The microphysics of ice accretion on wires: Observations and simulations

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The weather system, meteorological conditions, and microphysics of cloud, fog, and rain droplets are studied during the formation, growth, maintenance, and shedding periods of ice accretion on wires in Enshi, Hubei Province in China using 2008/2009 and 2009/2010 winter observations. The comprehensive observations include data of visibility, microphysics of fog and rain droplets, and ice thickness, as well as data from an automated weather station and other routinely recorded meteorological data. The results show that icing occurred during the passage of a cold front, with a high-pressure system and a cold temperature trough at 850 hPa, and a southeasterly at 500 hPa that provided abundant moisture. Ice formation usually started in the evening or early morning, and ice shed around noon the following day when the temperature was –1°C to 0°C. The averaged liquid water content of the fog droplet was distinctly greater during the growth period than during the other three periods, and there was precipitation during the growth period in each case of ice accretion. The growth rate of the ice thickness was clearly correlated with the liquid water content, with a correlation coefficient of 0.62. Simulations using empirical equations were carried out, and the simulated ice thickness agreed with observations fairly well.

Ice accretion on wires, growth of ice accretion, meteorological condition, microphysics, simulation of ice thickness


Ice accretion on wires can occur when the ambient temperature drops below 0°C and super-cooled droplets or raindrops are in contact with power lines. The economic loss caused by ice accretion on wires can be huge, especially when power transmission is interrupted owing to insulator flashover, downed power lines, or tilted or downed utility poles and transmission towers.

In the 1950s, researchers from countries seriously affected ice accretion on wires, such as Finland, Norway, Iceland, England, and Canada, began investigating the relationship between ice accretion on wires and meteorological variables [1–3]. They came up with empirical equations to estimate ice loads and conducted numerical modeling to simulate icing processes [4–6].

In China, the earliest incident of downed power lines due to ice accretion was recorded in 1954 [7]. Incidents related to ice accretion numbered more than a thousand in the last several decades, causing huge loss to the country. In the last decade, serious ice accretion threatened even 500 kV transmission towers. During mid-January to early February 2008, persistent severe cold temperatures with snow and freezing rain over vast areas of southern China seriously affected power transmission in the region, resulting in property damage of RMB10.45 billion and a cost of reconstructing...
damaged power systems of RMB 39 billion [8].

Early research on ice accretion on wires in China focused on the relationships between ice thickness and altitude, ice thickness and the angle between the power line and wind, and ice thickness and power-line diameter [9, 10]. Jiang [11] analyzed the relationship between the growth rate of ice accretion on wires and meteorological conditions, using data collected during the Lu Mountain Fog Experiments in the winters of 1978–1981. Little progress was made until 2000, when Jiang et al. [7] provided a model for ice accretion on wires based on their survey of the relationships between ice accretion and meteorological variables and relationships between ice accretion and orographical and geographical conditions employing observational data, laboratory experiments, and theoretical study. Zhang et al. [12] and Wu et al. [13] independently studied ice accretion on wires in eastern Qinghai and in regions from Lanzhou to the Guanzhong Plain, focusing on relationships of ice accretion with transmission tower height, transmission power-line diameter, and routine meteorological variables. These studies mostly focused on large-scale meteorological conditions, with limited studies on microphysics of fog droplet carried out in Guizhou Province [14].

In this study, we use data from 2008/2009 and 2009/2010 winter observations recorded at the Enshi Radar Station at the top of Shiban Hill in Hubei Province (Figure 1), including observations of ice accretion on wires of 3 and 4 mm in diameter, and data from an automated weather station, a fog droplet spectrometer (FM-100), a Parsivel disdrometer, and a visibility meter, as well as other routinely recorded meteorological data. Our goal is to understand the weather system, meteorological condition, and microphysics of the cloud, fog droplet, and rain droplet during the formation, growth, maintenance, and shedding of ice accretion on wires in Enshi. Special attention is given to the event of January 9, 2010, when there was ice accretion on a 3-mm wire in the east-west direction. We obtained detailed observations of the main micro-physical features that affected ice accretion on wires and the evolution of the ice load. Calculations were carried out to simulate four individual events of ice accretion on wires. We hope our study will provide useful information for modeling and forecasting ice accretion on wires.

1 Observations and instruments

1.1 Observation site

We chose Enshi in southwest Hubei as the observation site because there are many 500 kV transmission lines in the area owing to its close proximity to the Gezhouba Dam Hydro Power Plant and the Three Gorges Dam Project. Enshi is at a high elevation (1722 m a.s.l.) and endures strong mountain-gap winds. As a result, it is severely affected by rime and glime in winter. During the heavy snow and freezing rain in 2008, three transmission towers of the Zhang-En circuit line toppled and the power switches in the area tripped many times, paralyzing the Sichuan-Chongqing Grid for an extended period. Four of the 10 damaged transmission lines in Hubei Province that winter were located in Enshi [15]. By choosing the Enshi Radar Station (30°17′N, 109°16′E) as our site for comprehensive observations of ice accretion on wires, we can obtain data that represent the unique orography and climate of a region favorable for ice accretion.

1.2 Instruments

During the 2008/2009 and 2009/2010 winter observations, we used many advanced instruments, such as a fog droplet spectrometer, Parsival disdrometer, wide-range particle spectrometer, photo-acoustic soot spectrometer, visibility meter, and ultrasonic anemometer. We also obtained data via an automated weather station. Table 1 details the instruments and their measurements.

1.3 Observation plan

The observation periods are January–March 2009 and December 2009–January 2010. The observation site is the Enshi Radar Station (30°17′N, 109°16′E; 1722 m a.s.l.) located at the top of Shiban Hill in southwest Hubei. For the observations during January–March 2009, the towers for ice accretion were set up on the ground within the radar station, and the instruments were set up according to the Specifications for Surface Meteorological Observation [16]. There were two groups of towers: one aligned in a north-south direction and the other aligned in an east-west direction. Wires were 4 mm in diameter, 1 m in length, and 1.6 m above the ground. Because the height of the wires in the January–March 2009 observation were not comparable to the actual height of power transmission lines, the towers were set on top of an office building that was 16 m tall for the observations during December 2009–January 2010. In this case, the wires were 3 mm in diameter (owing to the unavailability of 4-mm wires), 3 m in length, and about 2.5 m above the rooftop. Data were taken every 6 h for the 4-mm wires and hourly for the 3-mm wires. Since the ice load was much greater on the wires aligned in the east-west direction, only data for this direction are used in analysis.

Additional observations were carried out for snow depth, snow pressure, and ground temperature on three types of surfaces: soil, concrete, and asphalt. The results on these additional measurements have been published [17–19].

1.4 Observational data

A total of five ice accretion events were observed during the two periods (Table 2). We also obtained time series of ice thickness, snow depth, snow pressure, and ground temperature over the three types of surfaces, spectra of fog droplets and rain droplets, instantaneous three-dimensional winds, visibility, structures of the atmospheric planetary boundary layer and other routinely recorded meteorological variables...