ANALYSIS AND SIMULATED RESEARCH OF TOWER COLLAPSE BY ICE DISASTER OF HUNAN IN 2008

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Abstract: The damage of the transmission lines in Hunan during the 2008 ice storm is surveyed and the main causes of the tower collapses and line failures are analyzed. It is found that the situation may be worsened by the nonhomogeneity of the ice accretion due to microtopography and micrometeorology conditions, span distance, and the imbalanced tension caused by vertica1 load. Meanwhile, simulation models of power transmission line and tower using finite element method have been proposed and developed. It is pointed out that great differences of span and angle of height are the main factors which cause unbalanced tension and make tower falling down. The computation results of 500 kV Fusha line I show the finite element method is very effective.

1. INTRODUCTION

Under the influence of cold and warm air, there were four clear processes of rain and snow weather in Hunan from 01-11 to 02-07 at the beginning of 2008. The influence by long duration sleet and freezing weather to Hunan grid is disastrous. For the duration of ice disaster, Hunan grid was broken many times and there was large areas power failure in Hengyang, Chenzhou. It resulted in the most serious thread to Hunan grid since the memory of man. The direct economic loss reached several billions Yuan.

2. RESULTS AND DISCUSSION

The reasons for tower collapse and conductors breakage are summarized as follows:

1) The ice accretion thickness is far beyond the design standard.
2) The increase of ice accretion thickness and unbalance caused by microtopography and micrometeorology.
3) The tower is crushed by the vertical load.
4) Towers are damaged by unbalanced tension.
5) The impact load caused by conductors and string breakage.
6) Tower material and conductors become tired under long-term overload.

The model of finite element calculation is proposed and developed. It is pointed out that great differences of span and angle of height are the main factors which cause unbalanced tension and make tower falling down.

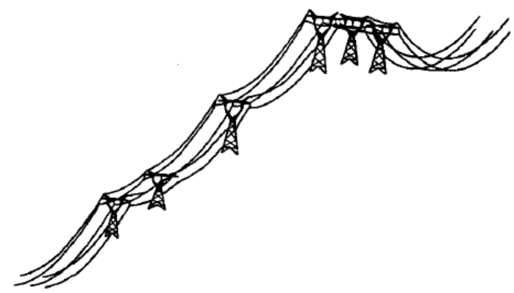

Figure 1: Transmission system's finite element model of Fusha line I

Table 1 Unbalanced tens ion of the #16～#21 transmission tower at critical point

KN

NO	#16	#17	#18
wire	−8.150×3	−1.050×3	−4.630×3
Ground wire	−4.383	0.967	0.088
cable	−4.526	1.179	0.314
resultant force	−33.359	−1.004	−13.568
NO	#19	#20	#21
wire	−4.900×3	4.180×3	12.8×3
Ground wire	−5.692	1.079	8.675
cable	−6.130	0.923	9.285
resultant force	26.522	14.542	56.360

3. CONCLUSION

Great differences of span and angle of height differences is the main reason for unbalanced tension. Unbalanced tension is the main reason for tower collapses.

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Keywords- Power Tower Collapse; Ice Disaster of Hunan in 2008; Analysis of Tower Collapse Reason; Simulation.

I. INTRODUCTION

Under the influence of cold and warm air, there were four clear processes of rain and snow weather in Hunan from 01-11 to 02-07 at the beginning of 2008. The influence by long duration sleet and freezing weather to Hunan grid is disastrous. There were 182 collapsed towers in fourteen 500kv transmission lines. 75 towers were deformed, 159 pieces of conductors and 322 pieces of ground wire were either broken or damaged. There were 679 collapsed towers in forty-four 220kv transmission lines and 1864 collapsed towers in 121 110kv transmission lines. In addition, there were 64000 collapsed telegraph poles in transmission lines (≤35KV), more than 50000 pieces of conductors were broken. 330000 telegraph poles were collapsed; about 370000 pieces of conductors were broken in low-voltage transmission lines. For the duration of ice disaster, Hunan grid was broken many times and there was large areas power failure in Hengyang, Chenzhou. It resulted in the most serious thread to Hunan grid since the memory of man. The direct economic loss reached several billions Yuan [1].

II. ANALYSIS OF COLLAPSED TOWERS IN 220KV AND OVERHEAD TRANSMISSION LINES

A. *Analysis of Collapsed Towers Features*

(1) Influence of design standards

There were 182 collapsed towers in 500kv transmission lines, 176 towers among collapsed towers are designed by 15mm ice accretion thickness.6 towers designed by 20mm is centered in Jiangcheng DC line. Towers designed by 30mm were not collapsed. The ice accretion thickness of collapsed towers is shown in Figure 1.

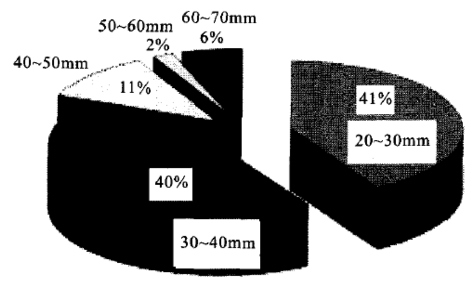

Fig.1 Distribution of ice thickness on the failed lines

There were 427 collapsed towers in twelve 220kv transmission lines, only one tower is designed by 20mm ice accretion thickness, the rest are all 15mm.The ice accretion thickness on the collapsed towers mostly fall in the range of 20~ 40mm.

(2) Influence of span distance

The span distance of most collapsed towers is more than 300m.In 500kv transmission lines, the span distance falls in the range of 300～500m, differences of span is less than 200m.In 220kv transmission lines, span distance is centered mainly in the range of 200～500m, differences of span is less than 300m.

(3) Influence of microtopography, micrometeorology and altitude

Microtopography, micrometeorology is closely related to ice accretion thickness and collapsed towers. The collapsed towers is centered mainly in an altitude less than 400m, the maximum quantity falls in the range of 100～200m(40%).It is relevant to passageway of transmission lines.

The recorded data about the ice disaster are obviously different comparing the information provided by the special monitoring system for ice disaster and the normal observing system for the meteorological phenomena. Microtopography and micrometeorology make local temperature lower and ice accretion thicker. In the same area, different locations present dissimilar meteorological phenomena parameter. The equipment for supplying electricity is obviously affected in this situation for examples the northern slope at the mountain, a place where there is a current of air and where steps ascend to a higher position.

B. The Main Types of Collapsed Towers

(1)Collapse under pressure

500kV Heyun Ⅱline is located at the area of Chang-Zhu-Tan, which belongs to the most suffering place. The ice thickness covering #94 tower in Heyun Ⅱline average 60mm and be up to 80mm. The ice thickness covering conducting wires and ground wires is up to 30mm. The falling of #94 tower is typically owned to the reason that the ice covering on the tower, the conducting wires, the earth wires and the insulation object is too thick compared to the designed level because of which the preceding and following towers are also distorted.

(2) Collapsed towers by unbalanced tension caused by ice accretion covering two sides of the conducting

Because of the distance between the two sides of the conducting wire is different, in the case of ice covering the pressure between the two sides of the conducting wire is also dissimilar.[2] It is the difference that may fall the tower pole down. This type of falling is common for example the falling cases between #979 tower and #983 tower in Jiangcheng line , in which the insulation object is totally covered by the ice accretion and the thickness of the conducting wires is more than 30mm and the tower pole whose average is more than 40 is up to 100mm. The distance between the preceding and the following tower pole of #983 is up to 722m, which make the unbalanced pressure which cause the falling case. #983 tower fell down forward to large side (span distance is greater), drawing the adjoining tower poles of #982、#981、#980、#979 down(Figure 2).

Figure 2 Ice thickness on the Jiangcheng-line failure

(3) Dragged by the adjacent tower which falls down.

This type of falling is also common but it causes the most cases.

Wumin line ＃430～＃440 belongs to one part of tension section. The preceding distance of ＃430 is 647m, the following distance is only 183m, and the difference is 464m. The thickness of ice accretion covering the conducting wires and earth wires is more than 30mm, which causes the unbalanced pressure that makes the tower pole of #430 fall down toward to large side and #431～#439 fall down toward to large side. #440 also fall down toward to large side because of the unbalanced pressure. According to the information collected from the falling scene, one based tower pole fell down then dragged others down, which is more than 80 percents in the cases of tower pole falling.

(4) The conductor’s breakage causes the tower falling down

During the ice accretion disaster, the earth wires were seriously disconnected, that made the tower pole suffer unbalanced pressure. #23、#33 in Xiangyun Ⅰ/Ⅱline were distorted, the #25 fell down to #24, the core pole of the synthetic insulation object is broke off, #24 fell down to #23, and #23 is tension tower. In addition, #26 whose head part gone off fell down to #27, #27～ #32 fell down to large side, some tower poles were broke off in the middle part for example #27，some were broke off in the head part for example #26 and #28, and disconnection appeared between #25 and #26.

(5) Towers distort by string breakage and adjacent towers fall down

String breakage appeared at #6 in Xiangyun line, and the following shocking pressure conducted to the adjacent tower pole then broke off the cross arm. The falling of #4、#5、#7 and #8 were affected by string breakage of #6

C. The Reasons for Tower Collapse and Conductors Breakage

(1) The ice accretion thickness is far beyond the design standard.

(2) The increase of ice accretion thickness and unbalance caused by microtopography and micrometeorology.

(3) The tower is crushed by the vertical load .This is one of the most important reasons for the damaged towers as well as for the clusters of collapsed towers.

(4) Towers are damaged by unbalanced tension. The unbalanced tension caused by ice cladding that includes vertical and horizontal tension, which is a main reason for collapsed towers and conductors breakage. Meanwhile, because of the traction caused by adjacent collapsed towers, a lot of unbalanced tension acted on towers, which result in clusters of collapsed towers. This type of collapsed towers is in the majority [3].

(5) The impact load caused by conductors and string breakage that damage the towers besides, it badly twist the towers and also cause damage to the adjacent towers.

(6) Tower material and conductors become tired under long-term overload, which would cause collapsed towers and conductors breakage. Some towers would be damaged in the process of melting ice, there are two reasons: one is at the result of fatigue, the other would be the unbalanced tension that caused by melting ice.

III. FINITE ELEMENT CALCULATION OF ICE ACCERTION ON POWER TOWER AND LINES

A. Structural Model of Towers and Lines

The model of tower is analyzed by thin-walled beam unit, meanwhile, influence of node stiffness link, geometrical and nonlinear material are taken into consideration.

Distance between two suspension points of overhead wires is long, Stiffness of material had little side effects on geometric shape of overhead wires, so the catenary's model is adopted. [4]

Designed ice accretion thickness of calculation segment in Fusha Ⅰ line is 15mm,20mm is used to check. Model of tower can be created by beam element; cross section of beam element is "L". [6]Model of lines, ground wire and cable can be created by cable element based on catenary's equation.[5] The model of finite element is shown in Figure 3.Calculation units is mm and kg.

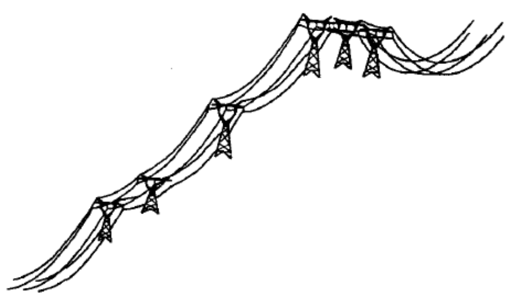

Figure.3 Transmission system 's finite element model of Fusha line I

B. Finite Element Calculation

According to actual measured climatic conditions of calculation segment in Fusha Ⅰ line**(**temperature $0^{\circ}C$,wind speed 2 m/s), with the increase of ice accretion thickness **d**, effect of unbalanced tension on towers can be calculated.

The maximum compressive stress of towers is $p_{\max}$ by calculation. Variation of $p_{\max}$ with **d** is shown in Figure 4, dashed line correspond to yield limit of towers. As shown in Figure 4, when **d**=20.6mm, the $p_{\max}$ of tower achieves yield stress**.** With the **d** going up**,** $p_{\max}$ of # 19 tower achieves yield stress**.** When **d** is close to 25mm, $p_{\max}$ of # 18tower achieves yield stress**.** When **d**=30mm,the strength of #16, #l7 and #20 meet the demand.[7]

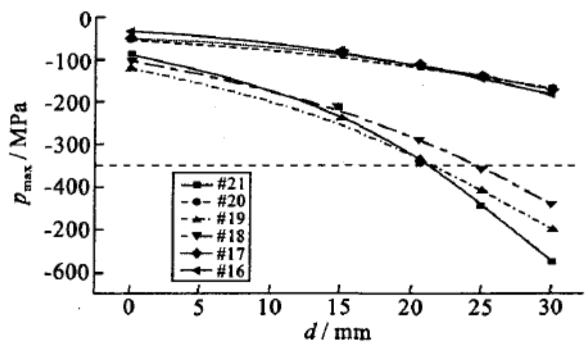

Figure 4 Transmission tower's maximum compressive stress varied with the ice thickness

When d=20.6mm, unbalanced tension of transmission lines, ground wires and cable acting on towers is shown in List 1 （positive number points to large side, negative number points to small side）. $p_{\max}$ of ＃21 tower is shown in Figure 4.

As shown in List 1， when **d**=20.6mm, unbalanced tension of ＃21 tower is 56.36kN, compressive stress acting on main materials at the bottom of crank web is 345Mpa，**,** it collapsed ＃21 tower closed to large side, then**,** ＃20、＃l9、＃18、and ＃17 towers were pulled down in turn. Because 33.359KN opposite-direction unbalanced tension acts on ＃l6tower，most tension by dilapidated ＃17tower is offset, the unbalanced tension resistance is strong.＃l6tower merely produces local deformation.

Table 1 Unbalanced tens ion of the #16～#21 transmission tower at critical point

KN

NO	＃16	＃17	＃18
wire	－8.150×3	－1.050×3	－4.630×3
Groud wire	－4.383	0.967	0.088
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Groud wire	－5.692	1.079	8.675
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resultant force	26.522	14.542	56.360

Great differences of span and angle of height differences is the main reason for unbalanced tension. If the span distance differences of tower both front and back is great, the tension differences of wires and the unbalanced tension acting on tower are great .If angle of height differences of tower is great, tension along horizontal direction of wires decreases and differences of tension along horizontal direction increases. On the other hand, it results in increase of span distance along vertical direction, the vertical load of tower accordingly increases.

Unbalanced tension is the main reason for tower collapses. When towers is in lines whose span distance or angle of height differences is great, unbalanced tension acting on towers increases with **d**. When stress of tower caused by unbalanced tension achieves yield strength of material, towers will collapse; adjacent towers will be pulled down accordingly. **[8]**

IV. CONCLUTION

The frozen weather of Hunan province in the beginning of 2008 last a long time and affect a broad southern country accompanying with rainfall, which caused the ice accretion on the electricity supplying circuit. Because of the effect of microtopography and micrometeorology the thickness of the ice accretion is more than the designed level that make the strong vertical tension and unbalanced pressure which is the main cause of the tower pole falling and the disconnection of electricity circuit.

In order to deal with the frozen weather disaster, some emergency programs should be improved, the designed level of ice covering should be 20mm at easily affected area, the smallest skeleton frame should be constructed, the researching and applying work for ice melting and monitoring should be quicken, the electricity supplying volume at main circuit should be raised in case of conducting wires frozen, and the monitoring work of microtopography and micrometeorology and drawing work of ice area distribution should also be done.

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