Electric Power Systems Research 141 (2016) 450–459

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Forecasting day-ahead price spikes for the Ontario electricity market

Harmanjot Singh Sandhu [a], Liping Fang [a,*], Ling Guan [b]

[a] Department of Mechanical and Industrial Engineering, Ryerson University, 350 Victoria Street, Toronto, Ontario, Canada
[b] Department of Electrical and Computer Engineering, Ryerson University, 350 Victoria Street, Toronto, Ontario, Canada

ARTICLE INFO

Article history:
Received 7 March 2016
Received in revised form 20 June 2016
Accepted 1 August 2016

Keywords:
Spike forecasting
Price forecasting
Electricity prices
Neural networks
Data mining

ABSTRACT

A novel methodology based on neural networks is presented to forecast day-ahead electricity spikes and prices. Day-ahead electricity prices are forecasted by the first neural network trained using a data set consisting of similar price days. Next, spike prices are identified from the forecasted prices using a spike classifier, and these spikes are re-forecasted by using neural networks trained over historical spike hours. Finally, a data re-constructor is used to achieve the overall day-ahead electricity spike and price forecasting. Numerical experiments are conducted using data from the wholesale electricity market of Ontario, Canada, and significant improvements are achieved in terms of forecasting accuracy.

1. Introduction

In the electricity market, price forecasting is important for setting rational offers in the short term, for signing bilateral contracts in the medium term, and for influencing long-term generation expansion planning. Research on electricity price forecasting has therefore gained momentum in recent years and is considered to be an important as well as challenging task [1]. To determine offering and bidding strategies, accurate forecasting of electricity prices is very useful for generators and consumers. Price forecasting information is also used by large wholesale consumers and independent system operators (ISOs) to reduce system demand and to shift peak demand.

Electricity may be considered as a special type of commodity whose generation and consumption occur simultaneously. The generation can be controlled, but electricity cannot be stored easily. Therefore, demand generated by the consumer market determines the level of electricity generation. The electricity consumption was almost doubled from 1990 to 2011 in most of the electricity markets all over the world [2]. To ensure continuous service to end-customers, generation and distribution of electricity were vertically integrated into state-owned or state-controlled utilities with supply overcapacity in many countries and regions.

The major economies of the world have moved electricity generation and distribution from vertically integrated operations to deregulated operations of the market. Market competition increases the affordability and dependability of the services, and consumers of electricity can choose among a set of energy providers. Hourly, half-hourly, five-minute interval electricity prices are determined during a day, considering various economic and operational factors by operators in a deregulated market. Therefore, operators in these competitive markets encounter challenges such as price uncertainty.

The competitive electricity markets around the world may be categorized as single-settlement electricity markets or two-settlement electricity markets depending upon the design and organizational implementation of generation and transmission systems [3]. Electricity prices in a single-settlement market, also known as real-time market, are settled on hourly, half-hourly, or five-minute bases depending on the demand and available supply. On the other hand, electricity prices for demand and supply, in a two or multi-settlement electricity market, depend on the day-ahead and real-time operation of the market. In a two-settlement market, day-ahead electricity demand and available supply are used to determine electricity prices and the difference between the proposed and actual demand and supply is covered using a real-time market. Trading of electricity in these competitive markets is carried out through spot markets, forward markets, or bilateral contracts. Large electricity consumers try to minimize their electricity cost using various load management strategies to shift peak demand and generate electricity using on-site distributed generation facilities. Therefore, in order to optimize the operation of market participants, it is important to forecast the future electricity market prices.

The main contribution of this paper is the development of a neural network-based method to forecast day-ahead electricity prices

* Corresponding author.
E-mail address: lfang@ryerson.ca (L. Fang).

http://dx.doi.org/10.1016/j.epsr.2016.08.005
0378-7796/

and spikes with high forecasting accuracy. The wholesale electricity market in the Province of Ontario, Canada, is selected as the market to study, and various days from different seasons in 2012 are chosen for forecasting experiments. First, a neural network-based model is developed and day-ahead electricity prices are forecasted. This neural network is trained with the similar price days, from the same year, starting from the day before the forecasting day, and from the previous year. Second, the forecasted prices that are greater than or equal to the spike threshold, which is calculated using the previous year's prices, are classified as spike prices using a spike detector and are separated from the normal prices. Third, these spike prices are re-forecasted using a new neural network-based model. To test the impact of input features, various neural network-based methods are developed for spike forecasting. Finally, these re-forecasted spike prices are combined with the normal forecasted prices in a data re-constructor to achieve the overall day-ahead price and spike forecasting. Price forecasting in the Ontario electricity market is challenging as it is one of the most volatile electricity markets in the world [4] and is interconnected with the neighbouring electricity markets of New York, New England, Midwest, and Pennsylvania–New Jersey–Maryland (PJM) [5,6].

The rest of this paper is organized as follows. Section 2 provides a brief review of the literature on electricity price and spike forecasting. Price spike is defined and factors affecting spikes are briefly reviewed in Section 3. Section 4 describes the initial neural network-based method with data mining techniques at the pre-processing stage to forecast electricity prices, and illustrates initial price forecasting results. In Section 5, a hybrid method for day-ahead electricity spike and price forecasting is presented. Numerical results and a comparison of models are given in Section 6. Section 7 summarizes the main contributions of this paper.

2. Electricity price and spike forecasting techniques

Various methods for forecasting electricity prices are reported in the literature: time series models [7–10]; multivariate dynamic regression models and transfer function (TF) models [7,11,12]; input/output hidden Markov models [13]; wavelet models and generalized autoregressive conditional heteroskedasticity (GARCH) models [8,14,15]; and neural network techniques [1,7,15–24]. Several methods are reported in the literature in the context of spike forecasting for different electricity markets of the world: neural network-based methods [25–27]; support vector machine (SVM) methods [27,28]; data mining techniques [29,30]; autoregressive conditional hazard (ACH) models and dynamic logit models [31,32]; and wavelet transform methods along with feature selection techniques [25]. Most of these spike forecasting studies explored the National Electricity Market (NEM) of Australia, Queensland electricity markets of Australia, and PJM electricity markets. To the best of the authors' knowledge, no work has been reported in the literature on the Ontario wholesale electricity market for spike forecasting.

In the literature, neural network techniques are often proposed to tackle electricity price and spike forecasting problems because of their ability to handle non-linear relationships more accurately [33]. Neural network models do not need prior assumptions, and the processing of information depends on available data. Therefore, in the present study, neural network techniques are used to forecast day-ahead spikes and prices. In a conference paper, Sandhu et al. [34] propose a neural network-based model combined with a data mining technique at the pre-processing stage to forecast day-ahead hourly electricity prices. This work significantly expands the method presented in Ref. [34] to forecast day-ahead hourly spikes and overall day-ahead hourly prices for the Ontario wholesale electricity market.

3. Electricity price spikes

The Ontario electricity market is more volatile than its neighbouring markets due to its single-settlement operation [4]. Historical and real-time Hourly Ontario Energy Prices (HOEP) are published by Independent Electricity System Operator (IESO) on its website. An examination of these historical prices shows that spike prices are much higher than the average normal prices. For example, on May 11, 2011, at 1600 h the electricity price was \$558.24/MWh, which is 15.4 times higher than the average electricity price of \$36.25/MWh in 2010. The occurrences of these abnormal high prices in an electricity market are considered as price spikes. In this study, price spikes are separated from normal electricity prices using a spike detecting classifier. A threshold level is calculated using the previous year's prices and the price values of the year under study above or equal to this threshold level are considered as spikes. These spike prices are re-forecasted to improve the overall forecasting accuracy. The threshold level for 2012 is calculated using the price data from the previous year of 2011, and similarly, the threshold level for 2011 is calculated using price data from 2010. Formally, let μ be the mean of the selected data set of historical HOEP, and δ be the standard deviation of the selected data set. The threshold level of the sample set can be calculated as [29]:

$$P_{TH} = \mu + 2\delta \tag{1}$$

where P_{TH} is the threshold value of the selected data set. Any HOEP value greater than or equal to P_{TH} ($\text{HOEP} \geq P_{TH}$) is considered to be a spike. To detect the spikes in 2012, the mean and standard deviation of prices over all the hours in 2011 are calculated and the threshold level is determined using Eq. (1).

Many of the studies on forecasting price spikes [25–32] argue that occurrences of these spikes are random, but the probability of their occurrences is higher if the available supply is less than demand or if the reserve margin is very low. Occurrences of electricity price spikes are affected by many factors. Important short-term factors include weather conditions (temperature, humidity, and dew point temperature), breakdown of low-cost generation facilities, low reserve margins, limitations of transmission lines, and generation capacity constraints [26,28,29,31]. Long-term factors—such as increases in natural gas and oil prices, inflation rates, shutting down of generators due to aging, and economic growth—may increase the overall electricity prices [26,29,31]. However, electricity price spikes over a day are mainly affected by short-term factors [28].

Spikes may occur for several hours, but normally not for more than a day [25,28]. The occurrence of spikes depends upon the system demand and available supply. During peak hours, normally day time, demand increases and higher cost operating generators become operative. These generators greatly influence the prices and hence spikes occur [31]. The threshold value could be different for different seasons and for different electricity markets. Spike hours are increasing every year in the Ontario electricity market. Hence, new generation facilities are required during these spike hours to meet the demand. As these spikes occur only for a few hours over a year, new facilities will operate only for a few hours over a few days in a year, but will greatly influence electricity prices. In this paper, the data set is selected with historical prices, demand, temperature, dew point temperature, and relative humidity as important features for forecasting price spikes. The data sets of historical prices and demand are available for public access on the IESO website (ieso.ca) and the deta sets of temperature, dew point temperature, and relative humidity are taken from the Government of Canada website (climate.weather.gc.ca) for the location of Toronto Lester B. Pearson International Airport.