Applied Energy 172 (2016) 132–151

Contents lists available at ScienceDirect

Applied Energy

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

Day-ahead electricity price forecasting via the application of artificial neural network based models

Ioannis P. Panapakidis [a,b,*], Athanasios S. Dagoumas [b]

[a] Department of Electrical Engineering, Technological Education Institute of Thessaly, 41110 Larisa, Greece
[b] School of Economics, Business & International Studies, University of Piraeus, 80 Karaoli & Dimitriou Str., 18534 Piraeus, Greece

HIGHLIGHTS

- The paper focuses in short-term price load forecasting.
- Several Day-ahead forecasting models are proposed and tested.
- The clustering tool is combined with neural network.
- We focus on no pre-processed data.

ARTICLE INFO

Article history:
Received 2 December 2015
Received in revised form 3 March 2016
Accepted 18 March 2016

Keywords:
Artificial neural networks
Electricity price forecasting
Day-ahead market
Time-series clustering

ABSTRACT

Traditionally, short-term electricity price forecasting has been essential for utilities and generation companies. However, the deregulation of electricity markets created a competitive environment and the introduction of new market participants, such as the retailers and aggregators, whose economic viability and profitability highly depends on the spot market price patterns. The aim of this study is to examine artificial neural network (ANN) based models for Day-ahead price forecasting. Specifically, the models refer to the sole application of ANNs or to hybrid models, where the ANN is combined with clustering algorithm. The training data are clustered in homogenous groups and for each cluster, a dedicated forecaster is employed. The proposed models are characterized by comprehensive operation and by high level of flexibility; different inputs can be taken under consideration and different ANN topologies can be examined. The models are tested on a data set that consists of atypical price patterns and many outliers. This approach makes the price forecasting problem a more challenging task, providing evidence that the proposed models can be considered as useful and robust forecasting tools to the actual needs of market participants, including the traditional generation companies and self-producers, but also the retailers/-suppliers and aggregators.

1. Introduction

1.1. Motivation

Modern power systems planning includes a variety of resources to cover the increasing demand subject to the various techno-economic and environmental constrains [1]. Load forecasting is of fundamental importance for power systems operation and this fact is reflected by the plethora of related researches. Many methodologies that differ in the data preprocessing, model selection, calibration and testing phases, have been presented [2]. The load forecasting literature is expanded. It includes single models or more sophisticated models that combine various computational intelligence algorithms [3].

On the other hand, the literature on price forecasting is less numerous [4]. This is due to the fact that most markets were structured as monopolies until recently; wholesale competition was absent or limited. While electricity markets become competitive, price forecasting is gathering research momentum. Price forecasting is a relatively more difficult task due to the endogenous characteristics of price time series [5]. Since the determination of the hourly market clearing price (MCP) is held within a dynamic and competitive environment, MCP is characterized by volatility [6]. MCP's chronological evolution is influenced by a set of diverse parameters like demand, fuel prices such as coal and natural gas, merit order of generation plants, hydropower capacity, market

* Corresponding author at: Department of Electrical Engineering, Technological Education Institute of Thessaly, 41110 Larisa, Greece.
E-mail address: ipanap@ee.auth.gr (I.P. Panapakidis).

http://dx.doi.org/10.1016/j.apenergy.2016.03.089
0306-2619/

participants strategies, network congestion and others [7]. Thus, special care should be placed on the inputs selection, model's parameters and calibration, model's assessment and generally, on the experimental set-up that will result in a robust forecaster.

The electricity price forecasting problem influences various processes expanded on different time frames in modern power systems operation. It is closely related with other contemporary scientific and engineering problems such as the optimal power generation units scheduling, fuel consumption, energy resources exploitation, GHG emissions, power systems simulation and electricity demand modeling. Therefore, it is inter-connected with other problems and tasks. Due to this attribute, it is a research topic targeting multi-disciplinary audiences within the power systems community. Also, while price forecasting is related to the energy market transactions and operations, various market participants (utilities, grid operators, retailers, aggregators and others) are interested in obtaining short-term predictions.

The aim of this work is to explore the potential of ANN based models on price forecasting. We examine models built solely on ANN and hybrid models that combine unsupervised machine learning via the clustering tool and supervised machine learning via the ANN. A reliable forecaster should be easy to implement and characterized by high level of parameterization. The analysis of the study is centered toward these goals.

In the price forecasting literature, many models have been proposed based on computational intelligence. The models refer to sole algorithms or more complex hybrid approaches. The present paper examines a set of single and hybrid models on the case of using no preprocessed data. The single models refer to ANNs and more specifically, to Multi-Layered Perceptrons (MLPs) and the hybrid combine MLPs and clustering. In the literature, many robust models such as Fuzzy Neural Network (FNN), Support Vector Machines (SVMs) and Radial Basis Function (RBF) networks. Our preference on the MLPs over the others is justified by the following reasons:

(a) Our focus is mainly on the current data. We adapt the most common approach of the literature (i.e., the MLPs) to examine their performance on special data sets. Also, by using single MLPs, it is easy to examine various configurations that differ in the number and type of inputs. The comparison with more complex models such as the FNN is left for future research.
(b) A basic advantage of the MLPs is their training flexibility. The user can select between a large set of modified back-propagation algorithms in contrast to SVMs and RBFs networks. Different training algorithms apply to various problems, providing the user a flexible and adaptable modeling tool.
(c) The MLPs require less training time contrary to SVMs and RBFs. For example, in the case of the RBFs networks, the number of RBF units equals to the number of patterns. This fact may increase the problem's complexity when dealing with large data sets.

Prior to entering the data into the forecasting models, some researches utilize the wavelet transform to decompose the original signal into low and high-frequency subseries (wavelet domain) [8]. This approach leads to better predictions in some cases. In the present paper, our main focus is to test the accuracy of some models on the raw data coming directly from the metering system. The wavelet analysis appears to be prominent and will be the regarded into a future study by the authors.

1.2. Solution approach

Due to their potential of simulating data with complex and non-linear relationships, ANNs are preferable in cases where a model that describes the data is absent [9]. ANNs are data driven models that are trained with a limited number of data and are to provide a generalization of their operation. A forecaster built on ANN receives as inputs the parameters that influence the quantity under examination, i.e. the MCP. For instance, the inputs include past MCP values, exogenous variables like temperature, fuel prices, day type identification codes and others. The majority of the price forecasting related literature focuses in specific electricity markets with relatively smooth data. Our approach differs from the related literature on the attributes of the data set. The models are tested on a raw data sample that contain null values and have missing entries. At least theoretically, this approach increases the difficulties that will prevent an analysis to formulate a robust forecasting model. To further analyze the problem of working with raw data, we explore the potential of utilizing the clustering tool for the purpose of increasing the forecasting accuracy of a feed-forward neural network trained by the Levenberg–Marquard algorithm [10].

The developed models are applied on the Southern (SUD) Italy electricity market [11–13]. The available data set covers the period between 01/02/2012 and 30/04/2015. Among them, the period between 01/02/2012 and 31/12/2014 is used as the training set and the rest is used as test set. The role of the training set is the determination of the optimal ANN configuration, i.e. the optimal selection of the type of neurons activation function, number of hidden layers, number of neurons in the hidden layer(s) and maximum number of training epochs. One training epoch corresponds to one forward pass and one backward pass of all the training examples. The test set is used for the models comparison.

1.3. Literature survey and contributions

From a market's participant perspective, the estimation of the MCP in short-term horizon aids on the adoption of a proper strategy in wholesale market exchanges, i.e. the establishment of bilateral contracts or the generation units scheduling. The importance of the estimation of MCP is evident in profit maximization problems [14,15]. The MCP is treated as a stochastic variable and a set of scenarios are constructed to estimate its future variation.

Reviews of the state-of-the-art on the existing techniques on price forecasting can be found in [4,16]. A literature review including the amount of the recently published papers can be found in [17]. These studies attempt to reveal both the similarities and the differences between current techniques. According to [4] the existing approaches can be distinguished in three major categories: Game theory models, simulation models and time series models. The latter can be further categorized to stochastic models, artificial intelligence models and regression models. Time series models, such as ARIMA and GARCH, are a popular approach; they can serve as benchmark models for further model comparison and can be combined with other models leading to the formation of hybrid models. Their widespread usage is due to the fact that the mathematical formulation that refers to is comprehensive. Time series models require historical values of the quantity under prediction and they assume that the quantity evolution follows a specific pattern. The prediction is accomplished through the pattern's extension to a pre-defined future time period [18,19]. A comparison of various time series models like AR, ARMA and ARIMA can be found in [20]. Various sub-models are built (i.e. AR(1) with jumps, AR(1) in logs with jumps, AR(1) with time variant mean and others) and tested on the LPX market. Another comparative simulation study is conducted in [21] between a k-factor GIGARCH process and a SARIMA-GARCH model. The test study is applied on one month data of EEX market and the models include only lagged price values.

The time series models category includes the ANN based models. Representative bibliography is registered in Table 1. The ANNs