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Electric Power Systems Research 77 (2007) 973–979
ELECTRIC POWER SYSTEMS RESEARCH
www.elsevier.com/locate/epsr

Storm modeling for prediction of power distribution system outages

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Received 9 June 2006; accepted 23 August 2006
Available online 11 October 2006

Abstract

Utility companies spend tremendous amounts of money on storm outage restoration. A storm model which can accurately predict time-varying outages for approaching or ongoing storms will help with outage management. With such a model both customer down time and outage costs can be reduced. This paper proposes a two-stage prediction method to forecast storm related outages. In the first stage, historical outage and weather data are employed to create empirical models for different types of storms. In the second stage, observers are employed for tracking storm outages in real time. The effectiveness of the prediction model is evaluated with simulations applying actual storm data. Lightning is a primary cause of outages during summer storms. Results are presented on a possible relationship between flash density and outages.
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Keywords: Storm outages; Storm classification; Lightning caused outages; Outage prediction; Circuit corridor; Flash density

1. Introduction

Major impacts of severe weather conditions on electric utility operations are equipment failures and power outages. It is estimated that an average storm costs an average utility about \$ 100,000 h^{-1} including materials and labor. For large utilities, storm costs can reach \$ 1,000,000 h^{-1}.

Manpower is a significant part of power restoration cost. A utility usually needs to send out a large number of crews to restore services during a storm. Some of the crews may be borrowed from neighboring companies or are contract crews that are hired during large emergencies. It is a challenging task to manage crews effectively during a major storm. If the number of outages that are going to occur as a function of time can be accurately predicted, then the management of crews and the power restoration can be more effectively planned.

The objective of this paper is to investigate storm models that may be used to predict outages due to approaching or ongoing storms. These models are functions of storm conditions. Accurate storm models hold the potential for lowering operational costs and reducing customer downtime.

Previous research has been performed on storm related power outages. Early in the 1980s, Ref. [1] proposed using a database of customer no-light calls to generate outage patterns. However, the outage patterns were not successful for use in identifying faulted sections. Ref. [2] uses a two-stage Monte Carlo simulation to evaluate the impact of high wind storms. This work quantifies storm interruptions in a power distribution system. In order to improve outage restoration, Ref. [3] suggests a rule-based prediction for determining outage locations from the available call patterns and telemetered data. None of the 'prediction' models in Refs. [1–3] provide an outage forecast ahead of time.

Ref. [4] proposes a predictor which applies a data grouping method and neural networks to estimate the amount of damage due to typhoons. Similar to Ref. [4], the work here uses a two-stage process. Instead of typhoons, typical storms in the northeastern section of the United States are analyzed and an observer [5] is used instead of neural networks in the second stage.

Ref. [6] presents a general procedure for storm outage management. It utilizes the information from weather forecasts and historical data to predict the storm damage in advance, and uses the prediction to manage the crews. However, Ref. [6] did not provide any specific storm outage models, and furthermore did not provide the details of how storm related information may be used to produce storm outage models.

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doi:10.1016/j.epsr.2006.08.020

In this paper 10 years' worth of storm outage data from a utility are investigated. As part of the analysis, storms are classified into six categories. Cumulative outage models for the six storm classifications are developed. For real-time storm tracking, an observer operates on the errors between predicted storm outages and actual storm outages. Simulations demonstrate that outages can be accurately tracked. A 1- and 5-h moving windows are used for predicting outages.

In the data analyzed, more than half of the storm outages during summer are attributed to lightning. Lightning related outages are estimated to cost the nation's utility industry over $ 100 million annually in materials and labor costs. Accurate forecasts of outages from storms with intense electrical activity could reduce customer outage time due to better crew management. Here storms with intense lightning activity are analyzed for correlations between lightning density and outages, where the lightning density is calculated inside defined circuit corridors.

In the next section a summary of the analysis of the historical weather and outage data is presented. Section 3 describes models and observers developed for real-time storm outage prediction and tracking. Simulations using actual data from two different storms are performed to demonstrate the accuracy of predicting the outages. Finally, an analysis of outages caused by lightning intensive storms is presented.

2. Historical storm outage data analysis

2.1. Data for analysis

Two sets of historical data were correlated and analyzed: outage data and weather data. The outage data analyzed covers approximately a 10-year period, from July 1995 to September 2004. There are a total of 8367 outage records considered. The weather data come from three weather stations located in the distribution system. Weather conditions such as wind speed, temperature and other variables are recorded at least every hour at these weather stations.

The analysis uses an hour as the basic unit of time. If there are multiple weather measurements made during an hour at a weather station, the weather data from the multiple records are averaged and the averaged weather variables are used in the analysis.

In the outage data, each outage is associated with a substation. Substations are associated with the closest weather station, and thus each outage is associated with a weather station.

Table 2
Number of outages for each storm type

Storm type	Number of storms	Number of outages	Average number of outages per storm
H	9	1306	145
HS	4	1407	352
L	4	248	62
LS	8	2329	291
M	10	632	63
MS	14	2445	175
Total	49	8367	171[a]

[a] 171 is the average number of outages per storm across all storm types.

2.2. Storm classification

Outages are grouped by storm. Outages that occur in consecutive days are considered caused by the same storm. Storms are classified by temperature and wind speeds. Table 1 presents the storm classifications. Note that the lowest and highest temperature and highest wind speed that occurred during the storm are used to classify the storms.

The number of storms for each storm type, the number of outages occurring during each type of storm, and the average number of outages per storm type are presented in Table 2. It may be observed that the average number of outages caused by storms during moderate temperature conditions (M and MS type storms) is less than the average number of outages caused by both high (H and HS) and low-temperature storms (L and LS). It may also be observed that for storms in the same temperature range, storms with strong winds cause more damage than storms without strong winds.

2.3. Average hourly outages

For each storm type, the average number of outages for each hour of a storm is computed. The average hourly outages are then plotted against the hour of the storm. The first hour of a storm is determined by the time of the first outage. The results of H storms (high-temperature-no-strong-wind) and HS storms (high-temperature-strong-wind) are presented in Fig. 1. It can be seen that the peak of the hourly outages appears at about the fifth hour of the storm. It may also be seen that the average hourly outages dramatically decrease after the first 20 h.

It should be noted that the two observations concerning the peak of the hourly averages and the dramatic decrease in the

Table 1
Storm types

Storm type	Description	T range (°F)	Wind speed range (mph)
H	High-temperature, no strong wind	MaxT > 80	WS ≤ 20
HS	High-temperature, strong wind	MaxT > 80	WS > 20
L	Low-temperature, no strong wind	MinT < 32	WS ≤ 20
LS	Low-temperature, strong wind	MinT < 32	WS > 20
M	Moderate temperature, no strong wind	MaxT ≤ 80, MinT ≥ 32	WS ≤ 20
MS	Moderate temperature, strong wind	MaxT ≤ 80, MinT ≥ 32	WS > 20

MaxT, maximum temperature; MinT, minimum temperature; WS, wind speed.

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