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The Method and Test of De-icing on Four Bundled-conductors by Leading Running Current into Various Sub-conductor Combinations

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***Abstract*—In this paper, a method of de-icing on four bundled-conductor by leading running current into various subconductor combination was proposed and verified by field test. The results show that by using insulative conductor spacer to separate the four bundled-conductor and setuping suitable control switches on the both sides of line span which is needed de-icing, running current on bundled-conductor is leaded into one subconductor combination or one subconductor to increase the subconductor's current density and to achieve de-icing. The ice shapes and types which coats on four bundled-conductor relative to the meteorological and environment parameters. The ice melting process of four bundled-conductor includes four stages: ice layer heating, ice layer rotating, ice layer melting, ice layer unloading. Reasonable method of de-icing on four bundled-conductor by leading running current into subconductor combination can achieve ice which coats on four bundled-conductor melting and unloading, and the ice melting speed relatives to the value of current, ambient temperature, wind speed and etc. Research results can provide a reference for icing and de-icing of various bundled-conductor.**

1 Introduction

The conductor icing of transmission lines is a serious threat to safe and reliable operation of power systems. Especially in 500kV backbone power network, the icing accident may cause split of an entire network. The designed current transmission capacity of 500kV transmission lines is about 3000A, but there are closeness relationship between the working current and the loads, and the lines are impossible to run with full loads generally speaking, to most transmission lines, the working current is below 1000A. Under this working current, the current of a single sub-conductor of the bundled-conductor is about 250A, which is too small to cause enough heat for the conductor to prevent icing.

2 Result and discussion

The method of using running current on four bundled-conductor to group de-icing is that leading running current into one sub-conductor to increase the sub-conductor's current density and to achieve de-icing, and de-icing on other sub-conductors can be achieved in the same way. This method includes that verifying the de-icing transmission lines, building insulated spacer conductor, setuping control switches and operating the working procedures of control switches.

Different single- and multiple-conductor were covered with ice in natural icing station and the ice on LGJ-240 four bundled-conductor is shown in Fig. 1.

Figure 1. The photo of ice on four bundled-conductor

Verification test of group de-icing using running current on four bundled-conductor bad been carried out in natural icing station. And the test results are shown in Tab. I.

TABLE I. TEST VERIFICATION OF SINGLE SUB-CONDUCTOR

Current of Sub-conductor (A)	Current type	Wind velocity (m/s)	Environment temperature (℃)	Ice melting duration (min)
600	DC	4	-3	100
600	AC	4	-3	95
600	DC	4	-5	250
720	DC	1.5	-7	130
720	AC	1.5	-7	130
600	DC	2	-5	66
720	DC	3	-7	26
600	DC	2.5	-6	40

3 Conclusion

In natural icing environment, the contour of ice on four bundled 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. Using running current of four bundled conductors to melt ice on each sub-conductor combination, the ice melting duration relates to working current, wind velocity and temperature. The ice melting duration will decrease with larger running current, which can also be achieved with smaller wind speed or higher temperature.

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***Abstract*—The conductor icing of transmission lines is a serious threat to safe and reliable operation of power systems. Especially in 500kV backbone power network, the icing accident may cause split of an entire network. In this paper, a method of de-icing on four bundled-conductor by leading running current into various subconductor combination was proposed and verified by field test. The results show that by using insulative conductor spacer to separate the four bundled-conductor and setuping suitable control switches on the both sides of line span which is needed de-icing, running current on bundled-conductor is leaded into one subconductor combination or one subconductor to increase the subconductor's current density and to achieve de-icing. The ice shapes and types which coats on four bundled-conductor relative to the meteorological and environment parameters. The ice melting process of four bundled-conductor includes four stages: ice layer heating, ice layer rotating, ice layer melting, ice layer unloading. Reasonable method of de-icing on four bundled-conductor by leading running current into subconductor combination can achieve ice which coats on four bundled-conductor melting and unloading, and the ice melting speed relatives to the value of current, ambient temperature, wind speed and etc. Research results can provide a reference for icing and de-icing of various bundled-conductor.**

I. INTRODUCTION

The conductor icing of transmission lines is a serious threat to safe and reliable operation of power systems. Especially in 500kV backbone power network, the icing accident may cause split of an entire network. In February, 2005, serious icing phenomenon took place in province Hubei, Hunan, Jiangxi and other places, leading to as many as 57 times faults of 500KV AC transmission lines in Huazhong power grid, Hunan power grid split from the main grid once, Hubei Enshi grid split from the main grid twice, and the west grid of Huazhong split from the east grid once. In the beginning of the year 2008, the whole country including Hunan, Anhui, Guizhou, Jiangxi and other areas experienced infrequent icing accident, causing the 500kV backbone power network of Hunan power grid encountering large area of tower collapse and icing flashover of insulators, and the 500KV network of Guizhou power grid were almost palsied, Guizhou grid were split into several isolated sub-grids, further more, 17 500kV lines of Jiangxi grid were cut off, the power network was destroyed, the security of the grid suffered threaten, as a result, the daily life of people was seriously influenced, the national economy suffered huge loss too.

To assure the safety and reliable of the power system, a large number of studies on anti-icing and de-icing technology have been carried out at home and abroad, tens of methods of thermodynamic anti-icing, mechanical de-icing and naturally icing shed off are put forward[1~10]. However, most de-icing methods are unable to be applied to transmission lines because of the difficulty of engineering or economy benefit, in all the de-icing methods that could be applied to overhead transmission lines, conductor short circuit melting-icing method is the most mature and feasible technique: Manitoba Hydro in Canada has carried out three-phase shot circuit melting-icing experiment since the beginning of 1970s[11]. In 1982, America melted ice using high density current[12]; China has been using AC short circuit melting-icing method to melt the ice of serious icing lines below 220kV since 1970s, contributed a lot to anti-icing[13]. During the icing disaster in the year 2008, Hunan province carried out AC de-icing to many lines 20 times totally, played positive roles for icing prevention[14~15]. In 2005, Canada Quebec Hydro collaborated with AREVA corporation developing a HVDC melting-icing equipment, being used for de-icing of 745kV four bundled-conductor and 315kV two bundled-conductor[16]. In December, 2008, the fixed DC melting-icing equipment developed by the national grid accomplished warming test at Hunan power grid 500kV Fusha I line[13]. In January, 2009, Southern power grid also successfully carried out DC melting-icing test at 220kV ShuiCheng transformer substation and 500kV FuQuan transformer substation of Guizhou LiuPanShui power supply bureau[17~18].

In order to enforce shot circuit melting-icing method, a large number of studies of melting-icing mechanism, the value of melting current and the relationship between the melting duration and the metrological parameters at home and abroad: Vargas and Bejan studied on interior contact ice melting of an icing cylinder in 1994[19]. The heat exchange coefficient of icing conductor surface was brought into melting-icing model and the method of calculating melting duration was proposed in reference [20]. References [21~23] analyzed the heat balance process of conductor melting-icing, base on this, it proposed the relationship between the critical current of DC short circuit melting-icing method of transmission lines and metrological parameters. Reference [24] carried out highest temperature test of the icing conductor surface during DC melting-icing process, deducing the formula of calculating the highest temperature of the conductor. The existing melting-icing techniques need to work only when the transmission lines are out of service, and because the melting-icing power source equipment is too expensive and too heavy, they could only be carried out at transformer substations commonly, actually the icing of transmission lines has something to do with the micrometeorology and the micro-geographic environment, there are only few parts of a line will be covered with thick ice, therefore, using existing shot circuit melting-icing method costs too much and is wasteful. This paper proposes the method of de-icing on four bundled-conductor by leading running current into various sub-conductor combination, achieving the melting-icing and ice shedding off for four bundled-conductor, the result could be used as reference for icing and melting-icing techniques of various kinds of bundled-conductors.

II. USING THE METHOD OF DE-ICING ON FOUR BUNDLED-CONDUCTOR BY LEADING RUNNING CURRENT INTO VARIOUS SUB-CONDUCTOR COMBINATION

The designed current transmission capacity of 500kV transmission lines is about 3000A, but there are closeness relationship between the working current and the loads, and the lines are impossible to run with full loads generally speaking, to most transmission lines, the working current is below 1000A. Under this working current, the current of a single sub-conductor of the bundled-conductor is about 250A, which is too small to cause enough heat for the conductor to prevent icing.

The method of using running current on four bundled-conductor to group de-icing is that leading running current into one sub-conductor to increase the sub-conductor's current density and to achieve de-icing, and de-icing on other sub-conductors can be achieved in the same way. This method includes that verifying the de-icing transmission lines, building insulated spacer conductor, setuping control switches and operating the working procedures of control switches.

(1) Verifying the de-icing transmission lines

To verify the serious icing transmission lines, it is very necessary to conduct a detailed investigation for the passageway of transmission lines and to observe the micro-meteorological and micro-environment nearby.

(2) Building insulated spacer conductor

Replacing the conventional spacer conductor with insulated spacer conductor within the span distance of bundled-conductor which is needed de-icing in order to make the subconductors insulate each other.

(3) Setuping control switches

According to the nearby principle, strain towers should be chosen during the transmission lines which require de-icing and control switches should be set on them (as shown in Fig. 1, 1 stands for the jumper clamp, 2 is a insulator string, 3 is a bunlded-conductor, 4 is the jumper wire of strain towers, and ZK is on behalf of control device). For single direction transmission lines, it is only necessary to set up control switches on the sending end and to set the collecting current spacer conductor on the receiving end (in Fig. 2, JG-J is the conventional spacer conductor, JG-C stands for the insulated spacer conductor, ZK is the control switches, TA is the sending end strain tower, TB is the receiving end strain tower, Li is on behalf of the de-icing transmission line, JS stands for the collecting current spacer conductor and F-C is the bunlded-conductor); for the bunlded-conductor of bothway transmission lines, control devices can be set on the both ends of transmission lines which require de-icing (as shown in Fig. 3, ZK-A and ZK-B stand for the number A and number B control device respectively)

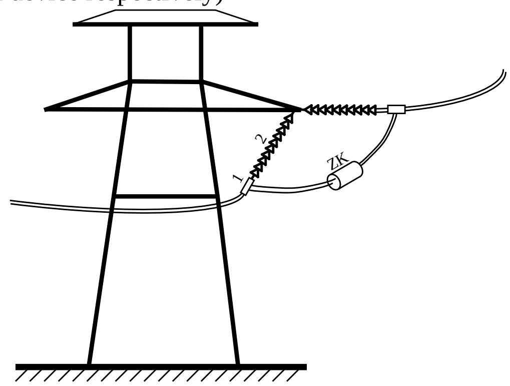


Figure 1. Setuping position of control switches

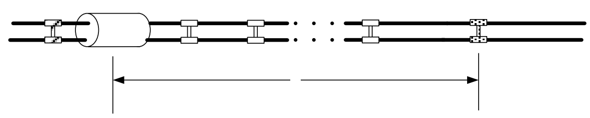


Figure 2. The de-icing program of single transforming bundled-conductor

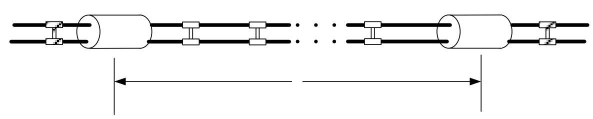
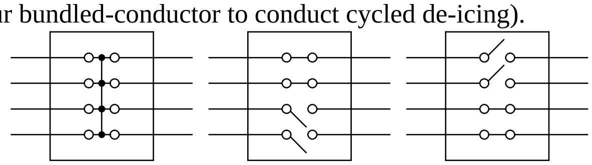


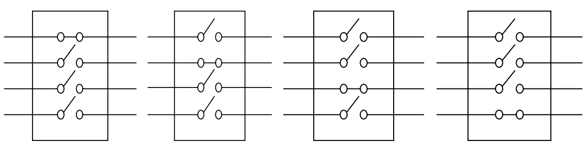
Figure 3. The de-icing program of bothway transforming bundled-conductor

(4) Operating the working procedures of control switches

Generally, each subconductor belonging to the bundled-conductor on the de-icing transmission lines leads the loading current as usual; when there is icing on the transmission line, control switches will be on. Thus, the control device will transform the current of each bundled-conductor on the sending end into a group of subconductors on the de-icing transmission lines at a time step ΔT. On the other hand, if there are control devices on the receiving end, the control devices on the sending end will send out instructions to the control devices on the receiving end. According to the instructions, the control devices on the receiving end will reassign the collecting current on the group of subconductors to each subconductor, to make the current density of the subconductor above the critical de-icing one and to reach the required current density; then, in accordance with the Joule effect, the over current on the subconductor is capable of melting the ice layer or destroying the icing formation conditions on the surface of conductors. Based on the number of subconductors of the bundled-conductor, the count of a group of subconductors can be set. For the four bundled-conductor, the running current can be transformed into one conductor (when running current is low) or two conductors (when running current is high) according to its value. Figure 4 shows the state sketch map that the subconductor is on of de-icing method of four bundled-conductor. Fig. 5 is the de-icing flow chart of four bundled-conductor (4-C represents the normal operation state of conductors; 4-A1 and 4-A2 stand for the two groups of subcondutors divided by the four bundled-conductor to melt ice repeatly; 4-B1, 4-B2, 4-B3 and 4-B4 are on behalf of the four subconductors divided by the four bundled-conductor to conduct cycled de-icing).

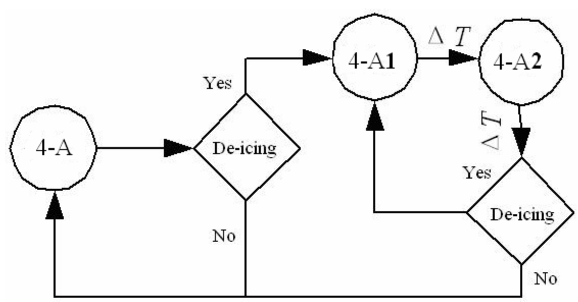


(a) Melt ice on two subconductors at the same time



(b) The repeated ice-melting of single subconductor

Figure 4. The schematic diagram of subconductor on



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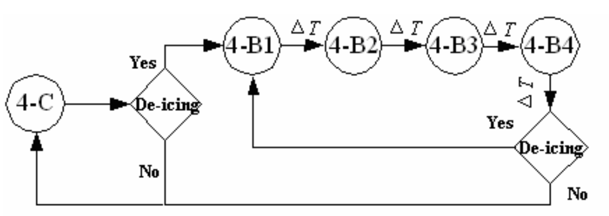

(b) The repeated ice-melting of single subconductor

Figure 5. The flow chart of de-icing method

III. THE FIELD TEST USING RUNNING CURRENT ON FOUR BUNDLED-CONDUCTOR TO GROUP DE-ICING

A. Field Icing onFour Bundled-conductor

After the ice disaster in 2008, Chongqing University has set up a natural icing test station, as shown in Fig. 6, at Xuefeng Mountain in Hunan. Xuefeng Mountain locates in the southwest of Hunan Province. This region has the humid subtropical monsoon climate. The annual average temperature and the annual average rainfall at the mountain is 12.7 ℃ and 1810mm, respectively. The natural icing station locates at Ping Shan Tang at Xuefeng Mountain. This area with an altitude of 1400m is a typical micro-topography and micro-weather icing zone. The natural icing station covers with ice over 60 days a year. The maximum thickness of glaze ice and maximum wind speed over 500mm and 25m/s, respectively. Early 2008, when most parts of Southern China encountered the serious ice and snow disaster, the weight of glaze ice on 400mm^2 conductors is up to 68kg/m at this place. And it is up to 48kg/m in February 2009 and 50kg/m in early 2010. So the Xuefeng Mountain natural icing station is the best place to study the icing of power grid.

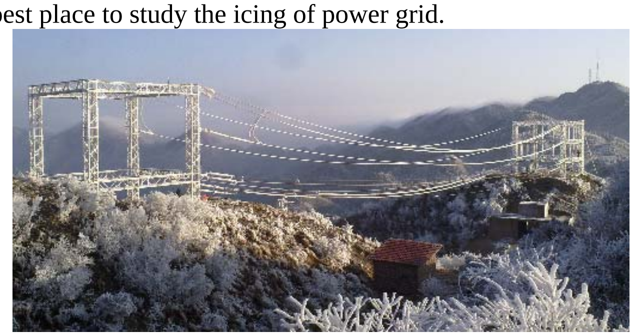

Figure 6. Xuefeng Mountain natural icing test station

There are two shelves for glaze icing in natural icing station. And the distance between the two towers is 80m. Some different single- and multiple-conductor can be installed on the two shelves as test need (as shown in Fig. 6). Using insulators connect the conductors and shelf to achieve the electrical insulation between them. So the studies about ice accretion on conductors, mechanism and method of de-icing of conductors can be carried out. The ice on LGJ-240 four bundled-conductor is shown in Fig. 7.

Figure 7. The photo of ice on four bundled-conductor

The shape and dimension of ice on four bundled-conductor are measured in test research. The measuring method as following: In order to observe the cross-section profiles of iced conductor, we cut down a segment of ice using a small saw blade firstly (as shown in Fig. 8). Secondly, make the iced conductor through a white paper with a hole, which has the same diameter with the conductor. Then sketch out the cross-section profile of iced conductor along ice layer using pencil. And then mark out the dimension of every section of iced conductor using vernier caliper. In the end, put all the coordinates of measuring points into computer and then draw, we can get the cross-section profile which is shown in Fig. 9.

From the results of measurement, we can get: Under natural icing environment, the shape of ice on four bundled-conductor is inregular and similar to the oval-shaped in most cases. And the ice is generally thickest on the windward side, while the thinnest on the leeward side.

Figure 8. The shape of ice on subconductor of four bundled-conductor

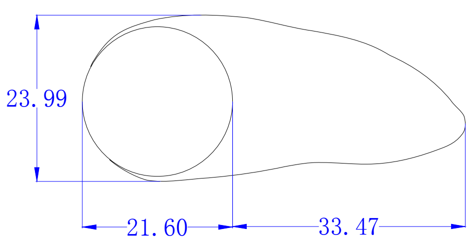

Figure 9. The cross-section profile of ice on subconductor of four bundled-conductor

B. *The Verification of Group De-icing Using Running Current on Four Bundled-conductor*

The ice-melting method using running current on four bundled-conductor was verified by the test of repeated ice-melting on single subconductor in natural icing station. The process of test verification as following: (1) install the insulated spacer conductor on four bundled-conductor; (2) make the four bundled-conductor covered with planning value of ice under natural icing environmental; (3) connect one subconductor of the four bundled-conductor with anyone of other conductors on one glaze shelf in test station; (4) access the two conductors to test current circuit on the other glaze shelf; (5) apply initial setting short-circuit current and record the meteorological parameters, the variation of temperature and tension on conductors and the corresponding time. Meanwhile, take photos on the de-icing conductors; (6) after the ice-melting of the subconductor, cut off the power supply and then carry out the ice-melting on other subconductors by the same method and process mentioned above.

The de-icing process includes three stages: (1) Temperature of conductor rising and ice rotating stage. When the current flow through the conductor, the temperature of conductor and ice begin to rise. When the inner surface temperature of ice reaches 0 °C, the cohesive force between the conductor and the ice is weakening gradually and then the ice sleeve will rotate with gravity torque. (2) Ice-melting stage. It is that the time when the ice shed from conductor after rotation of ice. In this stage, the temperature of conductor is rising continue and the ice melting gradually. (3) The ice shed from conductors stage. This stage starts from the ice begin shed from conductors to all the ice on conductors shed off.

Employing the method mentioned above, tests are carried out to verify the de-icing ability on sub-conductor of bundled lines in Xuefengshan natural icing station of Chongqing University. Test results are shown in Tab. I.

TABLE I. TEST VERIFICATION OF SINGLE SUB-CONDUCTOR

Current of Sub-conductor (A)	Current type	Wind velocity (m/s)	Environment temperature (℃)	Ice melting duration (min)
600	DC	4	-3	100
600	AC	4	-3	95
600	DC	4	-5	250
720	DC	1.5	-7	130
720	AC	1.5	-7	130
600	DC	2	-5	66
720	DC	3	-7	26
600	DC	2.5	-6	40

Several results can be obtained from Tab. I:

(1) The cycling ice melting method proposed in this article can attain the aim of de-icing as long as the working current in the four bundled conductor being not too small.

(2) Carrying out grouping de-icing test employing four bundled conductor running current, the ice melting duration has almost no relation with type of current. When the running current is 600A, with the wind speed of 4m/s and environment temperature of -3℃, the ice melting duration of each sub-conductor is 100min for DC test and 95min for AC ice melting test. With running current of 720A, wind velocity of 1.5m/s and environment temperature of -7℃, the ice melting duration of each sub-conductor is both 130min for the condition of DC and AC test.

(3) Applying four bundled conductor running current for grouping de-icing test, the ice melting speed could be influenced by wind velocity. A larger wind speed could reduce the ice melting duration. When running current is 720A and environment temperature is -7℃, the ice melting

duration become 130min and 26min with wind velocity being 1.5m/s and 3m/s respectively.

(4) Applying four bundled conductor running current for grouping de-icing test, the ice melting speed could be affected by environment temperature. The lower the environment temperature is, the longer the ice melting duration will be. For instance, with wind velocity being 4m/s and working current being 620A, the ice melting duration of each sub-conductor is 100min and 250min under temperature of -3℃ and -5℃ respectively.

(5) Using four bundled conductor running current for grouping de-icing test, the ice melting speed could be affected by the value of working current. Ice melting duration will be shortened with larger running current. With environment temperature being -5℃ and wind speed being 2m/s, the time cost for ice melting of each subconductor is 66min under the effect of 600A running current; when temperature being -7℃ and wind speed being 3m/s, with the running current of 720A, the ice melting duration is only 26min although the metrological condition for ice-melting is more severe than the former.

IV. CONCLUSIONS

(1) The method for de-icing on four bundled conductor by leading running current into various sub-conductor combination in this article is feasible, which can achieve cycling ice-melting and ice shedding of each sub-conductor in a four bundled transmission line.

(2) In natural icing environment, the contour of ice on four bundled 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.

(3) Using running current of four bundled conductors to melt ice on each sub-conductor combination, the ice melting duration relates to working current, wind velocity and temperature. The ice melting duration will decrease with larger running current, which can also be achieved with smaller wind speed or higher temperature.

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