Short Time Price Forecasting for Electricity Market Based on Hybrid Fuzzy Wavelet Transform and Bacteria Foraging Algorithm

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Abstract

Predicting the price of electricity is very important because electricity can not be stored. To this end, parallel methods and adaptive regression have been used in the past. But because dependence on the ambient temperature, there was no good result. In this study, linear prediction methods and neural networks and fuzzy logic have been studied and emulated. An optimized fuzzy-wavelet prediction method is proposed to predict the price of electricity. In this method, in order to have a better prediction, the membership functions of the fuzzy regression along with the type of the wavelet transform filter have been optimized using the E.Coli Bacterial Foraging Optimization Algorithm. Then, to better compare this optimal method with other prediction methods including conventional linear prediction and neural network methods, they were analyzed with the same electricity price data. In fact, our fuzzy-wavelet method has a more desirable solution than previous methods. More precisely by choosing a suitable filter and a multiresolution processing method, the maximum error has improved by 13.6%, and the mean squared error has improved about 17.9%. In comparison with the fuzzy prediction method, our proposed method has a higher computational volume due to the use of wavelet transform as well as double use of fuzzy prediction. Due to the large number of layers and neurons used in it, the neural network method has a much higher computational volume than our fuzzy-wavelet method.

Keywords: Price Prediction; Wavelet Transform; Fuzzy Logic; Bacteria Foraging Algorithm; Electricity Market.

1. Introduction

In the last couple of decades, the electric power industry, in most countries of the world, has undergone radical and fundamental changes which are referred to by different names such as deregulation, restructuring, law revision, etc.. Also in Iran, changes in the electric power industry, began with the launch of Iran's electricity market in November 2003. With Iran Grid Management Company being established in 2004, Iran's electricity market took a more serious shape. Also, considering the approval of the implementing regulations related to paragraph (b) of Article 25 of the Third Development Plan law by the Council of Ministers, the approval of the law related to the independence of distribution companies by the Islamic Consultative Assembly, and the interpretation of Article 44 of the constitution by the supreme leader, Iran's electricity industry will undergo fundamental changes in the coming years [1].

A lot of work has been done with respect to price prediction. In 2002, a paper was presented in which an autoregressive integrated moving average (ARIMA) model has been used to predict the prices in the electricity market. Since the price in the electricity market depends on various factors, by comparing the results of this study with future studies, it can be seen that this method has not had an appropriate solution. This method does not have a desirable solution especially where the price changes are big.

In 2009, a paper was presented in which a hybrid model, which combined an autoregressive integrated moving average (ARIMA) model and generalized autoregressive conditional heteroskedasticity (GARCH) model, has been used to predict the average daily price in Iran's electricity market. This method had a medium computational volume, and according to the results obtained, it can be seen that this forecasting method has not had a desirable solution where the speed of price changes were high. [1]

Since the time series models did not have a desirable solution in drastic changes in the desired signal, thus a paper was presented in 2008, in which the wavelet transform and a neural network have been used. One of the capabilities of the wavelet transform is that, where drastic changes occur, the length of the window, in which the signal is evaluated, becomes smaller and calculations will be done more carefully, and among the disadvantages of this method an increased computational volume can be mentioned. [5]

Reference [7] has presented a method in which a parallel method has been used to reduce prediction errors,

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which has been used to predict the next day price of the electricity market, and in which the data predicted in the previous period are used as data for the next period.

In 2009, a method was presented based on adaptive regression. According to the article, other prediction methods can at most predict up to next 3 or 4 steps, but this method can predict up to next 10 steps. A disadvantage of this method is that it requires the ambient temperature data simultaneously with the electricity price data for prediction. [8].

In the next section we consider linear prediction.

2. Linear Prediction

In this section we will explain linear prediction method. A linear prediction model represents the time series of the signal samples during a given time period. Its usual linear model is as follows [8]:

$$y(t+T)=a_1.y(t)+a_2.y(t-T)+\cdots+a_m.y(t-(m-1)T) \quad (1)$$

where a_1, a_2, ..., a_m are linear prediction coefficients, m is the model order, T is the sampling time, y(t+T) is the future sample, and y(t), y(t-T), ..., y(t-mT) are the present and past observations. In this relation, the function output is a linear combination of the present and past samples, thus this function is called a linear prediction.

Two stages have to be done to achieve a linear prediction of prices in the electricity market using equation (1). According to this equation, first the model order has to be chosen carefully, and then the coefficients a_1, a_2, ..., a_m have to be calculated from the modeling window. And then the obtained model can be used to predict the price of electricity market in the time steps ahead.

A least-squares error method can be used to estimate the coefficients a_1, a_2, ..., a_m in equation (1). This error is measured between the estimated value and actual value. In use of least-squares method, the energy in the error signal, falls to its minimum. A solution to this problem is vector B which estimates the unknown vector of parameter β. The least-squares solution is as follows:

$$b=\hat{\beta}=\left(X^T.X\right)^{-1}.X^T.y \quad (2)$$

In the next section prediction using the neural network method is studied.

3. Prediction Using the Neural Network Method

In this section we will explain prediction using the neural network method and the type of neural network that we use is considered throughly.

Due to their remarkable abilities to infer results from complex and ambiguous data, neural networks can be used to extract patterns and identify various trends, which are very difficult to identify for humans and computers. In this study, a back-propagation neural network is used, with 5 layers and 5 inputs, all of which are the data of the price of market electricity from the previous time period. The figure below shows how to choose a neural network.

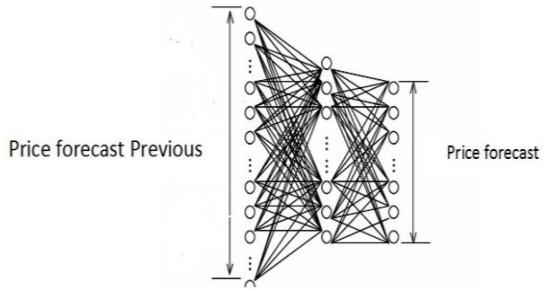

Fig. 1. The structure of a BP neural network for price prediction in the electricity market

4. Prediction Using the Fuzzy Regression Method

In the next section we study the history of fuzzy logic and fuzzy regression.

Dr. Lotfizadeh introduced the theory of fuzzy systems in 1965. In such an atmosphere where the scientists of engineering sciences were seeking for mathematical methods to defeat more difficult problems, the fuzzy theory took steps toward another kind of modeling.

In conventional fuzzy systems, the number and type of membership functions are determined by trial and error. But what is obvious is that, a larger number of membership functions are needed for more complicated systems. On the other hand, as the number of membership functions increases, the number of fuzzy rules usually increases, which ultimately leads to the complexity of implementation. Membership functions can have different shapes, such as triangular, Gaussian, bell, trapezoidal, etc.. In the linear regression, the goal is to find the fuzzy coefficients of the polynomial below. In other words, the goal is to express the linear prediction using the fuzzy coefficients.

Its usual linear model is as follows [8]:

$$y(t+T)=\bar{A}_1.y(t)+\bar{A}_2.y(t-T)+\cdots+\bar{A}_m.y(t-(m-1)T) \quad (3)$$

Where; ($\bar{A}_i$)s are fuzzy coefficients which are expressed by fuzzy membership functions. Here the goal is to find ($\bar{A}_1$)s in a way that the prediction error is minimized.

5. Our Propsed Method: Fuzzy-Wavelet Prediction

In this section the history of wavelet and our proposed method which is combination of fuzzy prediction method and wavelet is presented.

The constant resolution problem in the short-time Fourier transform, has its roots in Heisenberg's uncertainty principle. According to this principle, a time-frequency description of a signal cannot be achieved exactly; that is, it cannot be found out exactly that at a given signal, what frequency components are available at what time intervals, but we can only found out that what frequency bands are available at what time intervals. This principle directly returns to the concept of resolution. Although the time and frequency resolution problems are results of a physical phenomenon (theHeisenberg uncertainty principle) and exist regardless of the transform used, it is possible to analyze anysignal by using an alternative approach called the multiresolution analysis (MRA) .

The wavelet transform is a kind of windowing technique with variable- sized windows. The wavelet analysis gives us the possibility to achieve our goal both in a long duration where we require high accuracy at low frequency data, and in shorter durations where we need high-frequency data. The wavelet transform does not convert into a time-frequency region, but rather into a time-scale region.

Using the wavelet transform, the price signal of electricity market can be divided into data with big changes (details) and data with little changes (generalities). Figure 2 shows an overview of this conversion.

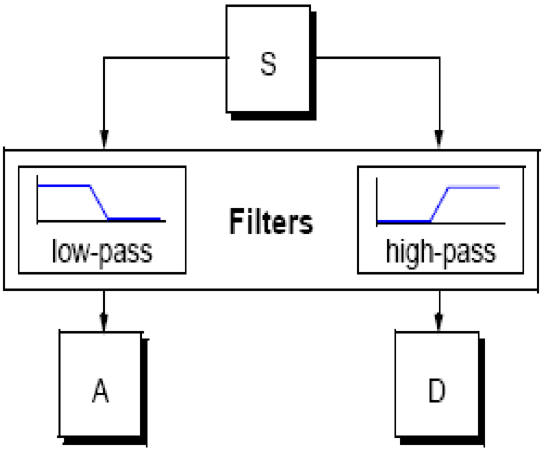

Fig. 2. The structure of the wavelet transform for price prediction in the electricity market.

Since in order to increase the accuracy of predictors when many changes occur, it is necessary to increase the number and/or degrees of membership functions, which increases the volume of calculations, another solution is to use the multiresolution analysis, in this way that; high frequency data (details) are estimated by a predictor and low frequency data (generalities) by another predictor. By doing this, the desired accuracy and less computational volume can be achieved.

This paper uses a combination of wavelet transform and fuzzy regression to predict the price of electricity market.

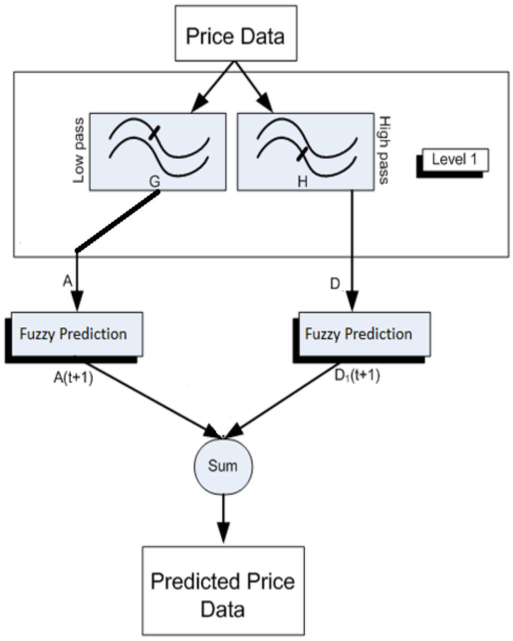

Fig. 3. shows an overview of this system.

Figure 3. The general structure of the proposed fuzzy-wavelet transform, for price prediction in the electricity market.

To compare the prediction methods presented in this paper, some indicators are defined as follows.

The mean absolute percentage error (MAPE): This error is defined as follows:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|PE_t\right| \qquad (4)$$

Where; n is the number of data, and PE represents a relative error and is defined as follows:

$$PE_t = \left(\frac{y_t - F_t}{y_t}\right)\times 100 \qquad (5)$$

If yt is the actual observation for duration t, and Ft a forecast for the same duration, then the error will be defined as in equation (6):

$$e_t = y_t - F_t \qquad (6)$$

The maximum forecast error: is the greatest value of error in the prediction for the test data set which is defined as in equation (4-1):

$$ME = \max(\text{Price}_{actual} - \text{Price}_{predicted}) \qquad (7)$$

The maximum forecast percentage error is defined as follows:

$$MPE = \max\left(\frac{\text{Price}_{actual} - \text{Price}_{predicted}}{\text{Price}_{actual}}\right)\times 100 \qquad (8)$$

Also the mean squared error (MSE) is defined as follows:

$$MSE = \sqrt{\frac{1}{N}\sum_{k=1,\dots,N}\left|\text{Price}_{actual} - \text{Price}_{predicted}\right|^2} \qquad (8)$$

In the next section the simulation results and comparisions are presented.

6. Simulation and Results

In order to determine the best model in quantitative terms, the three measures of prediction errors: MSE, mean absolute error (MAE), and mean absolute percentage error (MAPE), were used to evaluate and compare the models. For a better evaluation, the results of these forecasting methods as well as their instantaneous errors are presented in Figures 4 to 11.

By taking them into consideration, it can definitely be concluded that the values resulting from the wavelet-fuzzy forecasting method has a better solution than the previous forecasting methods.

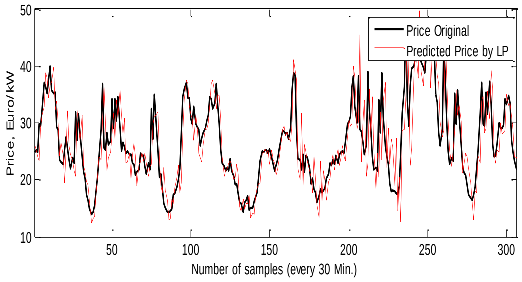

Fig. 4. The results obtained from the linear prediction, for price prediction in the electricity market

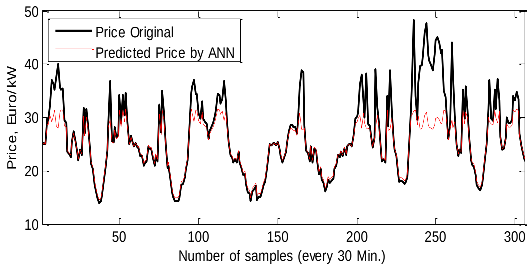

Fig. 5. The results obtained from the neural network prediction, for price prediction in the electricity market

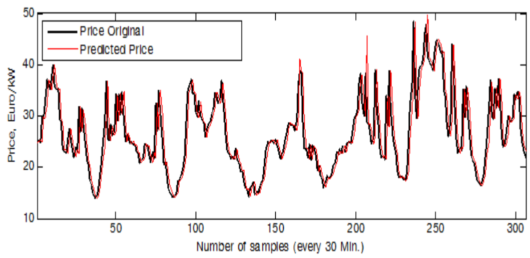

Fig. 6. The results obtained from fuzzy prediction, for price prediction in the electricity market

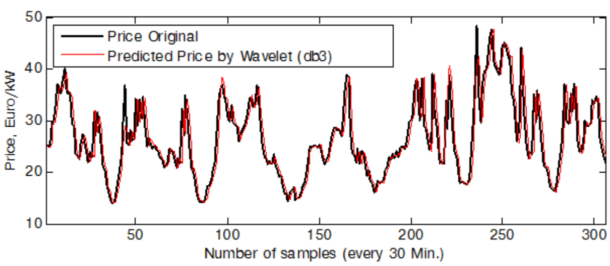

Fig. 7. The results obtained from our fuzzy-wavelet prediction, for price prediction in the electricity market

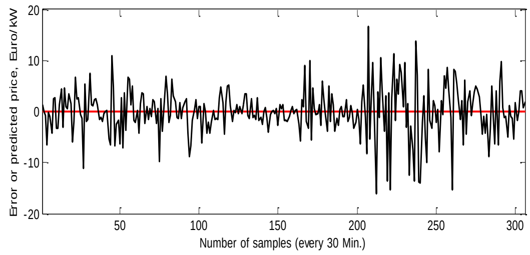

Fig. 8. The instantaneous error for price prediction in the electricity market, using the linear prediction method

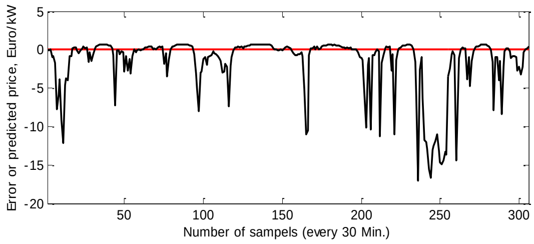

Fig. 9. The instantaneous error for price prediction in the electricity market, using the neural network predictio method

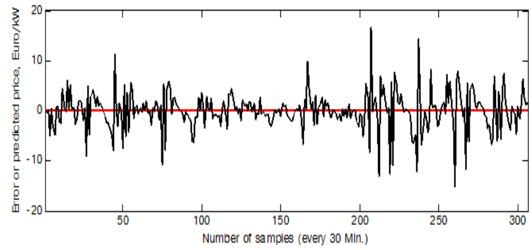

Fig. 10. The instantaneous error for price prediction in the electricity market, using the fuzzy regression prediction method

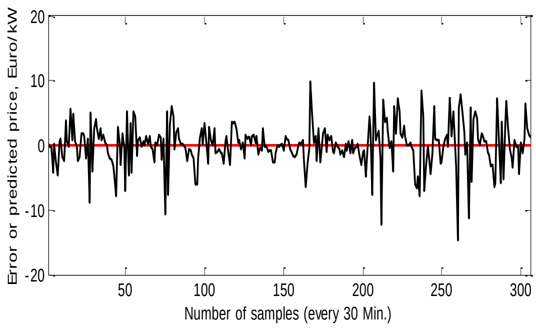

Fig. 11. The instantaneous error for price prediction in the electricity market, using our fuzzy-wavelet prediction method

Table 1. Comparison of errors among the prediction methods presented [13]

Method	MAPE (%)	Maximum (%)	MSE	Volume of calculations
Linear prediction[13]	12.59%	16.7	1.5294	High
Neural network prediction[13]	6.2%	1.346	17.06	Medium
Fuzzy prediction[13]	9.40%	1.2618	16.2	Medium
Fuzzy-wavelet prediction[our method]	8.11%	1.081	12.18	High

7. Conclusion

By evaluating the results obtained for price prediction in Queensland electricity market, it can be seen that use of fuzzy logic-wavelet forecasting method resulted in an improved performance, compared with that of fuzzy logic forecasting method. Also choosing two different types of filters; low-pass and high-pass, in the wavelet transform, increased the efficiency of the predictor in the fuzzy prediction method. To further investigate the presented methods, the results of these methods have been collected in Table 1. As can be seen, the fuzzy-wavelet method has a more desirable solution than the other presented methods have, also by choosing a suitable filter and a multiresolution processing method, the maximum error has improved by 13.6%, and the mean squared error has improved about 17.9%. But in comparison with the fuzzy prediction method, the proposed method has a higher computational volume due to use of wavelet transform as well as double usage of fuzzy prediction. Due to the large number of layers and neurons used in it, the neural network method has a much higher computational volume than our fuzzy-wavelet method has, but this method, depending on the data used for training, has a greater maximum error than the proposed method has.

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