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Long-term forecast method for ice disasters on power grids

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ABSTRACT

Ice disaster is a common form of natural disaster that threatens the safe operation of power grids. Long-term forecasting of power grid icing can provide valuable time for early deployment of power grid anti-icing measures, significantly reducing losses from power grid ice disasters. By analyzing the physical and quantitative relationships between power grid icing and multiple factors such as sunspots, atmospheric circulation, air temperature, and precipitation, the authors have proposed a novel analytic method based on key factors for long-term icing forecasting for power grids. In addition, a fuzzy membership-based forecasting model has been constructed to forecast the long-term icing degree of power grids. Example calculation results using the proposed models show that these models provides accurate forecasts of long-term grid icing degree, which demonstrates the effectiveness and practical usefulness of the proposed models.

1. Introduction

Ice storm is a major menace to the security and stability of electrical power grids (Chang et al., 2007; Meng et al., 2011; Wang et al., 2016; Xie et al., 2014; Wu et al., 2016; Lu et al., 2017; Sopper et al., 2017). In 2008, a catastrophic ice storm hit southern China and caused a disaster in the local power grid. The State Grid Hunan Electrical Company (SGHEC) was the worst-affected power grid; > 700,000 tower collapses and transmission-line interruptions occurred during the storm, which led to a large-scale blackout of the power grid with a direct economic loss of billions of USD (Lu et al., 2008, 2009, 2017). Hence, a forecasting system for power grid icing, especially in the long term, can provide valuable time for deployment of anti-icing measures on power grids ahead of the ice storm, which can reduce power grid losses exponentially. Therefore, long-term forecasting systems possess great application value for power grids.

The working principles of existing long-term icing forecast systems are as follows: they first analyze historical meteorological data; then they formulate empirical laws for icing based on the data; finally, they combine these laws with actual weather data for the current year and provide an icing forecast for power grids before winter comes. However, because power grid icing is also related to sunspots, atmospheric circulation, air temperature, precipitation, and other factors, it is very difficult to provide accurate forecasts for power grid icing. Ye and Zhao (1988) discussed the possibility of long-term ice formation forecasting from the point of view of meteorological science; they also indicated the relationship between ice formation and atmospheric circulation, temperature, and other factors. However, they did not combine the ice formation phenomenon with power grids. Lu et al. (2009) studied the rules governing power grid icing in Hunan, China, using historical data on power grid icing in Hunan and meteorological conditions, and proposed a long-term forecasting model by combining power grid icing with sunspots and atmospheric circulation (Song et al., 2011). However, only a few icing factors were included in the model, and the physical mechanisms of power grid icing and the icing factors were not discussed. Moreover, In the field of long term prediction of power grid icing research, the commonly used methods are multiple linear regression, fuzzy neural network, and so on (Song et al., 2011; Lu et al., 2012a, 2012b; Lu et al., 2015). However, these methods cannot model extreme ice cover disasters similar to the 2007, even during the model training stage (Song et al., 2011).

Therefore, this paper proposes a novel analytic method for long-term grid icing forecasting based on key factors, which includes multiple icing factors and the relationships between their physical mechanism and magnitude and power grid icing. Based on analytical results, a long-term forecasting model of power grid icing degrees based on 17 factors was derived. The forecasting model was validated on a practical example of long-term icing forecasting for the SGHEC.

This paper is organized as follows: Section 2 presents the proposed novel factor analysis method for power grid long-term icing forecasting; the long-term icing forecasting method for power grids is described in Section 3; Section 4 presents a case study of the long-term icing

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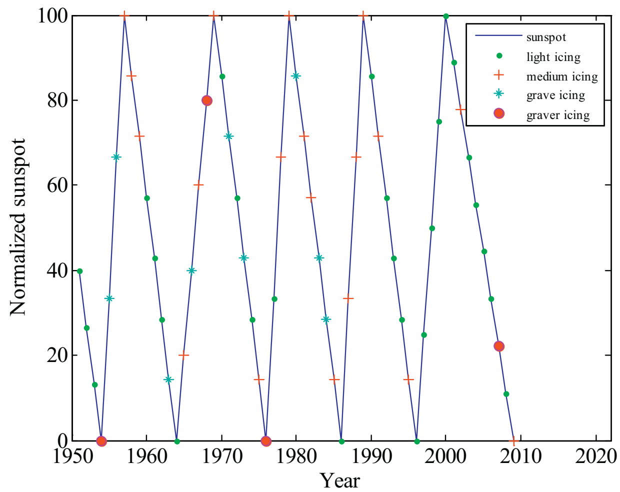

Fig. 1. Annual average icing days in Hunan vs. sunspots.

forecasting model; and conclusions are drawn in Section 5.

2. Factor analyses of long-term icing forecasts for power grids

Power grid icing and its trends are affected by sunspots, atmospheric circulation, air temperature, precipitation, and other factors. This section describes the quantitative analysis of average icing days with their corresponding indices of atmospheric circulation, sunspots, and precipitation for Hunan Province, China since 1951 and characterizes the key factors that affect icing of power grids.

2.1. Sunspots

Due to the energy fluctuations resulting from changes in sunspot activity in peak years, global climate changes frequently and causes abnormal weather in some ice-prone areas (Lean et al., 1992; Bard and Frank, 2006), such as Hunan Province in China. This research has studied the relationship between severe icing years and sunspot activity in Hunan Province from 1951 to 2012 (a total of 62 years), as shown in Fig. 1. The definition of the 4 categories ice disaster degree is given in the Table 1. And the number of ice covering days is the arithmetic average of the number of days on all sites in Hunan Province. It is apparent that 4 out of 13 severe icing years occurred during a peak sunspot year or within one year before and after. For instance, severe icing occurred in February 2008, which was only one year before the major 2009 sunspot year. Eleven out of 13 severe icing years, with a probability of 85%, occurred during a sunspot peak year or within two years before and after.

2.2. Polar vortex

The polar vortex is a low air pressure region in the Arctic that develops strongly during winter. The center of the polar vortex is sometimes in Asia and sometimes in Europe. The Asian polar vortex is the main source of cold air for southern China, and the size of the Asian polar vortex directly affects the strength of the cold area: the larger the Asian polar vortex, the stronger is the cold air mass and the more serious the icing, and vice versa.

Table 1
The definition of the 4 categories ice disaster degree.

Ice degree	Light	Medium	Grave	Graver
Icing days (I_d)	$0 < I_d < 3$	$3 \le I_d < 5$	$5 \le I_d < 11$	$I_d \ge 11$

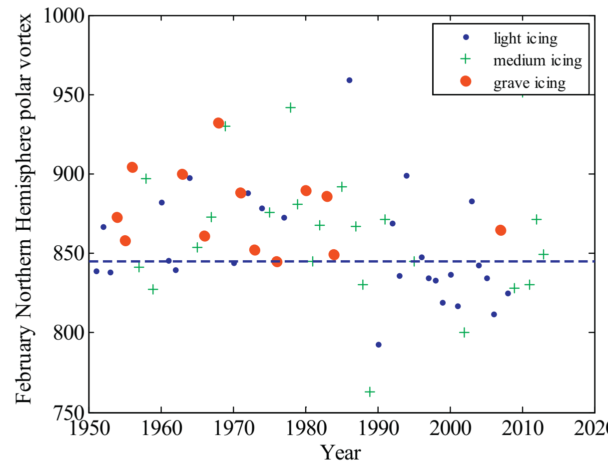

Fig. 2. Size index distribution diagram of the February Northern Hemisphere polar vortex.

2.2.1. Size index of the winter Asia polar vortex

According to historical statistics on the area of the winter polar vortex and the annual number of icing days over 62 years from 1951 to 2012, vortex area and number of icing days are significantly positively correlated, with a correlation coefficient of 0.5 and a confidence level of 95%, meaning that icing in the SGHEC is strongly affected by the polar vortex.

2.2.2. Size indices of the February Northern Hemisphere polar vortex

Fig. 2 shows a size index distribution diagram of the Northern Hemisphere polar vortex in February of each year. It is apparent that severe icing occurs in the SGHEC when the size index of the February polar vortex is > 845; when this size index is < 845, only light or medium icing occurs.

2.2.3. Size indices of the Northern Hemisphere polar vortex in February and the Asia polar vortex in March

Using the size index of the Asia polar vortex in March as the horizontal axis and the size index of the Northern Hemisphere polar vortex in February as the vertical axis, a distribution diagram of icing degree over 62 years was constructed, as shown in Fig. 3. Clearly, all severe or greater icing degrees are located in the dashed box.

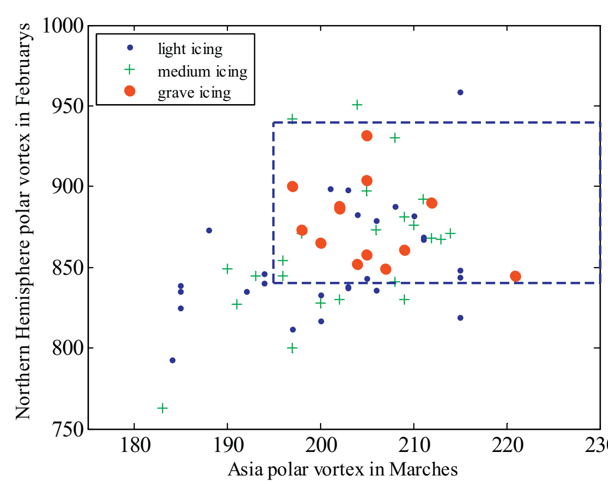

Fig. 3. Size index distribution diagram of the Northern Hemisphere polar vortex in February and the Asia polar vortex in March.