed of the solid.

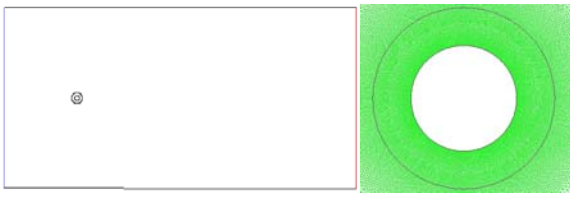
Continuity equation:

$$\frac{\partial \rho}{\partial t} + div(\rho \vec{v}) = 0 \tag{7}$$

III. NUMERICAL SIMULATION

A. Setting of computation model and solution

Numerical simulation employs the solidification and melting modules of the FLUENT software, divides the grids by triangular element and makes a grid refinement to the ice zone and the outer surface of the ice, so as to improve the accuracy of the solution. Assume the ice is circular, the computation model is as shown in Fig.1, the mid circle is the wire, the outer one is the ice zone and around the ice is the air flow field. The upper side and the lower side are set as surfaces, the left side is the velocity inlet, the right side is the pressure outlet, and heat flux is applied in the boundary of the wire. Initial condition: the temperature in the computation domain is ambient temperature. Make the solution through finite volume method, discretize pressure, convectional term and energy term with central differencing scheme and the first order upwind scheme, decouple velocities and pressure by the SIMPLE algorithm, and modify the under-relaxation factors of velocity term, pressure term and energy term.



(a) (b)

Figure.1 The Computation Model of the Ice-Melting: (a) Global Model; (b) Local Grid Model.

B. Setting of moving mesh

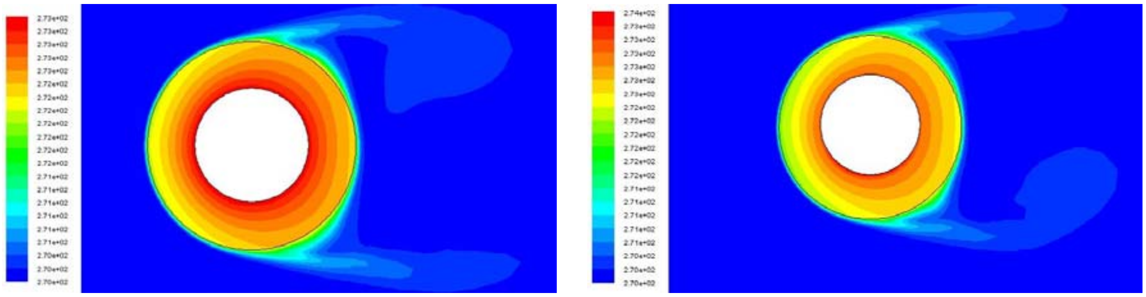
Movements of the wire in the ice zone are achieved through the moving mesh technology--- the UDF programming [21]. Moving mesh technology is a new developed mesh technology for adapting changes of the computation domain by stretching, squeezing, adding, reducing the grids and creating grids locally.

In the ice-melting process of high current wires, UDF is employed to control the interface movements of the wire. Local remeshing method is used to reorganize the grids near the moving interface. Local remeshing method could merge and re-divide the disqualified grids that exceed the gradient and size. If the new meshes satisfy the gradient and dimension, they would be adopted; and vice versa.

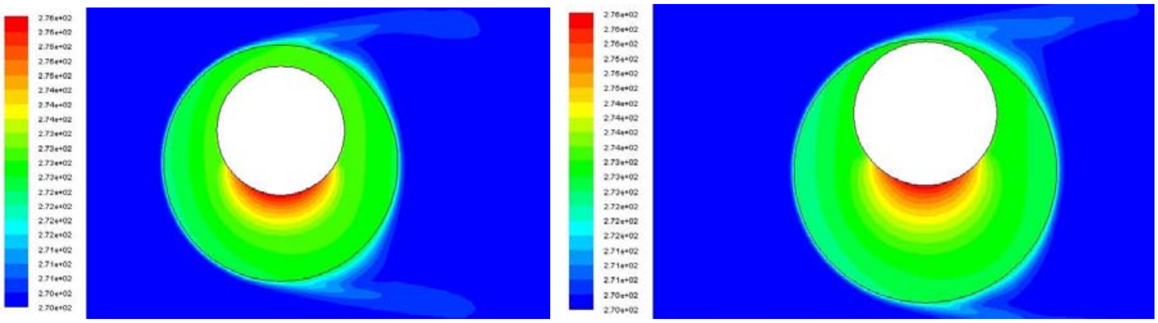
Grids satisfy one or more of the following conditions would be reorganized: ①the size is a smaller than the prescriptive minimum size; ②the size is larger than the prescriptive maximum size; ③the gradient is larger than the prescriptive minimum size.

IV. COMPUTATION OF ICE-MELTING PROCESS

With an example of the LGJ300/40 wire under such conditions: ambient temperature = -3℃, ice-melting current = 1000A, ice thickness =10mm and wind speed = 3m/s, changes of various parameters in ice-melting process are computed.

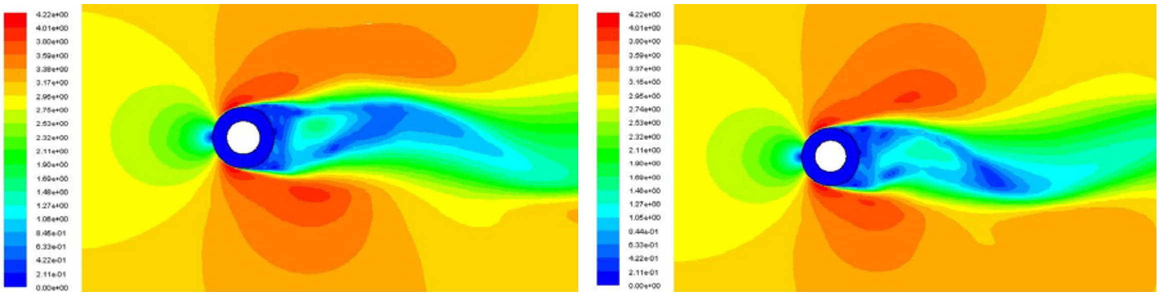


(a) t=110s (b) t=194s

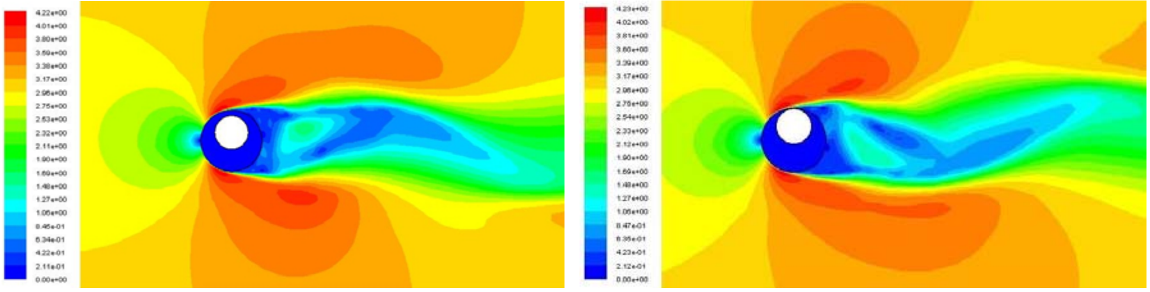


(a) t=880s (b) t=1324s

Figure.2 Changes of the Temperature Field in the Ice-Melting Process.



(a) t=110s (b) t=194s



(a) t=880s (b) t=1324s

Figure.3 Changes of the Velocity Field in the Ice-Melting Process.

A. *Temperature field*

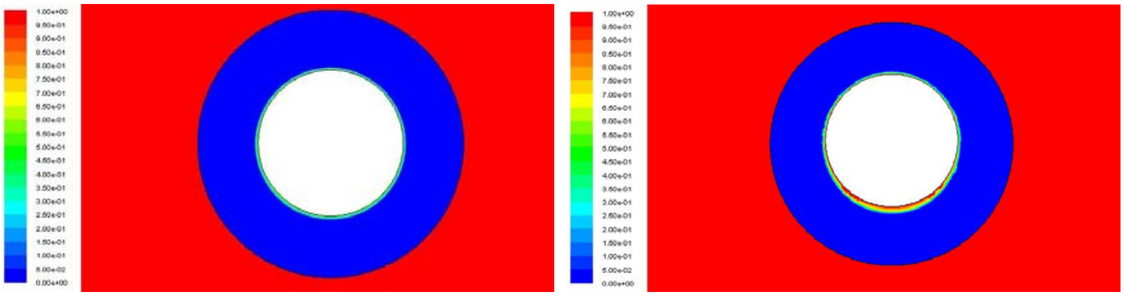
Fig.2 (a-d) shows changes of the temperature field through time in the ice-melting process. As shown in Fig.2, when t= 194s, ice starts to melt; when t=1324s, the first stage of ice melting ends. In the initial stage of ice melting, temperature in the ice zone increases outward gradually. Influenced by the wind speed, the temperature of the windward side of the ice zone is lower than that of the lee side. When the temperature of the surface connecting the ice and the wire reaches the melting point (0℃), ice melts, water starts to accumulate in the bottom of the wire, and the water temperature increases gradually with a maximum of nearly 4℃.

B. Velocity field

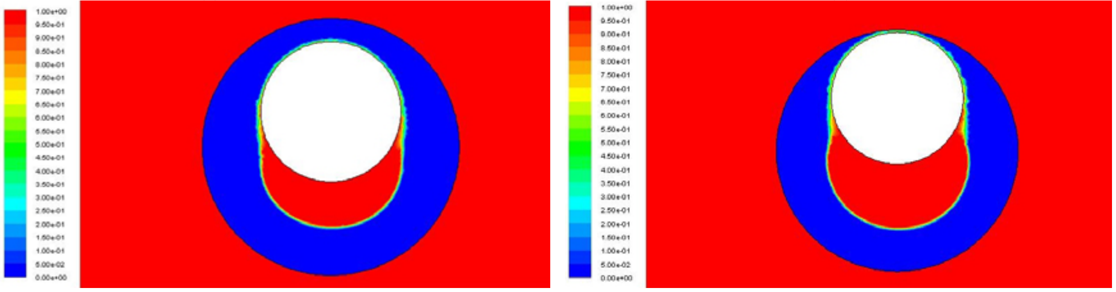
Fig.3 (a-d) shows changes of the velocity field through time in the ice-melting process. As shown in Fig.3, a speed zero point exists in the midpoint of the windward side of the ice zone. The maximum wind speed outside the ice zone is 4.2m/s. The wind blows around the ice zone, forms a vertex in the back and then an irregular vertex shedding. The wind speed doesn't change obviously in the ice-melting process.

C. Phase change rate

Fig.4 (a-d) shows changes of the volume fraction of ice and water through time in the ice-melting process. As shown in Fig.3, the red part is liquid and the blue part is solid. The figure indicates that the flow of the water melted from ice to the bottom of the wire changes the heat transfer in the bottom into this: heat is transferred to the ice through water. Re-solidification of the water accumulated in the bottom does not take place in the ice-melting process. The ice-melting zone is a rectangle with its width equal to the diameter of the wire.



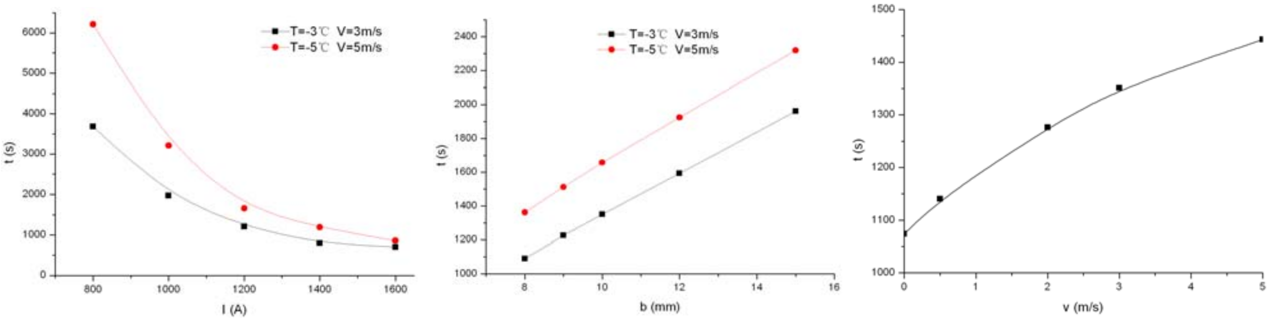
(a) t=110s (b) t=194s



(a) t=880s (b) t=1324s

Figure.4 Changes of the Volume Fraction of Ice and Water in the Ice-Melting Process.

V. COMPUTATION OF ICE-MELTING CHARACTERISTIC CURVES



(a) (b) (c)

Figure.5 The Characteristic Curve of Ice-Melting: (a) The Characteristic Curve of Ice-Melting Current and Time; (b) The Characteristic Curve of Ice Thickness and Ice-Melting Time; (c) The Characteristic Curve of Wind Speed and Ice-Melting Time.

Take the LGJ400/50 wire as an example, make a computation of the characteristic curves of ambient temperature, wind speed, ice thickness, ice-melting current and time. Fig.5 (a-d) gives the characteristic curves: (a) is the characteristic curve of ice-melting current and time when T=-3℃ V=3m/s or T=-5℃ V=5m/s, and ice thickness =10mm; (b) is the characteristic curve of ice thickness and ice-melting time when T=-3℃ V=3m/s or T=-5℃ V=5m/s, ice-melting current=1200A; (c) is the characteristic curve of wind speed and ice-melting time when ambient temperature=-3 ℃ ,ice thickness=10mm and ice-melting current=1200A.

The figure demonstrates that the ice-melting time decreases with the increase of the current, but increases with the decrease of ambient temperature and the increase of wind speed. The smaller the current is, the more ice-melting time increases. Ice thickness is linear with ice-melting time, ice-melting time increases with the increase of ice thickness.

VI. CONCLUSIONS

(1)The physical model of the ice-melting of high current wires has been analyzed, assumptions of numerical simulation have been proposed, and the CFD computation model of the ice-melting of wires has been built. The accuracy of simulation computation has been improved by employing moving mesh technology to track the moving interface.

(2)Changes of the temperature field, velocity field and phase change rate have been computed. In the ice-melting process: the temperature of the ice zone increases from the ambient temperature to the phase-change temperature, ice melts into water and accumulates in the bottom of the wire, re-solidification of water dose not occur, the ice-melting area is a rectangle with its width equal to the diameter of the wire. Ice-melting of the wire has no influence on the wind speed outside the ice zone.

(3)Computation of the characteristic curves has been made. Ice-melting time decreases with the increase of the current; ice thickness is linear with ice-melting time, ice-melting time increases with the increase of ice thickness; ice-melting time increases with the increase of wind speed.

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