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Energy Demand Forecasts Based on Improved Gray Neural Network Algorithm

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Abstract

Energy demand forecasting and energy consumption structure analysis were important foundation for energy planning and development of new energy, so energy forecasting result was required as close as possible to the actual value. To improve the prediction accuracy, this article combined back propagation (abbreviated bp) neural network and gray phase to build an improved gray neural network prediction method, and using genetic algorithms to optimize it. The experiment proved that this model has high prediction accuracy, and used it to predict the energy demand in Hebei Province, the results proved the validity of the model. Finally, the article also analyzed the energy structure and the development of new energy based on forecast results in Hebei Province.

Keywords: *energy consumption, energy forecasting, gray neural network, genetic algorithm*

1. Introduction

Energy is an important material foundation for economic development and social progress, with the rapid economic development, the provinces energy consumption is increasing year by year, the energy consumption has been an imbalance in supply and demand, Non-renewable energy is a major part of the energy consumption, energy waste is too serious, in recent years, although improvements in resource conservation and energy use due to the government policy, but in general, there is still a high consumption of resources [1], waste, and serious environmental pollution problems. Rapid economic development in Hebei Province, the energy consumption rely on primary energy coal, energy efficiency is low, Long-term development will limit the economic development of Hebei Province [2], therefore, on the basis of understanding of the status of the energy supply and demand in Hebei Province,and to forecast its energy demand for the next few years, it has a certain significance for the solution of the energy structure contradictions in the "12th Five-Year Plan" of Hebei Province Energy [3].

Economic development accompanied by excessive consumption of energy has become increasingly important, energy demand forecasting has become the focus of attention of domestic and foreign scholars. In this paper, it uses a gray neural network model to predict the energy demand, the convergence rate is fast , but randomly initialize the network connection weights and threshold values can easily fall into local optimum and affect the accuracy of energy projections. In order to improve the prediction accuracy of the network, it uses genetic algorithms (GA) to optimize gray neural network parameters. Relative to the reference model, the prediction accuracy of gray neural network has been further improved after the genetic algorithm optimizing.

2. The Proposed Method

2.1. Gray Theory

In gray system model, the gray model referred to as the GM model [4], the model builds differential equations base on the original data sequence. The most representative model in Gray modeling is GM modeling of time series, it converts the time-series data to differential equation and uses the system information making the abstract model quantified, and then forecasts system output in the case of lack of knowledge of system output.

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First, GM model do a cumulative of the original data sequence to make the accumulated data show a certain law, then using the typical curve to fit this curve [5]. Supposed there are time series $x^{(0)}$:

$$x^{(0)} = (x_t^{(0)} \big| t = 1,2,..., n) = (x_1^{(0)}, x_2^{(0)},..., x_n^{(0)}) \tag{1}$$

Making an accumulation for $x^{(0)}$ can obtain the new data sequence $x^{(1)}$ the t-th of the new data sequence $x^{(1)}$ is the sum of the first t terms of the original sequence $x^{(0)}$.

$$x^{(1)} = (x_t^{(1)}) \Big| t = 1,2,..., n) = (x_1^{(0)}, \sum_{t=1}^{1} x_t^{(0)}, \sum_{t=1}^{2} x_t^{(0)},..., \sum_{t=1}^{n} x_t^{(0)}) \tag{2}$$

We can establish the albino equation according to the new data sequence, that is:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = u \tag{3}$$

The solution of the equation is $x_t^{*(1)} = (x_1^{(0)} - u/a)e^{-a(t-1)} + u/a$

$x_t^{*(1)}$ is the estimated value of $x_t^{(1)}$, Do a regressive for $x_t^{*(1)}$ can obtain predictive value. Then:

$$x_t^{*(0)} = x_t^{*(1)} - x_{t-1}^{*(1)} \qquad t=2,3,... \tag{4}$$

2.2. Gray Neural Network

The gray question is to predict behavior eigenvalue development and changes of the gray uncertain system [6-12], the original series of the eigenvalue of the uncertain system $x_t^{(0)}$ (t=0,1,2,...,N-1) after time accumulated can generate series $x_t^{(1)}$, it shows exponential growth law, so it allows using a continuous function or differential equation for data fitting and forecasting. To express conveniently, the symbol can be redefined, The original series $x_t^{(0)}$, $x_t^{(1)}$ and $x_t^{*(1)}$ is expressed as $x(t)$, $y(t)$ and $z(t)$ respectively.

The expression of differential equation of the gray neural network model with n parameters is:

$$\frac{dy_1}{dt} + ay_1 = b_1 y_2 + b_2 y_3 + ... + b_{n-1} y_n \tag{5}$$

Where, $y_1, y_2,..., y_n$ are the input parameters for the system, y_1 is output parameters for the system; $a, b_1, b_2,..., b_{n-1}$ are the coefficient of the differential equations.
The time response formula of Equation (5) is:

$$z(t) = (y_1(0) - \frac{b_1}{a} y_3(t) - \frac{b_2}{a} y_3(t) - ... - \frac{b_{n-1}}{a} y_n(t))e^{-at} + \frac{b_1}{a} y_2(t) + \frac{b_2}{a} y_3(t) + ... + \frac{b_{n-1}}{a} y_n(t)$$

$$d = \frac{b_1}{a} y_2(t) + \frac{b_2}{a} y_3(t) + ... + \frac{b_{n-1}}{a} y_n(t) \tag{6}$$

Equation (6) can be transformed into Equation (7).

$$z(t)=\left((y_1(0)-d)\cdot\frac{e^{-at}}{1+e^{-at}}+d\cdot\frac{1}{1+e^{-at}}\right)(1+e^{-at})=$$
$$\left((y_1(0)-d)(1-\frac{1}{1+e^{-at}})+d\cdot\frac{1}{1+e^{-at}}\right)\cdot(1+e^{-at})= \tag{7}$$
$$\left((y_1(0)-d)-y_1(0)\cdot\frac{1}{1+e^{-at}}+2d\cdot\frac{1}{1+e^{-at}}\right)(1+e^{-at})$$

The equation (7) is mapped to an extended BP neural network to get the gray neural network of n input parameters and an output parameter, the network topology is shown below:

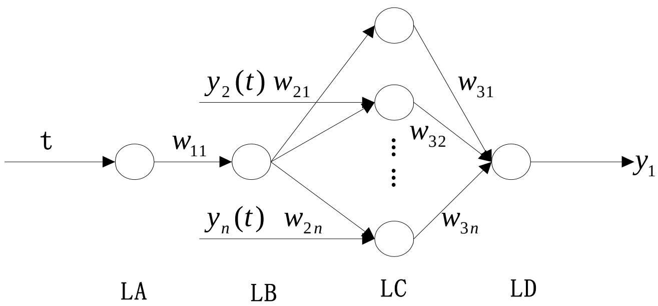

Figure 1. Gray Neural Network Topology

Where, t is the number of input parameter, $y_2(t),...,\ y_n(t)$ are network input parameters; $w_{21},w_{22},...,w_{2n},w_{31},w_{32},...,w_{3n}$ are network weights; y_1 is network predictive value; LA、LB、LC and LD represent the four layers of gray neural network respectively.

Making $\frac{2b_1}{a}=u_1,\frac{2b_2}{a}=u_2,...,\ \frac{2b_{n-1}}{a}=u_{n-1}$,then network initial weight value can be expressed as:

$$w_{11}=a,\ w_{21}=-y_1(0),\ w_{22}=u_1,w_{23}=u_2,...,w_{2n}=u_{n-1}$$
$$w_{31}=w_{32}=...=w_{3n}=1+e^{-at}$$

The threshold of the output node of LD layer is:

$$\theta=(1-e^{-at})(d-y_1(0))$$

Gray neural network learning process is shown as follows:

Step one: We can initialize the network structure and parameters a, b according to the characteristics of the training data, then calculate μ based on the value of a, b.

Step two: Calculate $w_{11},w_{21},w_{22},...,w_{2n},w_{31},w_{32},...,w_{3n}$ based on the weights of the network defined.

Step three: Calculate the output of each layer for each input sequence（t,y(t)）,t=1,2,3,...,N.

Step four: Calculate the network forecast output and the expected output error, and adjust weights and thresholds according to the error.

Step 5: judge whether the training is over, and if not, return to Step 3.

3. Empirical Analysis

3.1. Index Selection and Data Collection

There are many influencing factors which affecting energy demand, such as GDP, energy production, the level of consumption, year-end population, the proportion of coal in total energy consumption, the contribution rate of the secondary industry, technological progress, the level of urbanization, etc., but energy prices, energy processing and conversion rate data is incomplete. The paper selects the input indexes which can represent the vast majority of the index information as predicted input in order to improve the accuracy of the forecast, which including GDP, the level of consumption, year-end population, the proportion of coal in total energy consumption, the second industry contribution rate, the data of analysis are selected from 22 set of sample data which are from 1990-2011 of Hebei Province. The data are from Hebei Economic Yearbook.

The 22 sets of data is divided into a training set and a test set, the first 17 as a training set to train the network, the rest of the data as a test set to evaluate the prediction accuracy of the prediction model.

3.2. The Forecasting Results Analysis of Grey Neural Network

There are five main factors affecting energy consumption as input, network output is energy consumption, Gray neural network structure is 1-1-6-1, network training times are 50 times, in this paper, it uses MATLAB neural network toolbox function to initialize Gray neural network parameters, The learning rate of each layer is 0.015, Gray neural network forecasting fitting Figure is shown in Figure 3.

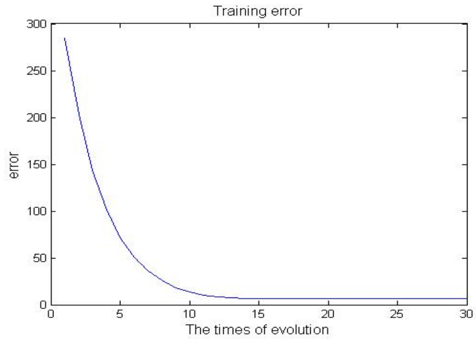

Figure 2. Gray Neural Network Training Process

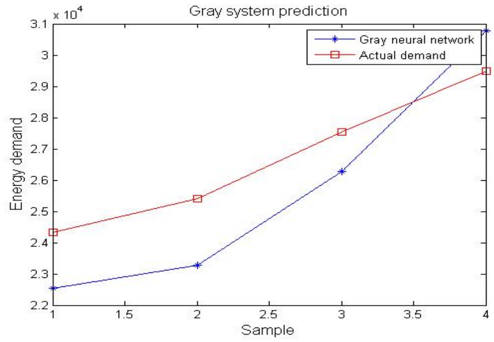

Figure 3. Gray Neural Network Fitting Figure

Gray neural network training error curve shows gray neural network convergence speed is quickly, but soon it falls into local optimum value and can not be further optimized, meanwhile, the optimal neural network parameters can not be obtained. Figure 3 shows the fitting of gray neural network, it can be seen from the figure, the network has a better fit.

3.3. GA Optimization Gray Neural Network

From Figure 3, we know that gray neural network convergence speed is quickly, but because random initialization method is often used to initialize the network weights and threshold, it makes forecast soon ran into a local optimum value, the predicted results are very unstable and the error is large. The genetic algorithm can optimize the parameters and improve forecast accuracy, we can use the knowledge of genetic algorithms optimizing the neural network to optimize the parameters of the gray neural network., including six parameters: a、b_1、b_2、b_3、b_4、b_5.The article uses Real-coded GA individual and takes Gray neural network prediction error as a function of the individual fitness, the optimal weights and threshold can be obtained through genetic evolution operation , programming method is similar to the GA optimization neural network, The predicted result is shown in Figure 4, at the same time, the optimal initial parameter values which optimized by the GA are shown in Table 1.

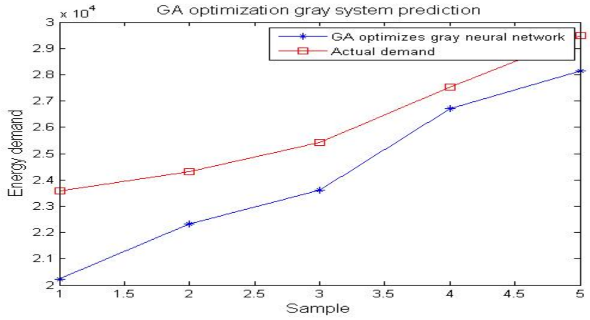

Figure 4. GA Optimization Gray Neural Network Fitting

Table 1. Optimal Initial Parameters Optimized by GA

Parameter name	a	b1	b2	b3	b4	b5
Parameter values	0.4026	0.5234	0.3145	0.3882	0.5033	0.3025

From Figure 3 and Figure 4, we can fit probably see the fitting degree between forecasting results of Gray neural network optimized by GA and desired output, in order to better illustrate the gray neural network optimized by GA has higher prediction accuracy, we select bp neural network, gray neural network as a comparative model comparison, we choose the same training set to train the network, the number of iterations is set to 50, and then use the same set of tests to test the network, the predict results of each prediction model are shown in Figure 5.

4. The Results and Discussion

It can be seen from Figure 6, compared with gray neural network without GA optimization and bp neural network, the predict curve fitting degree of gray neural network optimized by GA is the best. The calculated results show that average relative error of gray neural network optimized by GA, gray neural network and bp neural network are 7.43%, 8.11%, 10.61% respectively, it is suggested that gray neural network optimized by GA is successful, it can find the global optimum parameters of the neural network quickly, avoid gray neural network falling into local optimum defects easily and improve the accuracy of the energy demand forecast. Using trained network to predict the energy consumption in 2013-2015, the forecast results are shown in Table 2.

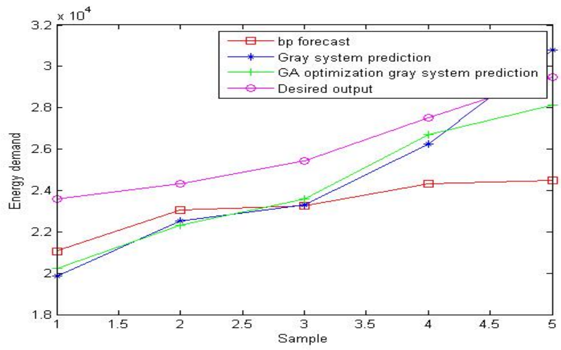

Figure 5. The Contrast of Different Predictive Models Predicted Results

Table 2. Total Energy Consumption Forecast in Hebei Province for 2013-2015

Year	2013	2014	2015
Energy consumption (Million tons of coal)	31825.1	32882.6	33912.5

It can be seen from Table 2 that the average growth rate of energy consumption is reduced in the next five years in Hebei Province, which may be due to the "12th Five-Year Plan" of Hebei Province, but in general, the trend is increasing, this is related to extensive mode of economic development in Hebei Province, economic development mainly depend on the secondary industry, and in the three major industries, the secondary industry accounts for the largest proportion of energy consumption, energy consumption structure is irrational, and the development of some areas in Hebei Province do not make full use of geographical advantages, the development of new energy sources is relatively backward, energy consumption is still dominated by coal high-polluting energy sources.

In the energy planning constraints, Hebei Province should speed up the adjustment of energy consumption structure, Secondary industry as a pillar industry in Hebei Province which highlight the extensive model of economic development, the secondary industry contributed 62.7% for Hebei region GDP in 2011, the industry contributed 62.7% for secondary industry, so the main energy saving planning in Hebei is to adjust the model of economic development, related sector units should deal with the relationship of economic development and energy development of high energy-consuming industries to complete the change of economic development from extensive to intensive. It should reducing the proportion of the high energy-consuming industries in the three major industries and develop the tertiary industry vigorously in order to reduce the energy and environmental pressures.

Meaning, taking full advantage of the geographical advantage in Hebei to develop new energy, for example: Zhangjiakou and Chengde develop photovoltaic power generation and wind power; Qinhuangdao and Cangzhou focus on the development of nuclear power; Langfang and Cangzhou develop biomass power generation, etc.

5. Conclusion

Energy demand forecasts has an important significance for energy planning and development of new energy, this article use the GA optimization gray neural network model making predictions, empirical analysis results show that the GA optimization gray neural network has higher prediction accuracy, then use this model to predict the energy demand in Hebei, The results show that energy demand continues to grow in the next three years, energy conservation is still a challenge, then it proposes to accelerate the adjustment of energy structure and the development of new energy sources in Hebei Province,this is the only way to achieve rapid development of the energy economy.

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