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Multi-step ahead electricity price forecasting using a hybrid model based on two-layer decomposition technique and BP neural network optimized by firefly algorithm

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HIGHLIGHTS

- A hybrid two-layer decomposition-ensemble model is proposed for multi-step ahead electricity price forecasting.
- VMD is specifically applied to further decompose the high frequency IMFs generated by FEEMD.
- The BP model optimized by FA obtains better forecasting performance.
- The proposed model is tested using the real-world data of Australian and French electricity markets.

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ABSTRACT

In the deregulated competitive electricity market, the price which reflects the relationship between electricity supply and demand is one of the most important elements, making it crucial for all market participants to precisely forecast the electricity price. However, electricity price series usually has complex features such as non-linearity, non-stationarity and volatility, which makes the price forecasting turn out to be very difficult. In order to improve the accuracy of electricity price forecasting, this paper first proposes a two-layer decomposition technique and then develops a hybrid model based on fast ensemble empirical mode decomposition (FEEMD), variational mode decomposition (VMD) and back propagation (BP) neural network optimized by firefly algorithm (FA). The proposed model is unique in the sense that VMD is specifically applied to further decompose the high frequency intrinsic mode functions (IMFs) generated by FEEMD into a number of modes in order to improve the forecast accuracy. To validate the effectiveness and accuracy of the proposed model, three electricity price series respectively collected from the real-world electricity markets of Australia and France are adopted to conduct the empirical study. The results indicate that the proposed model outperforms the other considered models over horizons of one-step, two-step, four-step and six-step ahead forecasting, which shows that the proposed model has superior performances for both one-step and multi-step ahead forecasting of electricity price.

1. Introduction

Electricity power, as a clean and efficient energy, is essential in our daily life. Compared with traditional energy, electricity power is more suitable for the requirement of environment-friendly society. The electricity power system has played a key role in the economy sector of a country [1]. In the last few decades, the traditionally monopolistic and government-controlled electricity market has been transformed to deregulated and competitive system in many countries. Thus, the role of electricity price in balancing electricity generation and consumption becomes more important. In such deregulated and competitive market environment, electricity can be freely traded under the market environment like other ordinary commodities, so the electricity price which can reflect the relationship between supply and demand of electricity becomes one of the most important elements in the electricity market [2]. Consequently, the decision makings of all electricity market participants are highly dependent on the electricity price, making modeling electricity prices become one of

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the cornerstones of research into the energy markets [3]. For instance, the electricity price forecasting is very useful for electricity generators, retailers and consumers to determine their offering and bidding strategies. Thus, accurate electricity price forecasting is essential and significant for the whole electricity power system and market. Simultaneously, because the electricity demand highly depends on many factors such as weather, intensity of business and daily activities [4], the electricity has its own special characteristics such as randomness, non-stationarity and non-linearity, which makes the electricity price frequently fluctuate. Therefore, it is far from easy to predict electricity price with high accuracy.

The electricity forecasting methods can be divided into two categories. One is the causal relationships forecasting method which looks for causal relationships between independent variables and forecast values [5]. The other is time series forecasting method which is based upon the hypothesis that the forecast value is related to the historical series. As mentioned before, the electricity price is influenced by many complicated factors which are difficult to be determined in practical life, thus, it is a big challenge job to build a precise forecasting model using causal relationships forecasting method. Therefore, many researchers turn to forecasting electricity price based upon the time series forecasting method [6].

The most frequently used time series forecasting methods can be divided into three categories: statistical models, artificial intelligence (AI) models and hybrid models [7]. In the first category, the widely applied models mainly include auto-regressive moving average (ARMA), auto-regressive integrated moving average (ARIMA), vector auto-regression (VAR), generalized autoregressive conditional heteroskedasticity (GARCH) and kalman filters methods. For example, Chu [8] forecasts tourism demand based on ARMA models, and the results show that the models perform very well. Ramos et al. [9] employ ARIMA model to forecast consumer retail sales, and the results demonstrate that the model owns good performances in both one-step and multi-step forecasting. Nyberg and Saikkonen [10] predict the inflation and marginal cost of the U. S. using VAR model. Byun and Cho [11] forecast carbon futures volatility based on GARCH model, and the results demonstrate that the model performs better than other models in the paper. Takeda et al. [12] propose an ensemble Kalman filter method for electricity load forecasting, and the simulation results indicate that the forecast accuracy of the model is obviously better than the present state-of-the-art models.

In the second category, a great number of AI methods have been used in different forecasting fields these years, such as artificial neural network (ANN), extreme learning machine (ELM), support vector machine (SVM) and least squares support vector machine (LSSVM). For instance, Panapakids et al. [13] forecast day-ahead electricity price through application of ANN models, and the results show that ANN topologies can be examined. Gutierrez-Corea et al. [14] focus on the application of ANN in global solar irradiance (GSI) short-term forecasting, and the results of the study indicate that ANN models are suitable for predicting short-term GSI. Hassan et al. [15] develop a novel model based on ELM for electricity load demand forecasting, and the results prove the superior performance of the proposed model. Zhou et al. [16] propose a modified SVM model for short-term wind speed forecasting, and the experiments show that the proposed model can outperform the persistence model in the majority of cases. Chen and Lee [17] develop a weighted LSSVM predicting model based on a learning system for time series forecasting, and the results testify the validity of the proposed model.

However, the traditional single forecasting models applied on the original data series cannot precisely expose the complicated relations existed in the non-linear and non-stationary data series. Therefore, many researchers have been making efforts to handle the non-linearity and non-stationarity existed in the data series using different data decomposition techniques before forecasting. For example, Wang et al. [18] propose a hybrid model based on wavelet packet transform (WPT), PSOSA, phase space reconstruction (PSR) and LSSVM for wind speed forecasting, and the experiments demonstrate that the WPT decomposition technique makes great contribution on the forecast accuracy. Meng et al. [19] study the similar forecasting issue based on the WPT decomposition technique with Ref. [18], and develop a novel hybrid model integrated crisscross optimization algorithm, WPT and ANN. Their results based on two wind speed series collected from a wind power observation station located in the Netherlands demonstrate that the proposed hybrid model outperforms other benchmark models. Liu et al. [20] also investigate the similar forecasting issues with Ref. [18], and develops a novel hybrid model based on wavelet transform (WT) and SVM optimized by genetic algorithm (GA). Xiong et al. [21] develop a novel bivariate EMD-based SVM model for interval-valued electricity demand forecasting, and the experiment demonstrates that the proposed model is a promising method.

Although the hybrid models integrated single decomposition techniques can improve the forecasting ability to some extent, while because the single decomposition techniques often cannot thoroughly deal with non-stationarity of random and irregular data series, there still exist some probabilities for improving the model's forecasting ability. Therefore, combining the advantages of single decomposition techniques, this paper proposes a novel hybrid model based on two-layer decomposition technique and BP neural network optimized by FA for multi-step ahead electricity price forecasting. Firstly, FEEMD is employed to decompose the electricity price series into a number of IMFs with different frequencies and a residual. Since high frequency IMF1 may increase the forecasting difficulty, therefore, VMD is further applied to conduct the secondary decomposition of IMF1, and a set of modes are obtained. Next, BP model optimized by FA is utilized to forecast the modes obtained from VMD decomposition, the IMFs apart from IMF1 and residual. Finally, the forecast value of IMF1 is obtained through aggregating the forecast values of all modes, and the forecast series of electricity price is obtained by adding up the forecast values of all IMFs and residual. The proposed model is tested using three electricity price data series collected respectively from the real-world electricity markets of Australia (New South Wales (NSW) and Queensland (QLD)) and France.

Based on aforementioned researches, the main novelties and contributions of the paper can be denoted in the following three respects: (1) the paper proposes a novel hybrid model based on two-layer decomposition technique and FA-BP method for multi-step ahead electricity price forecasting. Even though the existing single decomposition techniques and their variants such as EMD and EEMD have already been extensively applied in the forecasting issues, for example, [22] and [23], however, many researches show that the high frequency IMFs (especially IMF1) are influenced by many stochastic factors, making it very hard to model accurately [24]. In addition, it is found that the more non-linear and non-stationary original series leads to more irregular high frequency IMFs [25]. Therefore, to tackle the aforementioned problem, this paper proposes for the first time a two-layer decomposition technique where VMD is specifically applied to further decompose the high frequency IMFs into a number of modes in order to reduce their non-stationarity; (2) FA is applied to optimize the weights and thresholds between input layer and hidden layer of BP model in order to improve the function approximation ability of BP model, especially on the catastrophe points; (3) three electricity price series collected respectively from Australia (NSW and QLD) and France are employed for evaluating the proposed model. Since the different regional scales, population, geographical positions,