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Application of Improved Grey Model in Long-term Load Forecasting of Power Engineering

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Abstract

Grey model is usually been used for long-term load forecasting in power engineering, but it has significant limitations. If the moving average method and Markov model are connected with grey model, the accuracy of this improved grey model used for long-term load forecasting in power engineering can be effectively increased. In this paper, ordinary grey model and improved grey model are all chosen and used for long-term power load forecasting in power engineering, and the power load data of Qingdao in the past decade is selected for the analysis. The result of the analysis shows that the accuracy of improved grey model is significant higher than ordinary model, so the improved grey model can be used for long-term load forecasting in power engineering.

Keywords: Grey model; Moving average method; Markov model; Power engineering;

1 Introduction

Power industry, as the basic industry, provides sufficient energy support for economic development in any country. Stable power load is closely related with economic development, so accurate and timely power load forecasting is dramatically important for the development of power industry and national economy. View from macro point, the accuracy of load forecasting in power engineering is directly related to the decision-making about energy industry, to the power industry's overall investment and also to the grid layout and reasonable grid operation. View from micro point, the accuracy of load forecasting in power engineering is not only directly related to the stability of power grid, to the production efficiency and economic benefits of power plants, but also related to the daily work of the power grid companies and power plants.

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According to the length of time span, load forecasting can be divided into long-term, medium-term and short-term. And the methods of load forecasting can be divided into empirical analysis methods and quantitative analysis methods in a broad sense points. The empirical analysis methods includes experts predict method, analogy method and subjective probability method; the quantitative analysis methods includes unit power consumption analysis method, elasticity coefficient analysis methods, regression analysis methods, time series analysis methods, artificial neural network model and the grey model. In recent years, many experts have deeply studied grey model and found out many new regulations of this model, which have gotten the social recognition in certain degree. Due to having the advantage of need less date and less computation, grey model has been widely used for long-term load forecasting in power engineering. However, when the fluctuations of load growth curve is more large, if it continues to use grey model for long-term load forecasting in power engineering, the deviation between the predictive value and actual load may be more large, which will bring significant limitations for the application of this model. So, this paper proposes an improved grey method based on moving average method and Markov model, which can not only increase accuracy of ordinary grey model and be also be used for long-term load forecasting in power engineering in the condition of large load fluctuation.

2 Grey theory and grey model

In 1982, grey theory was first proposed by Chinese Professor Julong Deng, which was usually used for analysis with less data or uncertain data. The advantage of this model is that it can analyze the characteristics of things, know the behavior, find out the potential laws and reveal the internal changing laws in the condition of less relevant analysis data. The GM(1,1) and GM(1, N) are common grey models. The GM(1,1) is first-order model and only contains one variate, and the GM(1,N) is also first-order model but contains N variates. The essence of grey model is using the process of accumulation or regression or weighted to deal with original data with not strong regularity, and then the original data may become a new regularly number sequence, which can be used for GM(1,1) or GM(1,N). When the model is finished, the relevant differential equations can also be framed, so the relevant parameters of differential equations can be fixed by solving the equation. Finally, the grey model is been set up, which can be used for load forecasting in power engineering. Detailed method is as follows:

If the number sequence of original data is $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$, (1)

by accumulation the sequence becomes

$$\begin{aligned} x^{(1)} &= \left(x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n)\right) \\ &= \left(x^{(1)}(1), x^{(1)}(1) + x^{(0)}(2), \cdots, x^{(1)}(n-1) + x^{(0)}(n)\right) \end{aligned} \quad (2)$$

And

$$x^{(1)}(k)=\sum_{i=1}^{k}x^{(0)}(i)\quad (k=1,2,\cdots,n)$$

Mean sequence is

$$z^{(1)}(k)=0.5x^{(1)}(k)+0.5x^{(1)}(k-1)\quad (k=2,3,\cdots,n)$$

It also means $z^{(1)}=(z^{(1)}(2),z^{(1)}(3),\cdots,z^{(1)}(n))$ （3）

So the differential equations of this grey model can be expressed as

$$x^{(0)}(k)+az^{(1)}(k)=b\quad (k=2,3,\cdots,n) \tag{4}$$

In the differential equation, $x^{(0)}(k)$ is named as grey derivative， a is named as evolution system， $z^{(1)}(k)$ is named as evolution system background values， b is named as grey action, if the numbers $k=2,3,\cdots,n$ are introduced in the equation, the equation can be expressed as

$$\begin{cases} x^{(0)}(2)+az^{(1)}(2)=b \\ x^{(0)}(3)+az^{(1)}(3)=b \\ \cdots\cdots \\ x^{(0)}(n)+az^{(1)}(n)=b \end{cases}$$

Let $Y_N=(x^{(0)}(2),x^{(0)}(3),\Lambda,x^{(0)}(n))$, $u=(a,b)^T$ $B=\begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ M & M \\ -z^{(1)}(n) & 1 \end{bmatrix}$,

If Y_N is named as data vector， B is named as data matrix， u is named as parameter vector，

GM(1,1) can be expressed as vector equation $Y_N=B\cdot u$,

So the relevant whitening differential equation is $\dfrac{dx^{(1)}}{dt}+ax^{(1)}(t)=b$ （5）

Introducing the data solving the equation (least square method), the result is

$$x^{(1)}(k+1)=\left(x^{(0)}(1)-\frac{b}{a}\right)e^{-ak}+\frac{b}{a}\quad(k=1,2,\cdots,n-1)$$ （determining parameters a, b） （6）

According to above analysis, the whitening model of GM(1,1) can be expressed as

$$\hat{x}^{(1)}(k+1)=\left(x^{(0)}(1)-\frac{b}{a}\right)e^{-ak}+\frac{b}{a}\quad(k=1,2,\cdots,n-1)$$ （7）

If the processing of regression is used for the above model, the sequence of original data can be expressed as

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k)\quad(k=1,2,\cdots,n-1)$$ （8）

3The improvement for grey model

Although the principle of grey model is simple, the needed sample data is less and calculation is easy, the tradition GM(1,1) has some limitation. Especially when the discreteness of data is comparatively large, the accuracy may also be large lowered. So grey model can only be used for medium and long term load forecasting in the condition of Variables showing a constant monotonicity. Once the data is less significant variation regularity, the errors may be very huge. So the grey model needs to be improved to increase accuracy.

3.1 To process the original data using weakening regular pattern method

When begin to process the original data, it should firstly observe the dispersion degree of original data. If the dispersion degree of original data is smaller, the effect of the process is not conspicuous, so it needn’t to be processed by the method of weakening regular pattern. But when the dispersion degree of original data is bigger, it needs to be processed so that the adverse effects of abnormal data can be reduced. This paper firstly uses accumulation process to deal with the original data, and then uses the method of moving average to deal with the whole number sequence, the formula to deal with the number sequence is

$$\hat{x}^{(0)}(t)=\frac{x^{(0)}(t-1)+2x^{(0)}(t)+x^{(0)}(t+1)}{4}\qquad t=2,3,\cdots,\text{n}-1$$ （9）

Two endpoints of the new number sequence are

$$\hat{x}^{(0)}(1)=\frac{3x^{(0)}(1)+x^{(0)}(2)}{4}$$ (10)

$$\hat{x}^{(0)}(n)=\frac{3x^{(0)}(n-1)+x^{(0)}(n)}{4}$$ (11)

By using the method of moving average to deal with the number sequence, the adverse effects of the abnormal can be weakened, and the result of load forecasting may be more accurate. So using reverse process to deal with the result of load forecasting by grey model, the needed result of forecasting can be calculated.

3.2 To correct salvage value based on Markov model

The usual test method of GM(1,1) is salvage value test. So name salvage value as $\varepsilon(k)$ and calculate

$$\varepsilon(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)} (k = 1,2,\cdots,n) \tag{12}$$

If $\varepsilon(k) < 0.2$, it considers that the forecasting value meets the general requirements; if $\varepsilon(k) < 0.1$, it considers that the forecasting value meets the higher requirements.

But this test method is only using salvage value to test the accuracy of forecasting value, but not using salvage value to correct forecasting value. So this paper constructs a salvage value correction model based on Markov model, which uses salvage value to correct forecasting value and increase the accuracy it.

Firstly, to name salvage value sequence as $\mathrm{q}^{(0)}$:

$$\mathrm{q}^{(0)} = (q^{(0)}(1), q^{(0)}(2), \cdots, \; q^{(0)}(n),) \tag{13}$$

and: $$q^{(0)}(k) = x^{(0)}(k) - \hat{x}^{(0)}(k) \qquad k = 1,2,\cdots,\mathrm{n} \tag{14}$$

The grey model is also be used for salvage value sequence forecasting, by contrast with each other , it can be see that the salvage value includes positive and negative. If considering the case of time, it assumes that state 1 represents the positive salvage value and state 2 represents the negative salvage value, and Pij represents the probability when it stops at state i and next turns to state j. So the all probabilities are P11,P12,P21,P22. According to Markov model, the formula Pij=Nij/Ni（i=1,2;j=1,2）can be defined in annual load forecasting. Among the formula, the Nij represents the total years when the salvage value remains in state i at time t and remains in state j at time t+1, so the Ni represents the total years when the salvage value remains in state i at time t.

According to above suppose, the relevant transition probability matrix can be built as $P = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}$.After m time transforming, the probability is P_1^m when salvage value at state 1 and the probability is P_2^{m} when salvage value at state 2. If $P_1^m < P_2^{\mathrm{m}}$, it can be defined that the salvage is negative m time later. According to the theory of grey model, if load salvage value also meets the requiring judgments of $\varepsilon(k) < 0.2$ or $\varepsilon(k) < 0.1$, the salvage value can be added to predictive load value, which is revised predictive load value.

4 Analysis of examples

According the load data of Qingdao, China from 2000 to 2009, and using ordinary GM（1，1）and improved grey model for long-term load forecasting, the results can be gotten (as shown in table1).

Table 1 forecasting results and error rate

Years	Actual value 10^8KW h	Ordinary GM(1,1)		Improved GM(1,1)	
		Forecasting value (10^8KW h)	Error rate(%)	Forecasting value (10^8KW h)	Error rate(%)
2000	6908.25	7265.41	5.17	7064.38	2.26
2001	6945.45	7212.85	3.85	6825.29	-1.73
2002	8698.34	8991.47	3.37	8854.04	1.79
2003	8431.71	8680.45	2.95	8564.93	1.58
2004	10799.31	11044.45	2.27	10698.88	-0.93
2005	14615.95	15314.59	4.78	14503.41	-0.77
2006	17426.49	18114.84	3.95	16940.29	-2.79
2007	17578.68	18295.89	4.08	18067.37	2.78
2008	18699.92	19470.36	4.12	18834.56	0.72
2009	19507.5	20262.44	3.87	19815.72	1.58

From fig1, we can see that the error rate of load forecasting result rely on ordinary GM(1,1) is 3.84%, by contrast, the error rate of load forecasting result rely on improved grey model is only 1.69%, which is more low than the result of ordinary model. So it can indicate that the forecasting accuracy of improved grey model based on Markov model is more high than ordinary GM(1,1), so the improvement is more effective.

5 Conclusions

The above analysis has indicated that ordinary grey model can be used for long-term load forecasting in power engineering but with great error; if the grey model is improved based on Markov model and moving average method, the error rate of which can be effectively reduced. Although Markov model is usually used for short-term load forecasting in power engineering, but when it is combined with the gray model and applied in long-term load forecasting, it can reduce the error rate of grey model. So the improved grey model based on Markov model and moving average method is a more advanced method applied for long-term load forecasting in power engineering.

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