CALCULATION STUDY ON ICE-MELTING IMPLEMENTATION STRATEGY OF TRANSMISSION LINES

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Abstract: Technology characteristics of AD/DC-based de-icing is analyzed. The general finite element method (FEM) code ANSYS is employed to establish the unit model and calculate the stress situation of tower in different de-icing ways of wires. In this paper, researchers propose the AD/DC-based de-icing implementation strategy and set the ice critical thickness as 70% of design value and no more than 20mm, to control ice-melting implementation. When the ice thickness meets or exceeds 90% of design value, AD-based de-icing technology should be applied as much as possible.

1. INTRODUCTION

AC/DC-based de-icing technology is a technology that melts ice on transmission lines by making use of the heat effect of high alternating current or direct current on wires, with characteristics of high efficiency and large de-icing area[1]. AC-based short-circuit de-icing is mature in the application of low-voltage lines, but not suitable for 500kV and above voltage level. Compared with AC-based de-icing, DC-based de-icing possesses many advantages for high-voltage lines. The AC/DC-based de-icing implementation should not only consider the tower stress situation, but also the weather conditions and its changes. It is necessary to meet the requirements of safe operation, economy and justifiability.

2. RESULTS AND DISCUSSION

Tower ZBT21-36 is selected as the research object, of which/whose main and auxiliary materials are Q345 steel and Q235 steel respectively. Transmission line are 4 splitting conductors. The line model is LGJ-300/50,and ground wire model is GJ-100. Design ice thickness is 20mm.

Four typical ways of melting ice are calculated, which shows that ground wire bracket has large deform which exceeds 100mm in the following ice-melting ways: border signal phase conductor de-icing, border phase conductors de-icing and middle phase conductor de-icing. In other ice melting forms, the pressure and tensile stress of the tower are much smaller than the material yield stress. Therefore, tower de-icing stress situation can meet the requirement when the ice thickness is less than design thickness.

When the transmission lines are iced, imbalance tension of tower is affected by span and the height difference. Usually, the design span is greater than actual span. There is a certain margin in the anti-icing capacity compared with design value, which determines that the critical ice thickness selection should be combined with the ice growth conditions by AD/DC-based de-icing method.

TABLE I THE ICE THICKNESS THRESHOLD VALUE OF AC/DC-BASED DE-ICING (MM)

Number	***Design ice thickness***	***Ice thickness threshold value***
1	15	10
2	20	15
3	25	18

When the ice thickness of transmission lines reach the values shown in Table I, and is expected to continue to grow and lead to accidents within a certain time, ice-melting should be carried out immediately. For other design ice thickness, the ice thickness threshold value should be set as 70% of the design value, and should be less than and equal to 20mm. When the ice thickness meets or exceeds 90% of design value, regardless of the weather condition, AC-based de-icing technology should be applied as much as possible. When the ice cover is heavy, but less than design value, if the ice is no longer grow and the temperature rises to 0℃ and above in the following time, waiting for natural passive ice melting is a good choice.

3. CONCLUSION

The calculation of tower stress situation in different ice-melting ways shows that ground wire bracket has a large deformation in following ice-melting ways: border signal phase conductor de-icing, border phase conductors de-icing and middle phase conductor de-icing. If only the ice thickness of wires is less than design thickness, the stress state of tower in all ice-melting processes could meet the service requirement.

Implementation Strategy of AC/DC-based de-icing, especially the ice thickness threshold value which is the controlled factor of ice-melting implementation, is proposed. The ice thickness threshold value should be set as 70% of design value, and should be less than and equal to 20mm. When the ice thickness meets or exceeds 90% of design value, AC-based de-icing technology should be applied as much as possible.

4. REFERENCES

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Calculation Study on Ice-melting Implementation Strategy of Transmission Lines

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***Abstract*—In the ice-melting process of transmission lines, different ways of ice-melting would affect the safety of transmission tower. Furthermore, ice thickness should be considered in ice-melting implementation. Technology characteristics of AD/DC-based de-icing are analyzed. The general finite element method (FEM) code ANSYS is employed to establish the unit model and calculate the stress situation of tower in different de-icing ways of wires. The calculation result shows that ground wire bracket has a large deformation in following ice-melting ways: border signal phase conductor de-icing, border phase conductors de-icing and middle phase conductor de-icing. If only the ice thickness of wires is less than design thickness, the stress state of tower in all ice-melting processes could meet the service requirement. In this paper, researchers propose the AD/DC-based de-icing implementation strategy and set the ice critical thickness as 70% of design value and no more than 20mm, to control ice-melting implementation. When the ice thickness meets or exceeds 90% of design value, AD-based de-icing technology should be applied as much as possible.**

Keywords-transmission line；AC/DC-based de-icing；implementation strategy；FEM

I. INTRODUCTION

Wires icing is an important hidden trouble for safety and stable operation of transmission lines. On January 1998, a serious ice and snow storm hit Quebec, Ontario and other provinces of Canada. Russia, France, Iceland and Japan suffered similar accidents. Due to the influence of climate, micro-terrain and micro-climate, ice storm accidents happened frequently in China [1]. Early in 2005, wires icing led to icing flashover and tower collapse in Hunan province [2-5]. In early 2008, a bad weather of continuing large-scale low temperature, rain, snow and frost caused ice flashover tripping, breaking wire, collapse of tower in Hunan and brought a serious damage to the power grid [6-8].

Therefore, making researches on anti-icing and de-icing methods are of great importance to mitigate the effects of ice and snow storms. 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 [9], among which the AC-based and DC-based de-icing belonging to the first one are the most mature and feasible. In this paper, the technology characteristics of AC/DC-based de-icing are analyzed. The FEM code is employed to simulate the stress situation in accordance with different ice-melting ways, and the AC/DC-based de-icing implementation strategy is proposed.

II. AC/DC-BASED DE-ICING

AC/DC-based de-icing technology is a technology that melts ice on transmission lines by making use of the heat effect of high alternating current or direct current on wires, with characteristics of high efficiency and large de-icing area[10].

A. AC-based de-icing

AC-based de-icing can be divided into short circuit based de-icing and on-load de-icing. Short circuit based de-icing technology is a technology that melts ice by controlled short circuit current from deliberate short-circuit fault. According to the different fault types, short circuit based de-icing can be sorted as three-phase short circuit based de-icing, double-phase short circuit based de-icing and conductor-ground wire signal-phase short circuit based de-icing. Among the three kinds of short circuit based de-icing, the first one is generally applied in practical engineering. The key of short circuit based de-icing is to select appropriate power supply in accordance with icing line length, section and icing thickness. Usually, low voltage level system, which can provide high current, is chose as the electrical source to melt ice for high voltage level system [11]. In the case of small capacity requirement, mobile ice-melting systems can be used. As for a certain electrical source, if the ice-melting current is in excess of allowable current, a number of same voltage transmission lines in series can melt ice at the same time to protect the safety of transmission lines [12].

On-load de-icing is a method increases the current of iced transmission line through changing power load flow under the condition of operation without interruption. Compared with short circuit based de-icing, on-load de-icing can melt ice with operation of transmission lines. This characteristic is a distinct advantage, because the iced age is usually the age of peak load, but also the dry season. The researchers home and broad proposed many on-load de-icing methods, which mainly consist of scheduling power flow based on adjustment, de-icing based on increasing reactive currents and on-load de-icing based on phase shifter.

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AC/DC-based de-icing technology is a relatively mature ice melting method at home and abroad, but because of its power capacity constraints, it can not solve transmission line icing of 500kV and above voltage level with a large cross-sectional area line and long conductors more than 200km.

B. DC-based de-icing

Regarding the iced transmission lines as load, DC-based de-icing technology is a method that melts ice by short-circuit current from low voltage DC power. It can make up for the lack of AC-based de-icing technology [13, 14]. DC power capacity needed to melt the ice depends only on the resistance and length of iced line. By splitting conductors, the 500kV line possesses a large distributed capacitance. Moreover, DC resistance is only about 10% of AC impedance. It shows that AC short-circuit requires the power supply to provide a lot of reactive [15]. Therefore, compared with AC-based de-icing technology, DC-based de-icing technology need much smaller capacity under the same conditions and can be applied to different voltage lines. The development of modern direct current, high-current controlled rectifying components, HVDC technology with good controlled characteristics such as constant current and voltage, promote the DC-based de-icing technology. According to the nature of iced transmission lines, DC-based de-icing can be classified into DC current on AC transmission line de-icing and DC current on DC transmission line de-icing.

Direct current is commonly used for the ice-melting of DC transmission lines. It is convenient, merely switch rectifier wiring and change the system operation mode.

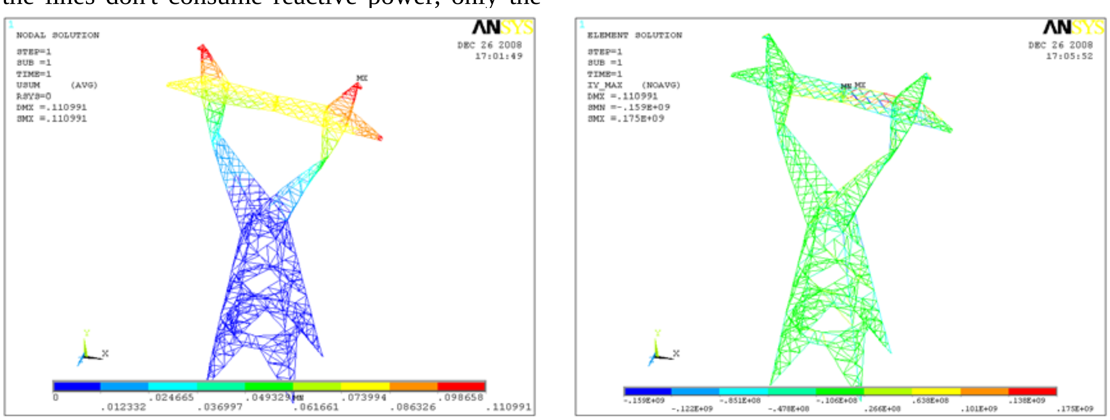
As for AC line de-icing, short-circuit method is commonly used. DC and AC short-circuit de-icing have the same basic principle. The difference is the DC short-circuit method transforms the AC current into DC current to heat iced line through a large-capacity power electronic device. The DC-based de-icing is only relative to the resistance of lines, so the lines don't consume reactive power, only the DC converter consumes its own reactive power. Therefore, DC short-circuit method can be used for each voltage level, while there is no need to consider the problem of inadequate power compensation.

III. DE-ICING ON THE INFLUENCE OF TOWER STRESS

In the ice-melting process of transmission lines, different ice-melting ways would lead to the ice-load change of wires and influence stress situation of transmission tower. General finite element model code ANSYS is applied for mechanical simulation of transmission tower in accordance with different ice-melting ways. Transmission tower is generally made from single-angle steel bolted by eccentric connection. Because the single-angle steel is thin-walled component with symmetrical cross section, coupled with the diversity of transmission tower structure type and the complexity of load conditions, it is difficult to analyze accurately the stress situation. The space truss method can't accurately calculate the bearing capacity of transmission tower, but just consider the stiffness of node connection. So the authors apply the general thin-walled beam element method and take into account the influence of geometric and material nonlinearity [16-18].

Tower ZBT21 is selected as the research object, of which main and auxiliary materials are Q345 steel and Q235 steel respectively. Transmission lines are 4 splitting conductors. The line model is LGJ-300/50, and ground wire model is GJ-100. Design ice thickness is 20mm. The beam element method is applied to establish the transmission tower model, beam element cross-section is "L" type. The type of connection is eccentric. The units of calculation are N and mm.

A. Border signal phase conductor de-icing on the influence of tower stress

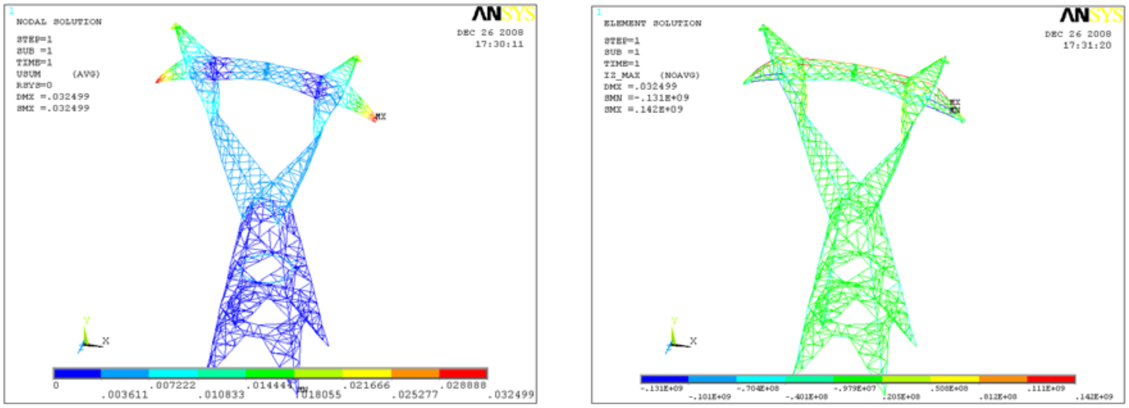


(a) displacement contour

(b)stress contour

Figure.1 Tower Displacement and Stress Contour of Border Signal Phase Conductor De-icing.

As for border signal phase conductor de-icing, the load of transmission tower is composed of gravity load of conductors and ground wires, ice load of ground wires, and ice load of border phase and middle phase conductors. The tower displacement and stress of calculation are shown in Fig.1. The largest deformation site is the tower head, whose displacement is 111mm. The maximum stress position is the central of cross arm. The maximum stress and minimum pressing stress are 175MPa and 159MPa respectively.



(a) displacement contour (b)stress contour

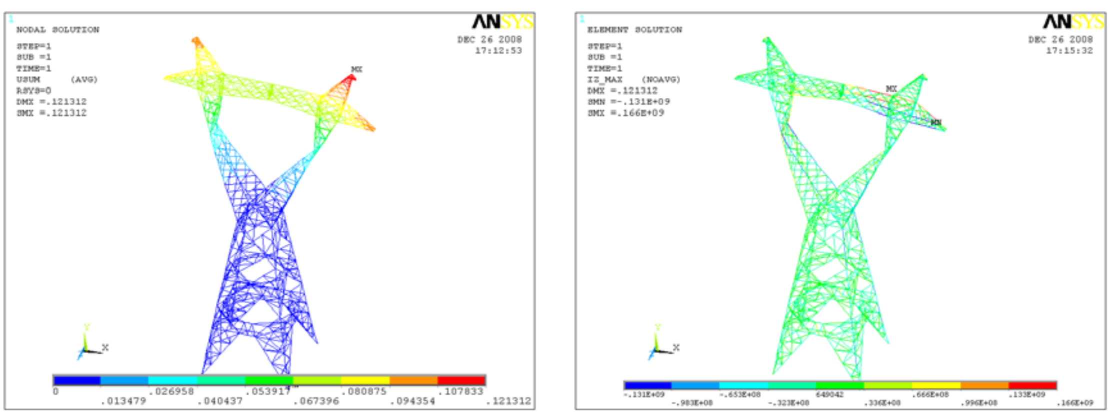
Figure.2 Tower Displacement and Stress Contour of Middle Phase Conductor De-icing.

B. Middle phase conductor de-icing on the influence of tower stress

As for middle phase conductor de-icing, the load of transmission tower is composed of gravity load of conductors and ground wires, ice load of ground wires, and ice load of two border phases conductors. The tower displacement and stress of calculation are shown in Fig.2. The largest deformation parts in the tower are the side points of cross arm both sides, whose displacement is32mm. The maximum stress position is the main material of cross arm side. The maximum stress and minimum pressing stress are 142MPa and 131MPa respectively.

C. Border and middle phases conductors de-icing on the influence of tower stress

As for border and middle phases conductors de-icing, the load of transmission tower is composed of gravity load of conductors and ground wires, ice load of ground wires, and ice load of border phase conductor. The tower displacement and stress of calculation are shown in Fig.3. The largest deformation site is the tower head, whose displacement is 121mm. The maximum stress position is the main material of cross arm central parts. The maximum stress and minimum pressing stress are 166MPa and 131MPa respectively.

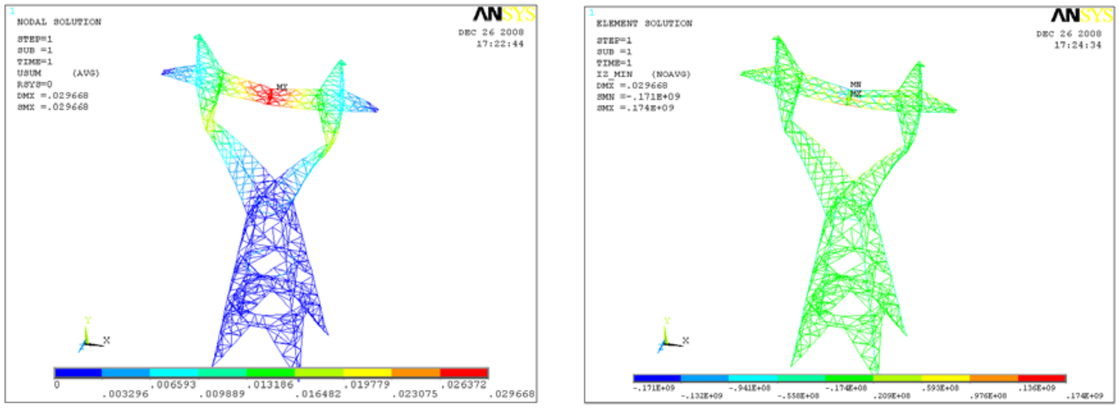


(a) displacement contour (b)stress contour

Figure.3 Tower Displacement and Stress Contour of Border and Middle Phases Conductor De-icing.

D. Both border phases conductors de-icing on the influence of tower stress

As for both border phases conductors de-icing, the load of transmission tower is composed of gravity load of conductors and ground wires, ice load of ground wires, and ice load of middle phase conductor. The tower displacement and stress of calculation are shown in Fig.4. The largest deformation site is cross arm central part, whose displacement is 30mm. The maximum stress position is the main material of cross arm central parts. The maximum stress and minimum pressing stress are 174MPa and 171MPa respectively.



(a) displacement contour (b)stress contour

Figure.4 Tower Displacement and Stress Contour of Both Border Phases Conductors De-icing.

The above calculation shows that ground wire bracket has large deform which exceeds 100mm in the following ice-melting ways: border signal phase conductor de-icing, border phase conductors de-icing and middle phase conductor de-icing. In other ice melting forms, the pressure and tensile stress of the tower are much smaller than the material yield stress. Therefore, tower de-icing stress situation can meet the requirement when the ice thickness is less than design thickness.

In addition, as for a certain tension section with a great deal of difference between front span and back span, the tension stress gap of the fore-and-aft lines will be larger when ice covers the transmission lines, which results in a large imbalance tension of the tower. When height difference is large, horizontal tension will reduce and horizontal tension difference will increase. On the other hand, the vertical span increases, which leads to the increase of tower vertical load. When the tower is in a great span or has a large height difference, the imbalance tension of transmission tower will increase with the increasing of ice thickness. So if the unbalanced tension on stress reaches the material yield strength, the tower will lose instability, collapse, and pulls down the adjacent towers. However, if the span difference and height difference is small, the tower will not collapse even if the ice load exceeds the design value. The breakage resulted from the tension of adjacent towers collapse should be excepted of course. Usually, the design span is greater than actual span. There is a certain margin in the anti-icing capacity compared with design value, which determines that the critical ice thickness selection should be combined with the ice growth conditions by AD/DC-based de-icing method.

IV. Implementation Strategy of AC/DC-based De-icing

The AC/DC-based de-icing implementation should not only consider the tower stress situation, but also the weather conditions and its changes. It is necessary to meet the requirements of safe operation, economy and justifiability. The specific requirements are as follows:

(1)Transmission lines should have power capacity and loop to implement ice melting. If the flux of some equipment can not meet the needs of ice melting in the ice-melting loop, these devices should be replaced, removed or shorted before the ice melting operation.

(2)When the ice thickness of transmission lines reach the values shown in Table I, and is expected to continue to grow and lead to accidents within a certain time, ice-melting should be carried out immediately.

TABLE I. The Ice Thickness Threshold Value of AC/DC-based De-icing (mm)

Number	***Design ice thickness***	***Ice thickness threshold value***
1	15	10
2	20	15
3	25	18

For other design ice thickness, the ice thickness threshold value should be set as 70% of the design value, and should be less than and equal to 20mm.

When the ice thickness meets or exceeds 90% of design value, regardless of the weather condition, AC-based de-icing technology should be applied as much as possible.

When the ice cover is heavy, but less than design value, if the ice is no longer grow and the temperature rises to 0℃ and above in the following time, waiting for natural passive ice melting is a good choice.

(3)When the insulation of transmission lines doesn't meet the requirement of ice melting (such as the ground wire disconnects and attaches to the conductors, or wires floor, etc.), AC/DC-based de-icing can't be carried out.

(4)In the process of ice melting, the observation of ice-covered area should be focused on preventing wires damage caused by falling ice. In case the ice separates itself from the wire or the wire temperature exceeds allowable value, ice-melting should be stopped.

V. Conclusions

(1)AC/DC-based de-icing technology is the most effective ice-melting method. AC-based short-circuit de-icing is mature in the application of low-voltage lines, but not suitable for 500kV and above voltage level. Compared with AC-based de-icing, DC-based de-icing possesses many advantages for high-voltage lines.

(2)The calculation of tower stress situation in different ice-melting ways shows that ground wire bracket has a large deformation in following ice-melting ways: border signal phase conductor de-icing, border phase conductors de-icing and middle phase conductor de-icing. If only the ice thickness of wires is less than design thickness, the stress state of tower in all ice-melting processes could meet the service requirement.

(3) Implementation Strategy of AC/DC-based de-icing, especially the ice thickness threshold value which is the controlled factor of ice-melting implementation, is proposed. The ice thickness threshold value should be set as 70% of design value, and should be less than and equal to 20mm. When the ice thickness meets or exceeds 90% of design value, AC-based de-icing technology should be applied as much as possible.

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