Comparative Analysis of Two Methods of Natural Gas Demand Forecasting

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Abstract. Based on the monthly dataset of natural gas demand and meteorological factors in heating season (November to next March) of Beijing from 2002 to 2013, an analysis of meteorological condition of natural gas fluctuation is done, which used by Empirical Mode Decomposition (EMD) and statistical correlation methods. A novel intelligent prediction model (EMD_BP) of natural gas demand in heating season via EMD and Back Propagation (BP) neural network algorithm is proposed. In addition, we adopt a prediction model only using BP neural network algorithm compare to the above combine method. The results are as follows, (1) EMD method is a better approach to decompose the social demand and meteorological demand of natural gas. (2) There is a close affinity between natural gas demand and meteorological factors in heating season. The meteorological demand of natural gas is significantly negatively correlated with the mean temperature (also minimum temperature, maximum temperature and negative accumulated temperature), but significantly positively correlated with rainfall and low temperature (≤-8℃) days. (3) Comparing with BP model, EMD_BP model can accurately fit the changing tendency of natural gas time series. The results show that the EMD_BP prediction model has better applicability and extensive popular prospect.

Keywords: Empirical Mode Decomposition (EMD), Heating Season, Meteorological Condition, Natural Gas Demand, Prediction Model

1. Introduction

With the rapid development of the economy and the improvement, the demand for energy continues are growing deeply, which became more serious that leading great social stress on energy-saving emission reduction and environmental protection. At present, a lot of research has been carried out on the analysis and prediction of natural gas demand in China [1-5]. Su Xin [6] summarized the characteristics of natural gas demand at home and abroad. Currently, the common forecasting methods are mainly statistical methods, artificial intelligence methods and economic mathematical models. Ding Feng [7] analyzed the relationship between natural gas demand and meteorological factors such as daily mean air temperature, pressure and precipitation, Wang Shugang [8] took effective temperature as the main factor and constructed natural gas demand forecasting model that combining with the temperature distribution rule of Dalian. However, there are few researches on natural gas influence mechanism and prediction method in Beijing.
The consumption of natural gas in winter that is mainly used for heating and power generation in Beijing, especially affected by meteorological factors. If it suffered disaster weather such as great snow, the low temperature lasted for a long time, which would be result in effecting the natural gas on supply and demand imbalance occurred temporarily, directly threatened the safe operation of the city's natural gas supply system. Therefore, accurate prediction of natural gas demand is conducive to ensure the optimal operation of the natural gas pipe network system, which provides a scientific basis for relevant management and departments to make natural gas schedule plans in Beijing.

This paper takes the natural gas demand in the heating season as the research object, aiming at the nonlinear and non-stationary characteristics of natural gas demand. Based on the empirical mode decomposition (EMD) method processing non-stationary signals and back propagation neural network approach (BP) method that advantages in dealing with nonlinear problems. Finally, together with both method to component the EMD_BP mothed to build natural gas demand forecast model and used by the absolute error method to test the model fitting quality.

2. Data and Methodsm

2.1. Data

The selection of natural gas date is that the monthly dataset of natural gas demand in heating season (November to next March) of Beijing from 2002 to 2013.

There are 20 number of normal weather stations in Beijing, 15 in which are chosen to research in this paper, the other 5 stations (Foyeding, Tanghekou, Shangdianzi, Zhaigang, Xiayunding) were built on the suburb of high altitude, which are unrepresentative that would not be considered. The meteorological factors contain maximum air temperature (Tmax), minimum air temperature (Tmin), mean air temperature (T), precipitation (Rain), wind velocity (Ws). As well as, two parameters that can represent the degree of cold and warm in winter are introduced, negative accumulated temperature [9] and low temperature days. Negative cumulative temperature (NAT) refers to the cumulative value of the daily average temperature less than or equal to 0°C. And low temperature days (LTd1 and LTd2, unit: d) refers to the cumulative number of days in which the minimum temperature is less than the certain threshold (-5°C and -8°C were selected) in this paper.

2.2. Methods

In this study, correlation analysis, EMD [10] and other methods are mainly used to analyse the characteristics of natural gas demand and mainly impacted meteorological factors. BP artificial neural network method [11] is used to construct prediction models of natural gas demand respectively based on BP and EMD_BP mothed.

Natural gas demand is a complex system and exist high complexity and nonlinearity. BP artificial neural network method has evident advantages on making predictions about this kind of problem [1]. At the same time, the time series of natural gas demand possess the typical nonstationary characteristic that using EMD method to smooth nonlinear and nonstationary signal, which to separate the fluctuation of different period from the original signal. Then it gets a set of different the Intrinsic Mode Function (IMF) and a trend component, which can make predict result more reasonable and effective.

3. Extraction of Natural Gas Meteorological Demand

Natural gas demand is mainly affected by social economic and meteorological conditions, which presents a long-term trend of change and fluctuation over time, while meteorological conditions are the main reason for short-term gas demand fluctuation. Therefore, social development and other factors would be excluded on studying the relationship between meteorological conditions and natural gas demand. In this paper, EMD method is adopted to decompose the time series of natural gas demand.
According to statistics, the total gas consumption accounted for 80% of the accumulative measurement from 2002 to 2013 in Beijing. In this paper, two decomposition quantities, IMF1 and IMF2, would be obtained by EMD analysis of natural gas demand timing sequence in heating season. Figure 1 showed the trend chart of EMD decomposition quantities, IMF1 and IMF2 of natural gas demand in heating season from 2002 to 2013. Compared with the total natural gas demand in the heating season, IMF1 was a high-frequency component with a fluctuating trend, while IMF2 was a trend term with showing a linear growth trend.

The high frequency component IMF1 represented the situation of short period fluctuation. The correlation coefficient between IMF1 component and average temperature, GDP, permanent population were -0.69, 0.47, 0.45. Only average temperature passed the significance test (α=0.05). It was obvious that the IMF1 component mainly reflect the influence of meteorological conditions. The average temperature was above 0°C during the heating season of Beijing from 2002 to 2013, except
2009(-1.3℃) and 2012(-0.9℃). From figure 1b, heavy snowfall and the low temperature lasted for a long time in 2009 and 2012 of winter [12-13]. This component that between the two peaks in the valley was defined as the meteorological demand of natural gas in this paper.

The trend item IMF2 represented the long-term natural gas demand. The figure 1c showed that IMF2 present a linear growth trend in a period of rapid growth from 2004 to 2009, with a growth rate up to 12%~18%, and the largest growth rate happened in 2008. The correlation coefficient between the IMF2 component and average air temperature was -0.26, while which with GDP and resident population was over 0.9. It was quite clear that the IMF2 component was in relatively good correlation with GDP and resident population.

4. Correlation between Natural Gas Meteorological Demand and Meteorological Factors
There is a very close relationship between the natural gas meteorological demand (NGMD) and meteorological factors (T, T_{min}, T_{max}, Ws, Rain, NAT, LTd{1}, LTd{2}) in Beijing during the heating season from 2002 to 2013 (Table2). Obviously, there was a negative correlation between NGMD and temperature (T, T_{min}, T_{max}), but a significant positive correlation with the number of low temperature days (<-8℃) and precipitation.

According to the trend chart of meteorological demand in the heating season from 2002 to 2013 (Figure 1b), there were two peaks and valleys respectively in NGMD, with the peaks in 2009 and 2012 and the valleys in 2007 and 2010. Compared with the average heating season temperature (0.8) in the past 10 years (2002-2013), the temperature in 2007 and 2012 were 0.6 and 1.7 that respectively higher and lower than other years. It was a warm winter in 2007, the numeric value of precipitation and low temperature days (< 8℃) significantly lower than the average in recent 10 years, the negative accumulated temperature on the high side, leading to negative growth of natural gas demand. However, because of cold winter in 2012, it was rarely occur that the temperature of partial intensity cold duration and heavy snow in recent years, natural gas demand growth to a highly record value, which up to more than 600 million cubic meters of nearly 10 years on a high side.

According to the correlation analysis and the comparison results of individual cases, the natural gas meteorological demand and meteorological factors were extracted by EMD method that own a good consistency and correlation. When it occurred the overall low temperature and the strong snowfall, the meteorological demand for natural gas would increase greatly in heating season.

| Table 1. The correlation coefficients between NGMD and meteorological factors |
|---------------------------------|-----------------|-----------------|-----------------|
| NGMD | T | T_{min} | T_{max} | Ws | Rain | NAT | LTd{1} | LTd{2} |
|------|---|---------|---------|----|------|-----|-------|-------|
|      | -0.69* | -0.62* | -0.66* | -0.32 | 0.80* | -0.68* | 0.56 | 0.59* |

note: * mean passed significance test α=0.05

| Table 2. The corresponding relation table between NGMD and meteorological factors |
|---------------------------------|-----------------|-----------------|
| NGMD | T | Rain | NAT | LTd{2} |
|------|---|-----|-----|-------|
| 2007 | -15158 | 1.4 | 22.1 | -231.0 | 29.2 |
| 2012 | 71160 | -0.9 | 106.0 | -421.8 | 49.4 |
| Recent 10 years | 10095 | 0.8 | 37.3 | -278.7 | 35.3 |

5. Forecasting Model Establishment and Analysis

5.1. Forecasting model
It is random and uncertainty for the natural gas demand, which represents a typical non-stationary time series and difficult to predict. Based on the EMD_BP method of natural gas demand forecasting model, considering the advantages of EMD method in dealing with non-stationary signals and BP neural network method in dealing with nonlinear problems, we made a flow chart (figure 2) for comparison
and validation that only using BP neural networks method to forecast model without EMD. The steps for building the two models are as follows.

1. BP neural networks method made the total natural gas demand as a predictor in heating season, as well as T,Rain,NAT,LTd2 and time series for modeling factors.
2. EMD_BP method was used to decompose from the original sequence on the meteorological and social demand. Selecting T, Rain, NAT and LTd2 as modeling factors of meteorological demand, while time series as modeling factors of social demand. Based on the BP neural networks method to build forecasting models of meteorological and social demand. Finally, the predicted value of natural gas demand would be built by sum of two components in heating season.

![Figure 2. Prediction model of EMD and BP neural network](image)

5.2. Contrastive analysis
To compare the accuracy of forecasting model by BP neural networks method and EMD_BP method, it was selected that natural gas demand of heating season as modeling sample in Beijing from 2002 to 2013. And the absolute error was used to test above two methods. It represented the fitting results and actual trends by vector graph (figure 3), which were the meteorological demand (IMF1), social demand (IMF2) and total natural gas demand from 2002 to 2013.

It can be seen that the fitting and observation of the two components, IMF1 and IMF2, were similar. In particular, the forecast model of meteorological demand displayed a good fitting effect for abrupt increase and decrease points. The fitting error of EMD_BP and BP method were 3.7% and 4.6% respectively, and the former get a higher fitting accuracy, especially in the abrupt increase points (2009 and 2012) and the abrupt decrease points (2010). However, BP method can only fit the overall growth trend, and the fitting effect of turning point is poor.

Natural gas demand mainly consists of growth and randomness signals, which set meteorological demand and social demand in this paper. It is a good predictive ability to grow a steady growth in social demand, while not good forecast on meteorological demand by the effort of disaster weather like heavy snowfall, low temperature. Based on the decomposition of EMD method result, it gets nearly an order of magnitude of difference between social demand and meteorological demand. If the total demand is not decomposed, using BP method can only fit the linear growth trend of social demand, while not well for the fitting effect of abrupt point caused by meteorological conditions.
To deal with the problem, the ideal of EMD_BPS method is to decompose two signals with different change rules, and then select the main influencing factors respectively to establish the prediction model. In this way, it is well fitted that the growth trend affected by social factors and the fluctuation trend affected by meteorological conditions, the predict result would be closer to the actual demand.

Also discussed are the fitting results of two method, EMD_BPS method shows the better accurate results. In the prediction of natural gas demand in heating season, we first choose EMD method to stabilize the original series, which can reduce the impact of non-stationary characteristics of the series on the prediction results, and then use BP method to obtain a better prediction effect.

Figure 3. The comparison between fitting value and actual value of IMF1 (a) and IMF2 (b) components, natural gas demand (c) in heating season in Beijing during 2002-2013
6. Conclusion and discussion

Introduced EMD method for smoothing nonlinear and non-stationary signal processing in this paper, which to carry on the time-scale separation for the time series of natural gas demand of heating season in Beijing, and to analyze the relationship between the natural gas demand and meteorological elements. A novel intelligent prediction model (EMD_BP model) and BP neural network algorithm of natural gas demand in heating season are built the prediction models, the main conclusions are as follows.

(1) The social demand and meteorological demand of natural gas can be better extracted by EMD method, among which the former shows a stable growth trend, and the latter shows a fluctuating change trend due to the influence of meteorological conditions.

(2) There is a very close relationship between the natural gas meteorological demand and meteorological factors in Beijing during the heating season. Obviously, there is a negative correlation between NGMD and temperature, while a significant positive correlation with the number of low temperature days (<-8°C) and precipitation.

(3) To compare the accuracy of forecasting model by BP neural networks method and EMD_BP method, the fitting error of EMD_BP and BP method were 3.7% and 4.6% respectively, and the former get a higher fitting accuracy, especially in the abrupt increase points (2009 and 2012) and the abrupt decrease points (2010).

Considering the poor sample data, it is only test the fitting ability of the prediction model. With the data accumulation, the prediction ability of the model will be further tested and continuously improved through the accumulation of samples.

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