The method to prevent 10kV aerial insulated wire from breaking caused by lightning stroke is put forward according to the mechanism of the break of 10kV aerial insulated wire caused by lightning stroke and the motion rules of power frequency arc via the probability calculation and analysis of lightning stroke flashover. It is verified through test that the phenomenon of the lightning stroke discharge can occur between the gap of high voltage electrode and low voltage electrode of the special arc protection device. It is also able to effectively lead the arc root of power frequency arc after lightning flashover, protecting the insulated wire from being burnt and broken and making it able to withstand above five times of large current arc burning of power frequency to achieve the expected effect.

1 INTRODUCTION

Since the year of 1980, insulated wire has been widely used in the aerial lines of Chinese distribution network in China. However, the accidents of wire break caused by lightning stroke occur frequently. Take South City Supply Co. of Shanghai Electric Power Co. Ltd. as an example, wire break caused by lightning break occurred 2.78 times per hundred kilometers every year on average based on the statistics from 1998 to 2003. Therefore, only when the problem of wire break caused by lightning stroke is properly solved can we insure safety operation of aerial insulated distribution network. During 2003, Shinan Power Supply Co. of Shanghai Electric Power Co., Ltd., cooperating with China Electric Power Research Institute and Shanghai Electric Porcelain, carried out a research on the protection measures against break of aerial insulated wire of 10 kV distribution network caused by lightning stroke, and successfully developed a combined arc protection device - the arc protection device of FHJ series and the PS—12/4 anti-lightning supporting insulator, which have been put into the operation in electricity network and effectively solved the protection problem of break of insulated wires caused by lightning stroke.

2 ANALYSIS OF WIRE BREAK CAUSED BY LIGHTNING STROKE

The arc developing processes of lightning striking insulated wires and naked wires differ greatly. When the over-voltage of direct lightning or induction lightning acts upon naked wires and causes insulator flashover, the consistent power frequency short current arc moves quickly along the wires in the direction against the power supply, with the arc root running along the wire surface, the arc belly moving forward with arc root and continuously floating in the air under the effect of heat stress. According to the temperature distribution characteristics of arc, when the temperature of arc root reaches the highest degree, the conductor will be burnt most severely while the temperature of arc belly is relatively low with the conductor staying safe generally. Since in the above-mentioned process, the arc root is moving along the wires, therefore, it won’t cause integrated burning of the wires and the probability of wire break caused is very small. The situation differs when the over-voltage of direct lightning or induction lightning acts upon insulated wires, because of the high amplitude and short time(grade kV/μs), it only breakdowns the insulation layer of the insulated wires and causes the insulator surface flashover and ionization of the air between the wires. The true reason of burn-out of insulated wires is the heat produced that is thousands times of the former consistent power frequency short current (grade kV/μs). When the amplitude of the over-voltage of the lightning striking spot is not high enough to breakdown the air between the two phase wires and the insulation layer of the wires at the same time, the electric wave of lightning will move quickly towards the two sides of the pole. Reaching the position near the insulator, it will discharge on iron cross arm and consequently lead to two phase short circuit. The break point of the wire is near the insulator and in the range of 10cm to 40cm.

3 EXISTING MEASURES IN CHINA AND OTHER COUNTRIES

The countries widely using aerial insulated wires globally have adopted different measures to prevent wire break caused by lightning stroke in accordance with their respective research results and operation practice, which can be reduced to two methods as “jamming and leading”. The core of the so-called “jamming” method is to increase the insulation level of the lines as high as possible to decrease flashover possibility of the insulator stroke by lightning and the arc rate of power frequency continuous current. For example, Japan has abundantly adopted limited current eliminating arc angle, i.e., metal oxide lightning arrester with external ring gap in series, and is now making a research on the method of strengthening the wire insulation along the two sides of the insulator and
extending the flashover route of the lightning stroke so as to decrease the power frequency arc rate. The method of “jamming” makes a good effect on prevention but is complex in construction and needs enormous investment. The method of “leading” is to permit certain flashover probability of lightning stroke in the lines while leading the power frequency arc root after flashover caused by lightning stroke to prevent burning of the wires. For example, Finland has adopted flashover protective clamp in the striped insulation layer of the coupling point of the insulator and the wires. Sweden and the United States has adopted the method of stripping a length of insulated wires on the two sides of the insulator and additionally installing an arc-protection clamp\(^{[3]}\). Japan has also adopted discharge clamping porcelain insulator on the stripped segment of the insulation layer in insulator\(^{[0]}\). The method of “leading” is simple with small investment, but local bareness has the defects in seal and insulation.

Domestic applications of aerial insulated wires started relatively late and the research of measures about how to handle the wire break caused by lightning stroke has aroused the attention just in recent years. The power supply departments in Shanghai, Beijing and other cities have successively carried out research and practice on prevention measures of wire break caused by lightning stroke.

4 THE RESEARCH AND DEVELOPMENT OF THE COMBINED ARC PROTECTION DEVICE

The combined arc protection device shall have the ability of positioning the discharge route of the lightning stroke, leading the arc root of power frequency, protecting the insulated wires from being burnt by arc and withstanding certain times of arc burning of power frequency. Therefore, the confirmation of capability parameters of the combined arc protection device shall be decide as follows:

4.1 Confirmation of the enduring current amplitude of power frequency and the time of duration. Because of the short circuit capacity of 10kV bus bars in the area of Shanghai, the chosen virtual value of the short circuit current in the arc test of power frequency is 12.5 kA to cover most of the on-site areas. Accordingly, two kinds of current arc tests of power frequency are chosen, i.e., large current of power frequency with short-time test and small current arc tests of power frequency are chosen, i.e., large current of power frequency with long-time test. The result is listed in Table 2.

Table 1 The 50% of the Discharge Voltage Caused by Lightning Stroke of the Combined Arc Protection Device (kV)

<table>
<thead>
<tr>
<th>Model of the matched insulator</th>
<th>U50% (+)</th>
<th>U50% (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS15</td>
<td>130</td>
<td>185</td>
</tr>
</tbody>
</table>

Over-voltage of lightning stroke is the reason that causes insulation flashover of aerial distribution lines and wire break of insulated wires. The probability calculation of lightning stroke flashover shall take two factors into account: the criterion of insulation flashover and the probability of discharge flashover of the pole-tower protection device caused by induction over-voltage. The former can adopt the value of 50% of the discharge voltage caused by lightning stroke when the protection device is used together with the insulator; the latter can be achieved via calculation (calculation process omitted) taking account the times of lightning stroke flashover in lines per kilometer every year.

In the equation, \( N_s \) stands for the times of lightning stroke flashover in the region, \( S \) stands for the distance, \( U_{50\%} \) is the 50% of the discharge voltage of lightning stroke, \( \gamma \) stands for the falling density of the thunder on the ground, and \( h \) stands for the average height of the lines.

Assuming that the probability of positive lightning stroke is 10\( ^{-5} \), and that of negative lightning stroke is 90\( ^{-5} \), considering the relatively great regional differences and non-uniformity of thunderbolt activity, five times of power frequency arc cauterization of combined arc protection device shall be taken to achieve a good flexibility throughout the country. The result is listed in Table 2.

Table 2 Yearly Limit of the Discharge Flashover of Monobasis Pole Tower Arc Protection Device Caused by induced Over-Voltage of Lightning Stroke (Year)

<table>
<thead>
<tr>
<th>Model of matched insulator</th>
<th>( I_{\text{max}}=80kA )</th>
<th>( I_{\text{max}}=100kA )</th>
<th>( I_{\text{max}}=120kA )</th>
<th>( I_{\text{max}}=300kA )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS15</td>
<td>1337.47</td>
<td>1179.11</td>
<td>1101.80</td>
<td>1006.68</td>
</tr>
</tbody>
</table>
4.3 Design of the combined arc protection device

4.3.1 Figure and principle introduction. FHJ-type arc protection device consists of a hump-like puncturing wire clip and a low voltage pole. The material of the puncturing wire clip is aluminium alloy. Apply a moment wrench to secure the upper two stainless steel bolts with the torque value stated to ensure a close intact between the puncturing insulator and the wire core. Cover the puncturing wire clip with an undersurface uncorked insulating boot to prevent short circuit caused by impurity. The low voltage pole is made of A3 class galvanized plate. During the short circuit caused by lightning stroke, the arc gathers on the orbicular extruding platform of the puncturing wire clip and passes from the undersurface uncorked insulating boot to the arcing short circuit of low voltage pole to protect the insulation wires from being damaged by lightning stroke. For coupling lines between two power supplies, another arc protection device shall be mounted on both sides of every phase insulator. Please refer to the following figure:

Figure 1 Model of FHJ-type Arc Protection Device

Figure 2 Model of PS—12/4 Anti-lightning Supporting Insulator

Figure 3 FHJ-type Arc Protection Device and Insulating Boot Disposed on Both Sides

PS—12/4 anti-lightning supporting insulator consists of a porcelain-exterior strut-type insulator, a discharge clamp accompanying a discharge ring on the tip and a low voltage pole at the root. Aluminum alloy material is adopted at the tip to prevent hysteresis and vortex loss. When the insulated wire layer around the tip of the insulator was stripped, waterproof treatment at the wire core and the insulation layer with AD -- 70 insulating waterproof adhesive tape shall be adopted. Wrap 1-2 layers of aluminum belt and secure the wire tight with a clamp bolt, put on an insulating boot; the low voltage pole is made of Q235 class galvanized plate. During the short circuit caused by lightning stroke, the arc gathers around discharge clamp and the discharge ring. It can emit energy from the undersurface uncorked insulating boot to the low voltage pole with a simultaneous arcing short circuit so as to protect the insulated wires from being burnt by lightning stroke; as the low voltage poles can be fixed symmetrically on both sides of the insulator, the lightning protection effect won’t be influenced even for the coupling lines between two power supplies. Please refer to the following figure:

Figure 4 PS—12/4 Anti-lightning Supporting Insulator

5. ARC ENDURANCE VERIFICATION TEST

5.1 Discharge route verification. Apply a standard lightning stroke voltage on single-phase insulated wire to the insulator (the voltage is educed from sample tests). Gradually increase the voltage from 50% of the stroke discharge voltage and carry out 5 tests to every discharge spot correspondingly. It is found that nearly all of the lightning stroke flashover occurs between the high voltage electrode and low voltage electrode by observing and recording the discharge routes. Therefore, the average discharge voltage and average discharge time can be educed and the volt per second characteristic curve of stroke discharge and the picture of typical discharge route can be made. Please refer to Figure 5.

5.2 Heat stabilization verification. Since FHJ-type arc protection device is connected with the insulated wire via puncturing, the focus is put on whether the wire core can be kept completed after the arc burning. In order to verify the effect of the test is carried out for 5 samples made of insulated wire with the section of 70mm², 120mm² and 185mm² on the basis of extensive measuring tests of packing force and contact resistance. Refer to Figure 6 for test wiring and Table 3 for test
result. Refer to Figure 7 and Figure 8 respectively for typical test current oscillogram. After the test, strip the insulation layer of the sample respectively and inspect the wire core. There is no damage on them!

<table>
<thead>
<tr>
<th>Wire section [mm²]</th>
<th>Sample number</th>
<th>Heat stabilization current [kA]</th>
<th>Time of duration [s]</th>
<th>Typical current wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>1</td>
<td>10.2</td>
<td>0.991</td>
<td>Figure 7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10.1</td>
<td>0.980</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>12.6</td>
<td>0.980</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>4</td>
<td>15.6</td>
<td>0.987</td>
<td>Figure 8</td>
</tr>
<tr>
<td>185</td>
<td>5</td>
<td>20.4</td>
<td>0.977</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Result of Heat Stabilization Test of Protection Device

In order to verify the burning degree and protection effect for the wire of larger short-circuit current arcing, after 5 times of tests of arc endurance of power frequency short-circuit current for each combined arc protection device, and implementation of other tests for FHJ-type arc protection device of 20kA, 0.23 S, 1 time and PS-12/4 anti-lightning supporting insulator 16kA, 0.3 S, 3 times and 20kA, 0.2 S, 2 times etc., the burning degree of combined arc protection device is more serious than that with the virtual value of 12v.5 kA of short-circuit current, with the insulated wire protected in good condition. As showed in the figure:

5.3 Verification of arc endurance of power frequency  
The purpose arc test of power frequency is to verify whether the arc root of power frequency continuous current can burn with fixed position between the high voltage electrode and low voltage electrode of the arc protection device after occurrence of lightning stroke flashover, check the burning degree of the insulating boot, the high voltage electrode and low voltage electrode, and check the protective effect of insulated wire against burning.

Through arc endurance test for power frequency short-circuit current of combined arc protection device (please refer to Figure 9 and 10), we can find that under the mode of two-way installation, even if the arc originates from the power side, under the electromagnetic force, the arc root will move to the loading side along the aluminum tied line and burn on the high and low voltage electrode of the loading side of the arc protection device, (insulating boot won't affect the protection effect), and it can effectively protect the insulated wire from being burnt and broken. The test has proved that the theoretic assumption is correct!

In order to verify the burning degree and protection effect for the wire of larger short-circuit current arcing, after 5 times of tests of arc endurance of power frequency short-circuit current for each combined arc protection device, and implementation of other tests for FHJ-type arc protection device of 20kA, 0.23 S, 1 time and PS-12/4 anti-lightning supporting insulator 16kA, 0.3 S, 3 times and 20kA, 0.2 S, 2 times etc., the burning degree of combined arc protection device is more serious than that with the virtual value of 12v.5 kA of short-circuit current, with the insulated wire protected in good condition. As showed in the figure:

6. INTEGRATE PRECAUTION

Since the occurrence of the break of insulated wire caused by lightning-stroke depends on many factors after lightning stroke, it seems incomprehensive and incomplete to apply only one method for the precaution.
Therefore, we must make selections according to the actual situation on site:

- In order to prevent insulated wire from being broken by lightning stroke, one combined arc protection device shall be equipped on every electrical pole; considering that the line condition of 10kV split-phase insulated wire, PS□—12/4 anti-lightning supporting insulator and FHJ-type arc protection device are recommended.

- Water-block insulated wire matched with combined arc protection device shall be selected for the newly-built line of 10kV split-phase insulated wire to avoid accidents of break caused by stress and lightning stroke.

- The distance between the existing 10kV split-phase insulated wires shall be about 40cm, 60-70cm and disposal of a triangle device are recommended to reduce odds of lightning stroke arc.

- 10kV zinc oxide arrester is recommended for dead-end pole and end pole, etc.

- 10kV aerial insulated stand cable can be selected to avoid going through of regions of residential houses, architectural complex and virescence where the distance is limited with aerial insulated line as the only choice for the power supply. Original switchgroup is developed and tried on the line of 10kV split-phase insulated wire; when lightning stroke causes short circuit, the switch group closes and misalign (the function of outlet switch trip and superposition of the transformer substation stays the same); then it is trial transmitted and checked for exceptional conditions such as open-phase or earthing on the back line of the switch; the power will be cut as soon as exceptional conditions are found, which can avoid effectively accident of electric shock after break of insulated wire caused by lightning stroke.

**REFERENCE**


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