# Study on the icing process of transmission lines and the local meteorological parameters

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*Abstract*—**Meteorology is an important factor to the icing of power system. The study on meteorology and icing was delayed for absence of the effective scene icing data. An On-line Monitoring System of Transmission Line Conductor Icing Based on GSM SMS was designed and produced, by which the local meteorology, such as temperature, humidity, wind speed, wind direction, rain and snow, air pressure etc., and the icing status, such as gravity of the iced conductor, the thickness of icing coating, the frequency of gallop etc. can be measured in time. The study on meteorology and icing was made based on the scene icing data. The results show that the formation and dropping of icing of transmission lines was related to the special meteorology, such as the temperature between -10℃and 0℃, the humidity large than 80%, the wind speed less than 10m/s, and the stationary wind direction, that reliability of forecasting icing is very poor according to a single meteorology, and the error is very large. The error is 248% when the temperature is used only to forecasting icing. The accuracy, error, failure of forecasting icing is 67%, 18% and 39% when some meteorology are used together. The accuracy, error, failure of forecasting icing is 86%, 13% and 3% when the fuzzy theory is used.**

## I. INTRODUCTION

Transmission line icing is one of the serious problems which destroy the safe operation, and the ice disasters around the world happened frequently [1,2] for the micro-climate and topography, micro-meteorological conditions. Meteorological parameters have a decisive influence on the power system icing. In recent years, Russia, Canada, the United States, Japan, Britain, Finland and Iceland started the study, such as the relationship between icing line and meteorological factors[3]: Japan carried out in a wind tunnel test facilities for research, by which the unit time of the snow around the wire weight (distribution), wind speed, humidity, temperature, snow in the liquid water content, unit weight of snow on the length of wire, wire rotation angle, test duration , as well as working conductor parameters such as surface temperature can be measured, and the analysis of the impact of meteorological parameters on icing and snowing[4] can be made. EA technology companies in United Kingdom developed a monitoring system of predicting the ice load based on meteorological models, and through analysis of the winter monitoring data from 2004 to 2005 they found that when the temperature, wind direction and the Gerbers (liquid water content) are in the icing conditions, the icing condition can be confirmed by the force sensor, when one of the three factors did not in any freezing condition, the no-icing condition by the force sensor[5]. In the past 15 months in winter (November 1989 -2004 in May), Japan has collected the ground data of air water coagulation, and the environmental data (including air temperature, relative humidity, wind speed, air pressure and precipitation volume, etc.) from 153 weather stations. They analyzed the regional distribution of freezing rain and hail occurred in Japanese. In November 2000, Southwest Electric Power Design Institute of China started the observation of the icing by 8 icing observing stations built from Yichang Sandouping Shihmen Township line, the meteorological parameters for the ground wire icing were observed and the effect of meteorological factors on icing was analyzed, the meteorological factors variables include the continuous-time fog, effective ice time, rainfall, the effective average wind speed, the average ice humidity, vapor pressure variation, temperature variation, the greatest snow depth, wet-bulb temperature variation, etc.[6]. Dr. Makkonen of Finland studied the relationship of the air humidity and icing, and found that the air relative humidity is regularly greater than 100% in icing conditions.

In short, the meteorological data are from meteorological stations, and icing data from observation of the human eye in the above-mentioned study, by which the icing weather data has poor consistency relation to the real-time data, the variation in icing can't accurately measured in a short period of time, and the accuracy on studying the relationship between line icing and the meteorological factors is low. Author has developed an on-line monitoring system of transmission line icing, by which the micro-meteorological conditions ( such as the temperature and humidity, wind speed, wind direction, rain and snow, as well as air pressure, etc.) and the icing conditions (icing conductors of gravity changes, insulator angle of inclination, wind angle, the frequency of conductor galloping, etc.) can be measured and calculated at the same time. In this paper a preliminary study on the relationship between the weather conditions and icing data monitored by the on-line monitoring system of transmission line icing is made.

## II. INTRODUCTION TO MONITORING POINTS

According to the requirements of Shanxi Xinzhou Power

Supply Branch, two on-line monitoring apparatus of transmission line icing were equipped in the NO.109 and NO.108 towers of Shenyuan First Return. Then the surrounding environment and the icing status around the tower can be monitored timely, and the sampling time interval can be changed from the 5min to 1 week by GSM SMS. The corresponding information of towers are shown in Table I.

TABLE I
INFORMATION OF MONITORING POINTS IN SHENYUAN FIRST RETURN

| Monitoring points | height difference of the tower and the smaller tower nearby (m) | height difference of the tower and the larger tower nearby (m) | span of the tower and the smaller tower nearby (m) | span of of the tower and the larger tower nearby (m) | wire length of the tower and the smaller tower nearby | wire length of the tower and the larger tower nearby (m) |
|---|---|---|---|---|---|---|
| 109# | 34.54 | 61 | 190 | 309 | 199.5 | 32[illegible] |
| 108# | 24.64 | 34.54 | 138 | 190 | 145 | 199.5 |
| Monitoring points | Equivalent wire diameter (mm) | Wire elasticity modulus (MPa) | Wire tensile strength (MPa) | The main tower type | Insulator type | Voltage Level (KV) |
| 109# | 18.88 | 76000 | 168 | Straight-line | Suspension | 220 kV |
| 108# | 18.88 | 76000 | 168 | Straight-line | Suspension | 220 kV |
| Monitoring points | Wire density (N / m) | Conductor cross-sectional area (mm) | Split number of Wire | Design icing thickness (mm) | | |
| 109# | 7.326 | 210.93 | Single | 10 | | |
| 108# | 7.326 | 210.93 | Single | 10 | | |

## III. INTRODUCTION OF ON-LINE MONITORING SYSTEM OF TRANSMISSION LINE ICING

### *A. Working Principle*

The whole system consists of the provincial monitoring center, the municipal monitoring center, the online monitoring unit and expert software etc., and the system topology is shown in Figure 1. The on-line remote-monitoring system of transmission line insulator contamination based on GSM SMS communication net is firstly produced. One on-line monitoring unit is placed on every transmission line tower, which can timely measure the above parameters of icing such as the environment temperature, the humidity, the wind velocity, the wind direction, the rainfall, the deviation angel of insulators for wind, the deflection angel of insulators etc.. By GPRS/CDMA/3G communication net, both the system time and the sample interval of the monitoring unit can be modified remotely according to the command far away from the municipal monitoring center. The municipal monitoring center can estimate the icing status by analyzing the data from the measured towers, which can also remotely modify the running parameters of very online monitoring unite by GPRS/CDMA/3G communication net. The municipal monitoring centers are connected to the corresponding provincial center by LAN, which can directly determine the conductors icing and galloping status of all transmission lines in the province by receiving the force, the angel, the galloping frequency, the temperature, the humidity, the wind speed, and the rain fall of some towers from every municipal center. The modified theoretical modal, experimental results and running results are used to determine the status of icing and galloping of conductors by the expert software and the alarm model. The expert software can intelligently draw the force, the frequency, the wind speed and the stress figure corresponding to time, and give out an alarm message of clearing ice.

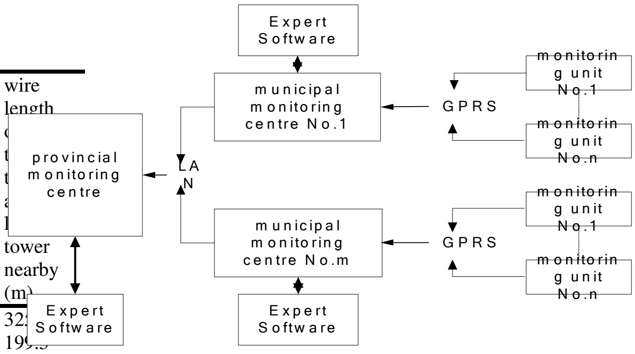


Fig.1 System topology

### *B. The Main Technical Indicators of the System*

The design of icing online monitoring system detailed in the literature [7], the main technical indicators are as follows:

Transmission distance: GPRS / GSM signal coverage area;

Sampling time interval: the smallest 5min and up to 1 week;

Force measurement range: 0 ~ 30 tons; measurement accuracy: ≤ 0.3%;

Tower load force range: 0 ~ 30 tons; measurement accuracy: ≤ 1%;

angle range: -75 ° ~ +75 °; measurement accuracy: ≤ 1%;

Icing thickness range :0-200mm; accuracy: ≤ 3%;

Temperature measuring range: -40 ℃ ~ +60 ℃; measurement accuracy: ≤ 1%;

Humidity measuring range: 0 ~ 100%; measurement accuracy ≤ 1%;

Wind speed measurement range: 0 ~ 35 m / s; measurement accuracy ≤ 0.5m / s;

Wind direction measuring range: 0 ~ 360 °; wind direction measurement accuracy: 3 °;

Rainfall measuring range: 0 ~ 8mm/min; rainfall measurement accuracy: 0.25mm/min;

Air pressure measurement accuracy: ± 0.4mbar;

The scene installation of on-line monitoring system of transmission line icing is shown in Fig.2

Fig.2 The scene installation

### C. *Calculation of Equivalent Ice Thickness*

According to the whole load $q$

$$q=\frac{2\Delta T_V}{S_{D1}^{AB}+S_{D1}^{AC}}=\frac{2\Delta T_V}{\frac{2T_H^{AC}}{q_0}sh\frac{l_{D1}^{AC}q_0}{2T_H^{AC}}+\frac{2(T_H^{AC}+T_V\,tg\theta)}{q_0}sh\frac{l_{D1}^{AB}q_0}{2(T_H^{AC}+T_V\,tg\theta)}} \quad (1)$$

Where, $q$ is the whole load, $\Delta T_V$ is the difference between the whole load and the wire weight, ice, $\theta$ is the insulator string tilt angle on the main tower, $S'$ is the wire length under the self-load, $S$ is the wire length under self-load at the temperature of -5 ℃, $\alpha$ is the linear temperature expansion coefficient of the wire, 1/℃.

$$q=q_0+q_{wind}+q_{ice} \quad (2)$$

Here, $q_{ice}$ is the icing load of the wire, $q_0$ is the self-load of wire, $q_{wind}$ is wind load. To calculate the icing load $q_{ice}$, we must first solve the wind load $q_{wind}$。

$$q_{wind}=0.735a(d+2b)v^2 \quad (3)$$

Here, $c$ is the wind vector-type factor, $a$ is the non-uniform coefficient of wind speed, v is the design wind speed (m / s), $d$ is the Calculated diameter of wire, $b$ is the ice thickness. For the ice thickness $b$ is unknown, $(d+2b)\approx d\cdot k$ is supposed, and k is the correction factor.

According to the calculated icing load $q_{ice}$, the ice thickness can be calculated based on the density of ice （0.9g/cm$^3$） and the wire diameter. According to the standards set for the homogeneous ice cylindrical shape in power system 7], a standard solution of the icing thickness can be got:

$$b=(\sqrt{\frac{4q_{ice}}{9.8\pi\gamma_0}+d^2}-d)/2 \quad (4)$$

here, $\gamma_0$ is the ice density (the rain song), $d$ is the calculation of equivalent diameter wire, $b$ is the icing thickness。

## IV. THE SCENE MONITORING DATA OF ICING WIRE

In February of 2006, the on-line monitoring system of transmission line icing were installed in Shanxi Xinzhou Power Supply Branch, and they are well-functioning at present. Figure 3 gives 4496 meteorological and icing monitoring records from February 1 to May 1 in 2007. A serious icing disaster happened during February 28 to March 1, from the February 27, the vertical load tower B rapidly increased from 1.8 tons to more than 2.8 tons, the equivalent icing thickness reached 16.38 mm(where the icing density of 0.9g/cm$^3$ is set). A recent icing disaster appeared on April 16, 2007, the vertical load rapidly increased to more than 1.9 tons, and the equivalent icing thickness arrived at 6.7 mm.

In order to analyze the relationship between icing and meteorological parameters, one day data collected on the scene from April 1 to 25 in 2007 is shown in Table 2 and the sampling interval is one day. One hour data from pm 8:52:00 on Februaray 27 to PM 12:05:00 on March 1 is shown in Table 3. 7 minutes data from AM 6:43:00 to AM 7:43:00 on March 1 is shown in Table4.

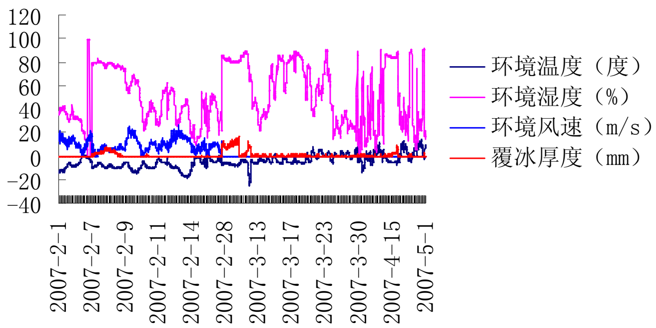


Fig. 3 the meteorological and icing data from February 1 to May 1 in 2007

TABLE 2. ONE DAY DATA COLLECTED FROM APRIL 1 TO 25 IN 2007 (INTERVAL 1DAY)

| Time | Vertical load (N) | Temperature (□) | humidity (%) | wind speed (m / s) | Wind direction | Rainfall （mm） | Air pressure （MPa） | Ice thickness （mm） |
|---|---|---|---|---|---|---|---|---|
| 2007-4-10 | 13876.96 | 2 | 16 | 2 | South | 0 | 828.06 | 0 |
| 2007-4-11 | 14211.92 | 2 | 47 | 3 | Southwest | 0 | 824.17 | 0 |
| 2007-4-12 | 13733.41 | 3 | 58 | 1 | North | 0 | 824.88 | 0 |
| 2007-4-13 | 14140.15 | -3 | 41 | 0 | North | 0 | 826.37 | 0 |
| 2007-4-14 | 14020.52 | 0 | 28 | 0 | South | 0 | 825.34 | 0 |
| 2007-4-15 | 15228.77 | -5 | 84 | 3 | South | 0 | 822.48 | 1.7056 |
| 2007-4-16 | 19798.6 | -5 | 87 | 2 | South | 0 | 825.91 | 6.7629 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2007-4-17 | 14283.7 | -3 | 43 | 8 | North | 0 | 828.46 | 0 |
| 2007-4-18 | 13829.11 | 0 | 37 | 0 | Southwest | 0 | 821.88 | 0 |
| 2007-4-19 | 13410.41 | 7 | 24 | 1 | Southwest | 0 | 823.48 | 0 |
| 2007-4-20 | 13290.78 | 6 | 42 | 0 | South | 0 | 823.25 | 0 |
| 2007-4-21 | 14271.74 | 8 | 24 | 1 | South | 0 | 825.54 | 0 |
| 2007-4-22 | 13685.56 | -2 | 21 | 0 | North | 0 | 819.73 | 0 |
| 2007-4-23 | 13912.85 | -1 | 54 | 0 | North | 0 | 827.17 | 0 |
| 2007-4-24 | 14439.22 | -3 | 90 | 2 | North | 0 | 827.06 | 0 |
| 2007-4-25 | 13805.19 | 1 | 27 | 0 | North | 0 | 824.88 | 0 |

TABLE 3 ONE HOUR DATA COLLECTED FROM FEB 27 TO MARCH 1 (INTERVAL 1HOUR)

| Time | Vertical load (N) | Temperature (□) | humidity (%) | wind speed (m / s) | Wind direction | Rainfall （mm） | Air pressure （MPa） | Ice thickness （mm） |
|---|---|---|---|---|---|---|---|---|
| 2007-2-27 pm 08:52:00 | 17310.32 | -6 | 85 | 7 | South | 0 | 821.56 | 4.2772 |
| 2007-2-27 pm 10:10:00 | 17477.8 | -7 | 85 | 5 | South | 0 | 826.83 | 3.6855 |
| 2007-2-27 pm 11:12:00 | 18865.49 | -6 | 84 | 7 | South | 0 | 821.33 | 4.4416 |
| 2007-2-28 am 12:15:00 | 18925.31 | -8 | 84 | 5 | South | 0 | 827.06 | 5.0654 |
| 2007-2-28 am 01:17:00 | 19439.71 | -8 | 84 | 5 | South | 0 | 826.14 | 6.2068 |
| 2007-2-28 am 02:19:00 | 20444.6 | -7 | 85 | 5 | South | 0 | 825 | 5.5905 |
| 2007-2-28 am 03:21:00 | 20229.26 | -8 | 85 | 4 | South | 0 | 822.25 | 6.6908 |
| 2007-2-28 am 04:23:00 | 21569.11 | -7 | 85 | 1 | South | 0 | 826.14 | 10.2274 |
| 2007-2-28 am 05:25:00 | 21700.7 | -7 | 85 | 3 | South | 0 | 823.17 | 7.7494 |
| 2007-2-28 am 06:27:00 | 22693.62 | -6 | 85 | 5 | South | 0 | 826.63 | 7.1373 |
| 2007-2-28 am 07:29:00 | 23578.88 | -8 | 85 | 6 | South | 0 | 823.17 | 10.9773 |
| 2007-2-28 am 08:33:00 | 23985.62 | -6 | 84 | 5 | South | 0 | 823.91 | 9.8333 |
| 2007-2-28 am 09:37:00 | 23734.39 | -6 | 83 | 5 | South | 0 | 826.66 | 9.5603 |
| 2007-2-28 am 10:41:00 | 23028.58 | -6 | 83 | 4 | South | 0 | 822.25 | 9.0148 |
| 2007-2-28 am 11:45:00 | 19296.16 | -6 | 82 | 3 | South | 0 | 827.29 | 5.9754 |
| 2007-2-28 am 12:49:00 | 19415.79 | -6 | 82 | 7 | South | 0 | 822.65 | 5.7246 |
| 2007-2-28 pm 01:46:00 | 19643.08 | -6 | 82 | 4 | South | 0 | 825 | 6.4557 |
| 2007-2-28 pm 02:45:00 | 20217.3 | -7 | 82 | 3 | South | 0 | 824.83 | 6.5489 |
| 2007-2-28 pm 03:49:00 | 20540.3 | -7 | 82 | 3 | South | 0 | 825.74 | 6.7114 |
| 2007-2-28 pm 04:53:00 | 21293.96 | -6 | 82 | 2 | South | 0 | 824.08 | 7.0649 |
| 2007-2-28 pm 06:59:00 | 22717.55 | -7 | 83 | 2 | South | 0 | 825.23 | 8.5036 |
| 2007-2-28 pm 08:03:00 | 23734.39 | -7 | 81 | 1 | South | 0 | 823.11 | 11.04 |
| 2007-2-28 pm 09:07:00 | 24535.91 | -7 | 80 | 3 | South | 0 | 823.39 | 8.7439 |
| 2007-2-28 pm 10:10:00 | 24799.09 | -7 | 80 | 3 | South | 0 | 823.11 | 13.3491 |
| 2007-2-28 pm 11:14:00 | 24739.28 | -7 | 80 | 3 | South | 0 | 822.16 | 10.9236 |
| 2007-3-1 pm 12:18:00 | 25564.72 | -8 | 81 | 3 | South | 0 | 824.8 | 10.565 |
| 2007-3-1 pm 01:20:00 | 26605.49 | -7 | 80 | 2 | South | 0 | 825.91 | 12.1595 |
| 2007-3-1 pm 02:23:00 | 27466.82 | -8 | 80 | 3 | South | 0 | 823.17 | 10.6422 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2007-3-1 03:27:00 | pm | 27478.78 | -8 | 80 | 3 | South | 0 | 827.54 | 9.487 |
| 2007-3-1 04:28:00 | pm | 27610.37 | -8 | 80 | 4 | South | 0 | 827.57 | 10.2115 |
| 2007-3-1 05:32:00 | pm | 27921.41 | -8 | 80 | 7 | South | 0 | 825.23 | 10.9342 |
| 2007-3-1 06:36:00 | pm | 28112.81 | -8 | 81 | 10 | South | 0 | 823.17 | 14.3566 |
| 2007-3-1 07:47:00 | am | 28160.67 | -8 | 81 | 12 | South | 0 | 827.74 | 11.588 |
| 2007-3-1 08:53:00 | am | 28567.4 | -7 | 81 | 13 | South | 0 | 822.25 | 14.1362 |
| 2007-3-1 09:57:00 | am | 14451.18 | -6 | 82 | 11 | South | 0 | 826.71 | 0 |
| 2007-3-1 11:00:00 | am | 13960.7 | -6 | 81 | 10 | South | 0 | 821.56 | 0 |
| 2007-3-1 12:05:00 | am | 14415.29 | -4 | 84 | 13 | South | 0 | 825.45 | 0 |

TABLE 4. 7 MINUTE DATA COLLECTED FROM AM 6:43:00 TO AM 7:43:00 ON MARCH 1 (INTERVAL 7 MINUTE)

| Time | | Vertical load (N) | Temperature (□) | humidity (%) | wind speed (m / s) | Wind direction | Rainfall （mm） | Air pressure （MPa） | Ice thickness （mm） |
|---|---|---|---|---|---|---|---|---|---|
| 2007-3-1 06:43:00 | am | 28208.52 | -8 | 80 | 12 | South | 0 | 821.79 | 12.7285 |
| 2007-3-1 06:50:00 | am | 27897.48 | -8 | 81 | 12 | South | 0 | 822.99 | 12.277 |
| 2007-3-1 06:57:00 | am | 27945.33 | -8 | 81 | 13 | South | 0 | 822.19 | 9.7195 |
| 2007-3-1 07:05:00 | am | 27957.3 | -7 | 80 | 10 | South | 0 | 825 | 11.7016 |
| 2007-3-1 07:12:00 | am | 27825.71 | -7 | 80 | 10 | South | 0 | 826.83 | 11.3674 |
| 2007-3-1 07:19:00 | am | 27765.89 | -8 | 80 | 9 | South | 0 | 823.91 | 11.0471 |
| 2007-3-1 07:26:00 | am | 27945.33 | -7 | 80 | 8 | South | 0 | 825.4 | 10.4886 |
| 2007-3-1 07:33:00 | am | 28148.7 | -7 | 81 | 10 | South | 0 | 823.88 | 12.4871 |
| 2007-3-1 07:40:00 | am | 28112.81 | -8 | 81 | 11 | South | 0 | 826.37 | 9.9906 |
| 2007-3-1 07:47:00 | am | 28160.67 | -8 | 81 | 12 | South | 0 | 827.74 | 11.588 |
| 2007-3-1 07:54:00 | am | 28663.11 | -8 | 80 | 10 | South | 0 | 825.74 | 15.982 |
| 2007-3-1 08:01:00 | am | 28017.11 | -8 | 81 | 12 | South | 0 | 825.23 | 14.2955 |
| 2007-3-1 08:08:00 | am | 28100.85 | -8 | 81 | 15 | South | 0 | 824.08 | 10.7182 |
| 2007-3-1 08:16:00 | am | 27969.26 | -7 | 81 | 12 | South | 0 | 823.62 | 10.2636 |
| 2007-3-1 08:23:00 | am | 28017.11 | -8 | 81 | 10 | South | 0 | 827.69 | 14.7019 |
| 2007-3-1 08:30:00 | am | 28220.48 | -7 | 81 | 9 | South | 0 | 828.49 | 16.3792 |
| 2007-3-1 08:37:00 | am | 28160.67 | -7 | 81 | 13 | South | 0 | 826.77 | 16.316 |
| 2007-3-1 08:37:00 | am | 28160.67 | -7 | 81 | 15 | South | 0 | 826.77 | 16.316 |
| 2007-3-1 08:44:00 | am | 28603.29 | -7 | 81 | 16 | South | 0 | 826.37 | 12.5514 |
| 2007-3-1 08:53:00 | am | 28567.4 | -7 | 81 | 13 | South | 0 | 822.25 | 14.1362 |
| 2007-3-1 09:00:00 | am | 28148.7 | -7 | 81 | 15 | South | 0 | 823.62 | 12.3895 |
| 2007-3-1 09:07:00 | am | 15348.4 | -6 | 82 | 14 | South | 0 | 828.49 | 1.5386 |
| 2007-3-1 09:14:00 | am | 14534.92 | -7 | 81 | 13 | South | 0 | 826.83 | 0 |
| 2007-3-1 09:21:00 | am | 14570.81 | -7 | 81 | 15 | South | 0 | 820.42 | 0.8363 |
| 2007-3-1 09:29:00 | am | 14355.48 | -7 | 81 | 17 | South | 0 | 825.91 | 0 |
| 2007-3-1 09:36:00 | am | 13829.11 | -7 | 81 | 15 | South | 0 | 825.91 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2007-3-1 09:43:00 | am | 14546.89 | -6 | 81 | 13 | South | 0 | 822.14 | 0 |

## V. THE RELATIONSHIP BETWEEN ICING AND METEOROLOGICAL PARAMETERS

### *A. The Basic Meteorological Analysis of Icing*

According to Table 3, the curves (see Figure 3) is drawn. The icing started (08:52:00 PM, Feb 27 2007, equivalent ice thickness is 4.2772 mm)、developed (04:23:00 Am Feb 28 2007, equivalent ice thickness 10.2274mm)、sometimes shed (06:27:00 Am Feb 28 2007, equivalent ice thickness 7.1373mm)、developed again (07:29:00 am , Feb 28 2007 , equivalent ice thickness 10.9773mm) and repeated above processing some times. In the development of the icing, the thickness increased wholely (08:53:00 am March 1 2007 equivalent ice thickness 14.1362mm), Under certain environmental conditions, the icing-shedding happened in a short period of time (08:53:00 to 09:57:00 am March 1 2007, only 14 minutes is used from the ice thickness 14.1362 mm to 1.5386 mm, see Table 4 ) , and the process of icing is over.

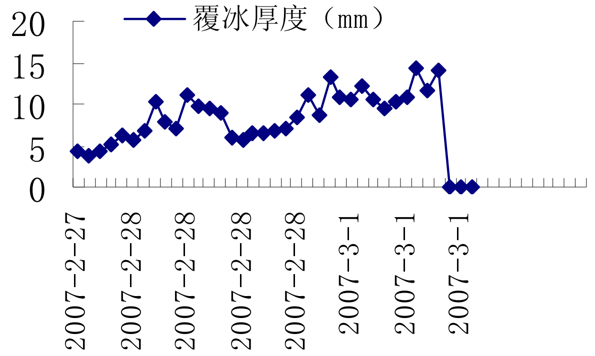


Fig. 3 The development process of the icing from February 27 to March 1 2007

The icing process of transmission lines is related to the micro-meteorological conditions around tower. As shown in Tables 2, the icing conditions are as follows: The temperature range :-10 □ ~ 0 □, More than 80% relative humidity, wind velocity 0m / s ~ 10m / s, a fixed direction (in this case, the wind direction is south when icing), The icing-shedding happened with special environmental conditions in the same way, usually require higher environmental conditions such as the variation of ambient temperature, conductor temperature, wind speed and other environmental parameters. As shown in Table 4, the maximum icing thickness of wire appearred on 08:30:00 am March 1, 2007, the icing thickness reached 16.3792 mm, however, when the environment wind speed reached 9m / s at this time and continued to increase at Maximum 16 m / s), With the help of wind, a quick icing-shedding with the gallop of wire.

### *B. Analysis of Correlation of Single-meteorological Factor and Icing*

British Meteorology Bureau studied the weather conditions and the icing, and a good consistency of icing to temperature, wind direction and ice wire Gerbers output is observed. The relationship between single-meteorological factor and icing and icing is studied by the scene data. According to the data in Table 3, we obtained the linear relationship and the correlation coefficient of the ice thickness to the ambient temperature, the humidity, the wind speed respectively.

The relationship between ice thickness $y$ and the ambient temperature $x_T$ is:

$$y = -2.1919 x_T - 7.118$$

Correlation coefficient: $R = 0.5628$

The relationship between ice thickness $y$ and the environmental humidity $x_H$ is:

$$y = -0.8449 x_H + 77.616$$

Correlation coefficient: $R = 0.4350$

The relationship between ice thickness $y$ and the environmental wind $x_W$ is

$$y = -0.2888 x_H + 9.4871$$

Correlation coefficient: $R = 0.2579$

Based on above analysis, we can find that a single climate factor has some relevance to the icing in some degrees, but the relevance coefficient is small and the icing status can't be judged by a single climate factor. The icing data record in Table 2 is 16 in all, The record with temperature varying from -10 □ ~ 0 □ is 7, only 2 of which monitored the icing really. The record with wind speed varying from 0 to 10m/s, only 2 of which monitored the icing really. Now, we suppose the icing happens when the ambient temperature range between -10 □ and 0 □, we can find the 4496 data records in Figure 2, the record with the temperature range of -10 □ and 0 □ is 3002, only 936 of which monitored the icing really (specifically see table 5), and the prediction accuracy is only 31%, the false rate is as high as 202%. If we use the humidity to forecast, the prediction accuracy of iced is 64%, the false rate was only46%.The fact shows that in a special icing period using air humidity to forecast icing has a higher reliability, this is similar to results by Dr. Makkonen in the Technical Research Center of Finland. However, a comprehensive analysis of wind speed, wind direction to icing is made, we can find that using a single meteorological parameters to determine icing has a great error, as shown in Table 5.

TABLE 5 ANALYSIS OF RELATION OF SINGLE-METEOROLOGICAL FACTOR AND ICING (4496 RECORDS IN ALL, 1022ICING RECORDS IN ALL)

| meteorological factor | Range | Predicted icing records | actual icing records | accuracy | False alarm rate | Missed alarm rate |
|---|---|---|---|---|---|---|
| Temperature | -10□ ~0□ | 3002 | 936 | 31% | 194% | 8% |
| Humidity | 〉75% | 1319 | 849 | 64% | 46% | 17% |
| Wind speed | 0 ~ 10m/s | 3560 | 1020 | 29% | 248% | 0% |
| Wind direction | South | 3023 | 1012 | 33% | 197% | 1% |

**Remarks:** The wind direction in the table (South) is determined by Shenyuan First Return, the specific direction depends on its geographical condition.

### *C. Analysis of Correlation of Multi-meteorological Factors and Icing*

The icing formation depended on specific environmental conditions, we use the scene data monitored by the system and study the relevance of icing to multi-meteorological factors (see Table 6). Using the multi-element analysis, 1206 icing records can be forecasted, 809 records of which are real, the accuracy reached 67 percent, the false alarm rate and missed alarm rates of the system are 18% and 39% respectively. The prediction accuracy is improved greatly based on correlation of multi-meteorological factors and icing.

TABLE 6 ANALYSIS OF RELATION OF SINGLE-METEOROLOGICAL FACTOR AND ICING (4496 RECORDS IN ALL, 1022ICING RECORDS IN ALL)

| meteorological factor | Range | Predicted icing records | actual icing records | accuracy | False alarm rate | Missed alarm rate |
|---|---|---|---|---|---|---|
| Temperature | -10～0□ | | | | | |
| Humidity | 〉75% | | | | | |
| Wind speed | 0～10m/s | 1206 | 809 | 67% | 18% | 39% |
| Wind direction | South | | | | | |

### *D. The Applications of Fuzzy Theory in Relation Between Meteorological Parameters and Icing*

According to the experimental results, the most relevant factors to icing are mainly the ambient temperature, humidity and wind speed etc.. Now we suppose the input vector is $X=\left[x_1,x_2,x_3\right]$, $x_i$ is the fuzzy linguistic variables of ambient temperature, relative humidity, wind speed respectively. Suppose $T\left(x_i\right)=\left(A_i^1,A_i^2,\cdots,A_i^7\right)$, and $\mathrm{A}_\mathrm{i}^\mathrm{j}(\mathrm{j}=1,2,\cdots,7)$ is the j linguistic variable value of $x_i$, the variable is divided into 7 levels（NB，NM，NS，O，PS，PM and PB）,the corresponding membership function is $\mu_{A_i^j}(x_i)(i=1,2,3;j=1,2,\cdots,7)$. An existing rule $R_1$ in the $l$ rules is that when ambient temperature is NS, humidity is PB, wind speed is PS, the icing is PB, thus $R_1=NS_T\times PB_H\times PS_W$. we can get $R=R_1\times R_2\times\cdots\times R_l$, the output of the system $u=i\circ R$, and use the weighted average method to calculate the precision control of the system.

## VI. CONCLUSIONS

The on-line monitoring apparatus of transmission line icing was early developed and has been applied in serious icing areas such as Central China Power Grid, the Northwest Power Grid, Beijing EHV power companies, Shanxi power companies. By the online monitoring system, the micro-meteorological conditions (temperature and humidity, wind speed, wind direction, rain and snow, as well as air pressure and etc.) and icing conditions (angle of inclination insulator, wind angle, the gravity variation of iced conductors, iced conductor thickness, conductor galloping frequency etc.) at the same time. Previously, the problem the meteorological parameters and artificial icing observation can't be carried out at the same time has been resolved. By the online monitoring system, the study on icing and meteorological factors can be made accurately.

The results show that the formation and dropping of icing of transmission lines was related to the special meteorology, such as the temperature between -10□and 0□, the humidity large than 80%, the wind speed less than 10m/s, and the stationary wind direction, that reliability of forecasting icing is very poor according to a single meteorology, and the error is very large. The error is 248% when the temperature is used only to forecasting icing. The accuracy, error, failure of forecasting icing is 67%, 18% and 39% when some meteorology are used together. The accuracy, error, failure of forecasting icing is 86%, 13% and 3% when the fuzzy theory is used. The results of fuzzy theory also shows that some intelligent algorithms such as fuzzy theory is necessary to study the icing model.

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