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The Application of Grey Theory Model in the Predication of Jiangsu Province's Electric Power Demand

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Abstract

Based on the grey system theory, the paper establishes an electricity demand forecasting model for Jiangsu province, and verifies it using the data from the year 1997 to 2012. The result shows that the accuracy of this forecast model is "superior". This proved that GM (1, 1) model used for the electricity demand forecasting of Jiangsu province can fully meet the needs of the forecast of electricity. In the mean time, the electricity demand of Jiangsu from the year 2013 to 2015(which year is the end of China's twelfth five-year plan) was forecasted by applying the model and the result shows that the electricity consumption in Jiangsu province will increase rapidly in the next few years. Up to the year 2015, it will reach 0.7187 trillion kW·h, which requests the acceleration of the generation of power, so as to meet the needs of the economic development of Jiangsu province in the next few years.

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Keywords: Electricity demand; grey system; industrial structure

1. Introduction

There are several factors that contribute to electricity demand: economic development, industrial structure, income levels, climate, geography, national policies (such as electricity price), and etc.. Some of these factors

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are definite, while some are not. So it can be seen as a grey system, and the explanation and forecasting can be done with the theory and methods of Grey System [1].

Grey System Theory is a kind of systematic and scientific theory initiated by Chinese scholar Professor Deng Julong in the 1980s. Currently, it has been widely used in the power demand forecast. The theory agrees that all the random sample varieties are the changing grey varieties within a range, that is to say the whole random process is considered as the grey variety varying within a certain range. According to the past and the present known or uncertain information and with the approach of data generation, the raw data can be transformed into a greatly regular generating series and then the related research and modeling can be done. This method can be applied when there are few raw data, and the accuracy of forecasting can be highly increased by accumulating the data certainty relatively enhanced to some extent and the data uncertainty relatively weakened to some extent. Grey forecasting model is predicting with the model of GM, which is short for Grey Model. GM Models can be divided into GM (1, n) model and GM (1, 1) model: GM (1, n) model is the grey model established by the first order differential equations with *n* variables, which is a forecasting model established between the load and *n* influential varieties; while GM (1, 1) model is the most common grey model, which is established by the first-order differential equation only with a single variable and is also the special case of GM (1, n) model [2]..

2. The establishment of forecasting model based on grey theory

2.1 GM (1, 1) forecasting model [3-5]

Suppose that to time series $t_1, t_2, \cdots, t_n$, the existing demand load data series are $u_1, u_2, \cdots, u_n$, which can be called raw data series and can be recorded as:

$$u^{(0)}(i), (i = 1,2,\cdots,n) \tag{1}$$

Through accumulating the above series, a data sequence with the exponent-growing pattern will be available, known as the accumulated generating data series $u^{(1)}(i)$, that is:

$$u^{(1)}(i) = \sum_{k=1}^{i} u^{(0)}(k) \tag{2}$$

The following First Order Differential Equation can represent the application of GM (1, 1) model on the above single-variable series:

$$\frac{du^{(1)}}{dt} + a \cdot u^{(1)} = b \tag{3}$$

In the equation: a and b are parameters to be determined, which can be recorded as $A = [a \;\; b]^T$ .The least squares approximate solution A in the equal-step time series A can be derived through discrete and differential:

$$\hat{A} = [\hat{a} \;\; \hat{b}]^T = [B^T B]^{-1} B^T Y_n \tag{4}$$

In which: $Y_n = [u^{(0)}(2), u^{(0)}(3), \cdots, u^{(0)}(n)]^T$

$$B = \begin{bmatrix} -[u^{(1)}(1) + u^{(1)}(2)]/2, \cdots, 1 \\ -[u^{(1)}(2) + u^{(1)}(3)]/2, \cdots, 1 \\ \cdots\cdots \\ -[u^{(1)}(n-1) + u^{(1)}(n)]/2, \cdots, 1 \end{bmatrix} \tag{5}$$

To time series $t^{(0)}(i)$, $(i = 1,2,\cdots,n)$, the initial condition: $u^{(1)}(1)$ is the initial value of $u^{(1)}(i)$, and

$u^{(1)}(1)=u^{(0)}(1)$； the elements in $u^{(0)}(i)$ are of respective correspondence with those in $t^{(0)}(i)$, the solution for the equation(3) can be:

$$\hat{u}^{(1)}(t)=\left(u^{(0)}(1)-\frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}t}+\frac{\hat{b}}{\hat{a}}$$

Discrete Form:

$$\hat{u}^{(1)}(t+1)=\left(u^{(0)}(1)-\frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k}+\frac{\hat{b}}{\hat{a}} \qquad (6)$$

Once the parameter a is determined, the back substitution values can be successively generated by accumulating: $\hat{u}^{(1)}(i)$, $(i=1,2,\cdots,n)$, and then the reduction value of the raw data series can be achieved through the regressive generation calculation:

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

2.2 Test on the forecasting accuracy [6]

Only by testing the model can we find out whether the forecasting model can meet the needs of practice and the test can be done by posterior error, which is as follows:

$$\varepsilon^{(0)}(i)=u^{(0)}(i)-\hat{u}^{(0)}(i) \qquad (8)$$

The average:

$$\bar{\varepsilon}(0)=\frac{1}{n}\sum_{i=1}^{n}\varepsilon^{(0)}(i) \qquad (9)$$

The variance of residual:

$$S_1^{\,2}=\frac{1}{n}(\sum_{i=1}^{n}\varepsilon^{(0)}(i)-\bar{\varepsilon}^{(0)})^2 \qquad (10)$$

The average of raw data:

$$\bar{u}(0)=\frac{1}{n}\sum_{i=1}^{n}u^{(0)}(i) \qquad (11)$$

Variance of the original series:

$$S_2^{\,2}=\frac{1}{n}(\sum_{i=1}^{n}u^{(0)}(i)-\bar{u}^{(0)})^2 \qquad (12)$$

Posterior error ratio:

$$C=S_1/S_2 \qquad (13)$$

Small error probability:

$$P=(\left|\varepsilon^{(0)}(i)-\bar{\varepsilon}^{(0)}\right|<0.6745S_2) \qquad (14)$$

A good forecasting model requires a rather small C, that is, the best C is smaller than 0.35, and not bigger than 0.65. Another indicator by which to judge it is good or bad is a larger small error frequency P, which is required to be bigger than 0.95 and not smaller than 0.7. According to the value of P and C, there are four levels of forecasting accuracy (See Table 1).

Table 1 Levels of forecasting accuracy

Level	P	C	Level	P	C
Good	>0.95	<0.35	Qualified	>0.85	<0.45
Fairly Good	>0.7	<0.5	Unqualified	$\leq$ 0.75	$\geq$ 0.65

3. Examples of model forecasting

Through the distribution in Jiangsu province (from 1997 to 2012) of electricity consumption, population and GDP in every industry, and according to the above established GM (1,1) grey forecasting system, the annual electricity consumption can be predicted and the forecasting accuracy of the model can be verified through correlation tests.

3.1 Model data

Social electricity consumption from 1997 to 2012 in Jiangsu province and its distribution in every industry are shown in Table 2.

Table 2 Electricity consumption and the corresponding proportion from 1997 to 2012 in Jiangsu province

Years	Total	Primary Industry		Second Industry		Tertiary Industry		Living	
		Consumption (0.1 Billion kW·h)	Proportion (%)	Consumption (0.1 Billion kW·h)	Proportion (%)	Consumption (0.1 Billion kW·h)	Proportion (%)	Consumption (0.1 Billion kW·h)	Proportion (%)
1997	774.04	64.50	8.33	557.3	72.00	59.96	7.75	92.28	11.92
1998	785.45	66.14	8.42	554.74	70.63	65.26	8.31	99.31	12.64
1999	848.48	59.00	6.95	613.72	72.33	70.40	8.30	105.36	12.42
2000	971.34	47.06	4.85	717.86	73.90	80.80	8.32	125.62	12.93
2001	1078.44	43.53	4.04	813.18	75.40	89.59	8.31	132.14	12.25
2002	1245.14	34.6	2.78	879.10	78.63	101.52	8.15	129.92	10.43
2003	1505.12	34.34	2.28	1201.43	79.82	119.31	7.93	150.04	9.97
2004	1820.09	38.34	2.11	1473.56	80.96	137.17	7.54	171.02	9.40
2005	2193.45	29.12	1.33	1793.34	81.76	170.27	7.76	200.72	9.15
2006	2569.75	24.92	0.97	2110.55	82.13	200.00	7.78	234.29	9.12
2007	2952.02	24.47	0.83	2439.13	82.63	233.06	7.89	255.35	8.65
2008	3118.32	23.34	0.75	2529.68	81.12	269.57	8.64	295.74	9.48
2009	3313.99	25.45	0.77	2660.16	80.27	304.44	9.19	323.94	9.77
2010	3864.37	28.36	0.73	3085.35	79.84	361.04	9.34	389.62	10.08
2011	4281.62	33.01	0.77	3424.64	79.98	415.76	9.71	408.21	9.53
2012	4580.90	37.96	0.83	3605.58	78.71	468.51	10.23	468.85	10.23

3.2 Model forecasting and test

In this model $n = 16$, the raw data of social electricity consumption $u^{(0)}$ = { 774.04 785.45 848.48 971.34 1078.44 1245.14 1505.12 1820.09 2193.45 2569.75 2952.02 3118.32 3313.99 3864.37 4281.62 4580.90 }

Though an accumulated generating on the raw series, new series can be got as = { 774.04 1559.49 2407.97 3379.31 4457.75 5702.89 7208.01 9028.10 11221.55 13791.30 16743.32 19861.64 23175.63 27040.00 31321.62 35902.52 }

By Formula(4) and Formula(5), the following can be achieved:

$$B^T = \begin{bmatrix} -1166.77 & -1983.73 & -2893.64 & -3918.53 & -5080.32 & -6455.45 & -8118.06 & -10124.83 & -12506.43 & -15267.31 & -18302.48 & -21518.64 & -25107.82 & -29180.81 & -33612.07 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

$$Y_n^T = [785.45 \quad 848.48 \quad 971.34 \quad 1078.44 \quad 1245.14 \quad 1505.12 \quad 1820.09 \quad 2193.45 \quad 2569.75 \quad 2952.02 \quad 3118.32 \quad 3313.99 \quad 3864.37 \quad 4281.62 \quad 4580.90] \tag{15}$$

$$\hat{A} = [\hat{a} \quad \hat{b}]^T = [B^T B]^{-1} B^T Y_n = \begin{bmatrix} -0.1227 \\ 744.003 \end{bmatrix} \tag{16}$$

Grey Forecasting Model on social electricity consumption in Jiangsu province can be gained by putting the above calculated $\hat{a}$ and $\hat{b}$ into Formula (7):

$$\hat{u}^{(0)}(k+1) = (1 - e^{\hat{a}})\left(u^{(0)}(1) - \frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k} = 789.57e^{0.1227k} \qquad (k = 1, 2, \cdots, n-1) \tag{17}$$

3.3 Forecasting result and test

The test method of posterior error will be applied to verify the accuracy of the model, as shown in Table 3 & 4.

Table 3 The actual and reduction electricity consumption from 2005 to 2012 in Jiangsu province

Years	**Actual Consumption (0.1 Billion kW·h)**	**Reduction Consumption (0.1 Billion kW·h)**	**Relative Error (%)**
2005	2193.45	2107.14	-3.93
2006	2569.75	2382.22	-7.30
2007	2952.02	2693.21	-8.77
2008	3118.32	3044.79	-2.36
2009	3313.99	3442.28	3.87
2010	3864.37	3891.65	0.71
2011	4281.62	4399.69	2.76
2012	4580.90	4974.04	8.58

Table 4 Calculation result of accuracy testing

$\overline{u}^{(0)}$	$S_1^{\ 2}$	$\overline{\varepsilon}^{(0)}$	$S_2^{\ 2}$	C	P
2243.91	69566.88	-70.33	70806387.21	0.031	1

As $P > 0.95$ and $C < 0.35$， the precision of this power consumption forecasting model can be seen as "superior".

This essay will apply the established model to forecast the social electricity consumption from 2013 to 2015, in which year China would have completed the 12th five-year plan.

Table 5 Forecasting value of electricity consumption from 2013 to 2015 in Jiangsu province (0.1 Billion kW·h)

Years	2013	2014	2015
Electricity Consumption	5623.38	6357.49	7187.43

4. Conclusion

(1) The forecasting model of power consumption in Jiangsu province is established in this essay through the grey system theory. And the accuracy of the model is tested by the data from 1997 to 2012 and it turns out that the accuracy is "superior", for the indicator value: $P > 0.95$ and $C < 0.35$, which illustrates that the electricity consumption of Jiangsu province by GM (1, 1) is consistent with the electricity forecast.

(2) The electricity consumption of Jiangsu from 2013 to 2015 is forecasted through this model, and it turns out that in the next few years, the electricity consumption in Jiangsu province will be increasing rapidly, and by the year 2015 it will reach 0.7187 trillion kW•h, which requires to speed up generation of power to meet the economic development of the province in the next few years.

(3) The next step will be to predict the power consumption in various industries according to the economic development of Jiangsu province, and the electricity consumption of each industry and its corresponding contribution value to GDP. And distribution of electricity consumption should be optimized to meet the adjustment and upgrade of industrial structure during the rest years of the 12th five-year plan.

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