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A hybrid wavelet-ELM based short term price forecasting for electricity markets

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ABSTRACT

Accurate electricity price forecasting is a formidable challenge for market participants and managers owing to high volatility of the electricity prices. Price forecasting is also the most important management goal for market participants since it forms the basis of maximizing profits. This study investigates the performance of a novel neural network technique called Extreme Learning Machine (ELM) in the price forecasting problem. Keeping in view the risk associated with electricity markets with highly volatile prices, relying on a single technique is not so profitable. Therefore ELM has been coupled with the Wavelet technique to develop a hybrid model termed as WELM (wavelet based ELM) to improve the forecasting accuracy as well as reliability. In this way, the unique features of each tool are combined to capture different patterns in the data. The robustness of the model is further enhanced using the ensembling technique. Performances of the proposed models are evaluated by using data from Ontario, PJM, New York and Italian Electricity markets. The experimental results demonstrate that the proposed method is one of the most suitable price forecasting techniques.

1. Introduction

Deregulation of electricity sector has led to the development of a competitive market structure where the participants compete for the market share through spot and bilateral markets. Electricity prices in such markets are directly or indirectly driven by a number of factors which are interlinked to each other in a complex fashion. Uncertainty in factors such as weather, equipment outages, fuel prices, and transmission bottlenecks result in extreme price volatility or even price spikes of electricity market. The complex, uncertain movement of electricity prices over different hours of the day is of great interest to the market participants. The market participants need reliable forecasted prices for either bidding or hedging against price volatility in the market. Driven by the importance of the future prices and the complexities involved in determining them, detailed modeling and forecasting of electricity prices has become a major research field in electrical engineering.

A significant number of research papers have addressed the problem of accurate price forecasting through different approaches. The most commonly observed one's are the time series based [1–4] and the artificial intelligence based approaches [5–8] which are basically regression models as they relate electricity prices variations to historical prices and other explanatory variables such as demand, fuel prices, temperature, time of day etc.

Some of the recent works which have addressed the problem of accurate electricity price forecasting are presented in [9–12]. In [9], the authors have based their research on the Grey system theory [GST] which considers uncertain systems which are partially known and have small samples. They proposed a new grey model in which the reference series is determined using the correlation method and the model parameters are identified using Particle Swarm Optimization (PSO) instead of Least Square method (LSM). A hybrid model comprising of Wavelet transforms (WT), Auto Regressive Integrated Moving Average (ARIMA) and Radial Basis Function Neural Network (RBFN) was proposed in [10]. Further, the network structure of RBFN used in this methodology is optimized using the PSO technique and the method works well even for lesser input data. Authors in [11] also combined well know techniques such as wavelet transforms, PSO and Adaptive-network-based fuzzy inference system (ANFIS) to develop a hybrid methodology. Wavelet transform is used initially for decomposing the non-linear price signal into independent, smooth signals which are later on recombined to form the individual signals. The prediction is done by the ANFIS module and the parameters of the network structure are optimized using PSO. In [12], a RBF-NN-GARCH model was proposed where the traditional RBF-NN model is extended by using GARCH specifications for modeling the variability of price signals. The model parameters are tuned using a maximum likelihood function which is further optimized using a derivative free genetic algorithm.

Many of the available papers including the ones discussed above have proposed hybrid methodologies and have some kind of network structure which needs to be tuned using optimization techniques

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Nomenclature

A_m	Approximate series at resolution m
D_m	detail series at resolution m
E	number of ensembles
$g(x)$	activation function
H	hidden layer output matrix
$H^{\dagger}$	Moore Pensrose generalized inverse of H
$L(\cdot)$	wavelet function
N	data samples
$\tilde{N}$	number of hidden nodes
P_t	actual price value at hour t
$\widehat{P_t}$	forecast price at hour t
T	target matrix
W	input weight matrix
β	output weight matrix
φ	father wavelet function
ψ	mother wavelet function

requiring additional computational effort. Neural network based structures are most commonly employed and the efficiency of NN based methods is highly dependent on appropriate tuning of their adjustable parameters, e.g., the number of hidden layers, nodes, weights and transfer function etc. Most ANN based forecasting methods use gradient-based learning algorithms, such as the back propagation neural network (BPNN), and are plagued with problems such as over-tuning and long computation time. Recently, a novel learning algorithm for single-hidden-layer feedforward neural networks (SLFN) called extreme learning machine (ELM) has been proposed in [13,14]. In the proposed algorithm, the input weights and hidden biases are randomly chosen, and the output weights are determined analytically by using the Moore–Penrose (MP) generalized inverse. ELM surpasses the traditional gradient-based learning methods in terms of faster learning speed with a higher generalization and it also avoids many difficulties faced by gradient-based learning methods such as stopping criteria, learning rate, learning epochs, local minima, and the over-tuning problems [15–17].

Up to now, the ELM has been successfully applied in various areas such as classification [18], terrain reconstruction [19] and protein structure prediction [20] etc. The ELM technique has been applied for the case of electricity price forecasting in [21] where the advantages of ELM over traditional NN structures were highlighted and also the uncertainties related to prediction were quantified using the bootstrapping technique. In this paper the ELM, in conjunction with other techniques, is selected to forecast Day Ahead electricity prices for some of the existing markets. When making a decision, participants usually consider results from many types of techniques that help them to achieve their objective. Relying on a single technique can be very risky particularly in case of power markets where volatility is very high and millions of dollars are at stake. Combining several techniques together to form a hybrid tool has become a common practice to improve the forecasting accuracy where each models unique feature are combined to capture different patterns in the data. Theoretical as well as empirical findings suggest that hybrid methods can be effective and efficient in improving forecasts. Therefore ELM method has been coupled with the Wavelet techniques to develop a hybrid model termed as WELM (wavelet based ELM) and it is shown to give faster and more accurate results. The robustness of the model is further enhanced using the ensembling technique. The rest of the paper is organized as follows. The fundamental principles of the proposed method are introduced in Section 2. The various steps of model development are discussed in Section 2. Case studies and experimental results are presented in Sections 4 followed by the conclusion of the work in Section 5.

2. Methodology

In this section, we present the methodology employed for electricity price forecasting using a model consisting of ELM and data is preprocessed using a wavelet decomposition technique. Electricity price signal is highly volatile, corrupted by occasional spikes and follows a weekly-daily cycle with each sample of one hour interval. Fig. 1 shows the price profile of the Ontario electricity market for the year 2004 which testifies the above statement. A price signal exhibits much richer structure than the load series and signal processing techniques like Fourier Transform (FT), Wavelet Transform (WT) are good tools to bring out the hidden patterns in the prices. WT is used for multi-scale analysis of the signal and decomposes the time series signal into the low-frequency sub-series (approximation part) and some high-frequency sub-series (detailed part) in the wavelet domain. These constitutive series have better statistical properties than original price series and hence better forecasting accuracy can be achieved by their appropriate utilization. In WT based models, first of all WT is applied to the price series, prediction is made in the wavelet domain using a ELM model and then inverse WT is applied to obtain the actual predicted value in time domain. A brief introduction to the ELM, wavelet technique, and other aspects relevant to the proposed methodology is presented in this section.

2.1. Extreme learning machines

The theoretical foundation behind the Extreme learning machine (ELM) architecture is explained in this section. ELM is an improved learning algorithm for the single feed-forward neural network architecture. ELM is different from the traditional neural network methodology in the sense that all the parameters of the feed-forward networks (input weights and hidden layer biases) are not required to be tuned in its case. The capability of SLFNs with randomly chosen input weights, hidden layer biases and a nonzero activation function to approximate any continuous functions on any input set has been demonstrated in [17]. The SLFN with randomly chosen input weights and the hidden layer biases can be considered as a linear system. For this linear system, the

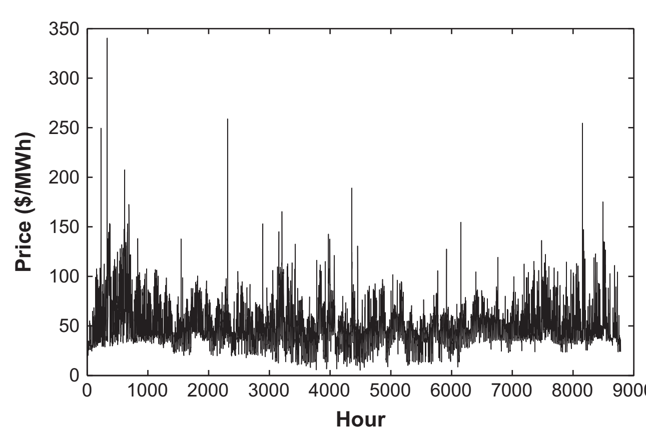

Fig. 1. Price profile of Ontario electricity market for the year 2004.