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Prediction of City Saturated Load Based on Combined Logistic Model

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***Abstract*—Accurate load forecasting is the prerequisite for efficient resources distribution among the power supply, power grid and the users. Based on traditional logistic model, data accumulated generating method and grade differential format are used to design the logistic of grade difference format. In the meanwhile, another two factors affecting power load, GDP and population, are introduced into the traditional logistic model, and next the rate of diffusion is turned into function to form the logistic expand model .Finally, combined logistic model is constructed by the combination of the weights from the error criteria of the two models. Compared to traditional logistic model, subjective parameters and constant environment can be avoided in the model. Thus, it can better reflect the dynamic growth trend of future urban electric load. With the application of the model, urban electricity saturation consumption and the arrival time in Beijing have been predicted. The result shows that Beijing would enter the stage of power saturation in 2023 and the saturation electricity consumption would be 121.5 billion kWh.**

Keywords—City Saturated Load; logistic model; grey theory; combination forecast.

I. INTRODUCTION

Power load forecast is based on the economic development, social conditions, weather and other historical data. It's essential to find the intrinsic link among the various factors and study the developing trends of power load to make scientific prediction in future. Accurate load forecasting is of great importance for realizing efficient utilization of resources among the power supply, power grid and the users. With the national economy enter into the new normal, China has entered the late stage of industrialization. According to the experience of the developed countries, the power load growth is slow or even stop under the influence of population, economy, resources and environment. Power load structure remains relatively stable, appears as a state of saturated [1-2]. Hence, the concept of saturation load, forecasting and research arises in urban power grid planning.

According to the analysis of the load development law of developed countries, load growth in one region or city often presents as the following trends: in the early stages of economic development, the growth of the power load is slow; with the rapid development of economy and society, it would promote the rapid development of power system load; but when the economy and society develop into a certain stage, power load growth would slow down and even stop growing with the limit of the regional energy structure, land resources, population scale, and environmental and resource conditions. In theory, "S" shaped curve can be used to show the development of the regional load, the whole development of power load growth stage can be divided into slow growth stage, rapid growth stage and saturation change phase, as shown in Fig. 1.

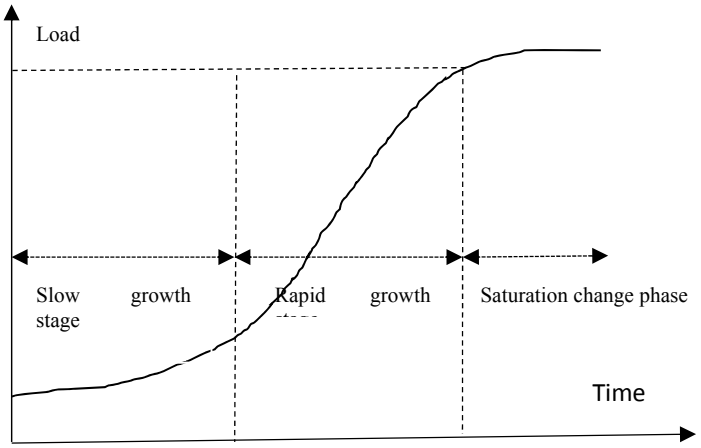

Fig. 1.Saturated logistic growth curve

II. ESTABLISH THE COMBINED LOGISTIC MODEL

Logistic curve is a common "S" type curve which was derived from the study of biomass. In many fields such as economy, society, population, the development characteristics were also consistent with the law of curve [3-4]. Traditional logistic model uses three parameters of nonlinear differential equation to reflect the dependent variable changes over time, the accuracy of the parameter estimates are the main influencing factors for prediction [5-6]. Firstly, the article considers the features of traditional logistic model and establishes the logistic expand model with the power load growth affected by main macroeconomic factors. Secondly, by using the gray accumulated generating method and the exact format of the gray model, the logistic model of grade difference format is established. In order to use of the advantages of the above two models better and improve the accuracy of prediction, a combination forecast model of saturated load power is built with the weights of a standard deviation. This model can analysis the long-term change rule of urban power load which is affected by various factors and the change trend of the urban power load saturation.

A. *The logistic expand model*

The traditional logistic model expressed as follows:

$$\mathrm{N}=\frac{1}{k+ae^{bt}}\left(k>0,a>0,b<0\right) \tag{1}$$

Where, t is a set of time series values; N refers to city power load value at time t; k indicates city power saturation factor, the smaller the k value, the greater the power saturation values; b indicates city power growth factor, the smaller the absolute value of b, the more smoothly logistic curve moves.

The change of the urban power load is influenced by economic development, population change, industrial structure and other factors [7].it is concentrated considering the main influence factors for the independent variables directly, and doesn't retain the characteristics traditional logistic model present S-form as dependent variable changing over time in previous studies. Through factor analysis and correlation analysis of each variable between similar factors, GDP and population are selected as affecting factors for urban power load. The urban power load growth factor measuring model is as follows:

$$b=\beta_1\ln\left(\mathrm{GDP}\right)+\beta_2\ln\left(\mathrm{POP}\right) \tag{2}$$

Put the formula 2 into the formula 1 and get logistic expand prediction model:

$$\mathrm{N}=\frac{1}{k+a*\exp\left(\left(\beta_1\ln\left(\mathrm{GDP}\right)+\beta_2\ln\left(\mathrm{POP}\right)\right)t\right)} \tag{3}$$

B. *The logistic of grade difference format*

Due to various factors, power load historical data has a lot of randomness. Parameter estimates tend to have large errors with regression model of historical data directly. In order to obtain more accurate and objective parameters, this paper reference gray theory accumulated generating method to deal with the historical data and use grade difference format to correct the logistic model. Let the sequence of power load historical data after taking the reciprocal is as follow:

$$x^{(0)}=\left\{x^{(0)}\left(t\right)\mid x^{(0)}\left(t\right)\geq 0,t=1,2,\cdots,n\right\} \tag{4}$$

$$x^{(0)}\left(t\right)=k+ae^{bt} \tag{5}$$

The sequence of once accumulation is as follow:

$$x^{(1)}=\left\{x^{(1)}\left(t\right)\mid x^{(1)}\left(t\right)\geq 0,t=1,2,\cdots,n\right\} \tag{6}$$

$$x^{(1)}\left(t\right)=\sum_{i=1}^{t}x^{(0)}\left(i\right)=kt+\frac{a}{1-e^{b}}-\frac{ae^{bt}}{1-e^{b}} \tag{7}$$

Calculated differential to get:

$$\frac{dx^{(1)}\left(t\right)}{dt}+\lambda x^{(1)}\left(t\right)+\mu t=\beta \tag{8}$$

Where, $\lambda=-b$, $\mu=kb$, $\beta=k+\frac{ab}{1-e^{b}}$

In order to reduce the error, this paper use comprehensive front and rear differential mean value theorem format, the calculation is as follow:

$$x^{(0)}\left(t\right)=p_1x^{(1)}\left(t+1\right)+p_2x^{(1)}\left(t\right)+p_3t+p_4f\left(t\right)+p_5 \tag{9}$$

Where, $f\left(t\right)=\frac{\left(1+\left(-1\right)^{t-1}\right)}{2}$, $p_1=1$, $p_2=-e^{-2b}$,

$p_3=k\left(e^{-2b}-1\right)$, $p_4=\zeta$,

$p_5=k\left(e^{-2b}+1\right)+\left(a+k+\left(ae^{b}\right)e^{-2b}\left(1+\zeta\right)\right)$

By computer simulation to get the p_2 value, and use $p_2=-e^{-2b}$ to solve the b value. Parameter a and k are obtained through linear fitting depending on $x^{(0)}\left(t\right)=k+ae^{bt}$, Model result is as follows:

$$\hat{\mathrm{N}}=\frac{1}{\hat{k}+\hat{a}e^{\hat{b}t}} \tag{10}$$

C. *The combined logistic model*

Logistic expand model takes the main influencing factors of the city power load into account, and can objectively reflect the load change when the other main factors change. However, we should first predict the various factors when this prediction model for urban power load is used in the long-term forecast. Different prediction accuracy would cause knock-on effect on the city power load forecast. The logistic model of grade difference format is a time series essentially. It reflects the changing trend from the comprehensive level, but does not reflect the impact of other factors. Combination forecasting model can make full use of information independent of each prediction method contained in. So this paper would establish combination forecasting model based on the above two models. The core is to determine the weight of each single prediction method. As the forecast results of each model are known, this article adopts the minimum variance standard deviation to determine combination weights.

Suppose standard deviation and the weight of the i-th prediction models are δ_i, ω_i and $\omega_i=\left(\delta-\delta_i\right)/\sum_{i=1}^{2}\delta_i$. Combined logistic model is as follow:

$$N_t=\omega_1N_t^1+\omega_2N_t^2 \tag{11}$$

Where, N_t, N_t^1, N_t^2 represents the predictive value of combined model, logistic expand model and logistic model of grade difference format in year t respectively.

III. THE PREDICTION OF BEIJING SATURATION POWER LOAD

From the Beijing Statistical Yearbook, historical data of Beijing about electricity consumption, GDP and population from 1978 to 2014 are obtained. The parameters of logistic expand model is solved by nonlinear regression of 1stopt:

$$\mathrm{N}^1=\frac{1}{8.24\times10^{-8}+1.21\times10^{-6}\times e^{b*(t-1977)}} \tag{12}$$

$$b=-0.015\times\ln\left(\mathrm{GDP}\right)+0.006\times\ln\left(\mathrm{POP}\right) \tag{13}$$

$R^2=0.998$, $F=7580.43$, δ_1=105306.08.

It shows that the model has high accuracy and factors can explain 99% of the Beijing power load changes.

The parameters of logistic model of grade difference format is solved by MATLAB software programming, the result is as follows:

$$N^2=\frac{1}{5.11\times10^{-8}+2.52\times10^{-6}\times e^{-0.102\times(t-1977)}} \quad (13)$$

$R^2=0.995$, $F=3267.1$, δ_2=199419.11

The weight of combination forecast model can be get based on the error standard deviation of the above two model: $w_1=0.654$, $w_2=0.346$.

Therefore, the combination forecast model formula is:

$$N_t=0.654\times N_t^1+0.346\times N_t^2 \quad (14)$$

TABLE I. THE COMPARISON BETWEEN ACTUAL VALUE AND PREDICTED VALUE OF BEIJING POWER CONSUMPTION FROM 2004 TO 2014(UNIT: BILLION KWH)

Year	Actual value	Logistic expand model		Logistic model of grade difference format		Combined logistic model	
		predicted value	*relative error*	*predicted value*	*relative error*	*predicted value*	*relative error*
2004	51.32	51.64	0.63%	51.28	-0.08%	51.51	0.38%
2005	57.05	55.99	-1.87%	55.24	-3.18%	55.73	-2.32%
2006	61.16	60.63	-0.87%	59.38	-2.91%	60.19	-1.58%
2007	66.70	65.96	-1.11%	63.69	-4.52%	65.17	-2.29%
2008	68.97	70.37	2.02%	68.15	-1.19%	69.60	0.91%
2009	73.91	74.33	0.56%	72.76	-1.57%	73.78	-0.18%
2010	80.99	79.10	-2.33%	77.49	-4.33%	78.54	-3.02%
2011	82.17	83.60	1.74%	82.31	0.17%	83.15	1.20%
2012	87.43	87.32	-0.12%	87.22	-0.24%	87.29	-0.16%
2013	91.31	90.96	-0.39%	92.18	0.96%	91.38	0.08%
2014	93.70	94.06	0.38%	97.18	3.70%	95.14	1.53%

The comparison between actual value and predicted value of Beijing electricity consumption from 2004 to 2014 are shown in table I. The maximum relative error of the three models were 2.33%, 4.52%, 3.02% and the minimum relative error were 0.12%, 0.08%, 0.08% respectively. Three model has higher prediction accuracy, but the combined logistic model can better comprehend the advantages of other two models. So the combined logistic model is used to predict the future city electricity power consumption of Beijing, the predicted results is in table II.

TABLE II. THE PREDICTED VALUE OF BEIJING ELECTRICITY CONSUMPTION FROM 2015 TO 2030 (UNIT: BILLION KWH)

Year	Logistic expand model		Logistic model of grade difference format		Combined logistic model	
	predicted value	*growth rate*	*predicted value*	*growth rate*	*predicted value*	*growth rate*
2015	97.26	3.40%	102.17	5.14%	98.96	4.02%
2016	99.97	2.79%	107.14	4.87%	102.45	3.53%
2017	102.40	2.42%	112.06	4.60%	105.74	3.21%
2018	104.55	2.10%	116.91	4.33%	108.82	2.92%
2019	106.45	1.82%	121.67	4.07%	111.71	2.65%
2020	108.13	1.58%	126.31	3.81%	114.41	2.42%
2021	109.61	1.37%	130.81	3.56%	116.93	2.21%
2022	110.91	1.19%	135.16	3.32%	119.29	2.02%
2023	112.06	1.04%	139.34	3.09%	121.49	1.84%
2024	113.08	0.90%	143.34	2.87%	123.53	1.69%
2025	113.97	0.79%	147.16	2.66%	125.44	1.54%
2026	114.76	0.69%	150.79	2.46%	127.21	1.41%
2027	115.46	0.61%	154.22	2.28%	128.85	1.29%
2028	116.08	0.54%	157.45	2.10%	130.38	1.18%
2029	116.63	0.47%	160.49	1.93%	131.79	1.08%
2030	117.12	0.42%	163.34	1.77%	133.09	0.99%

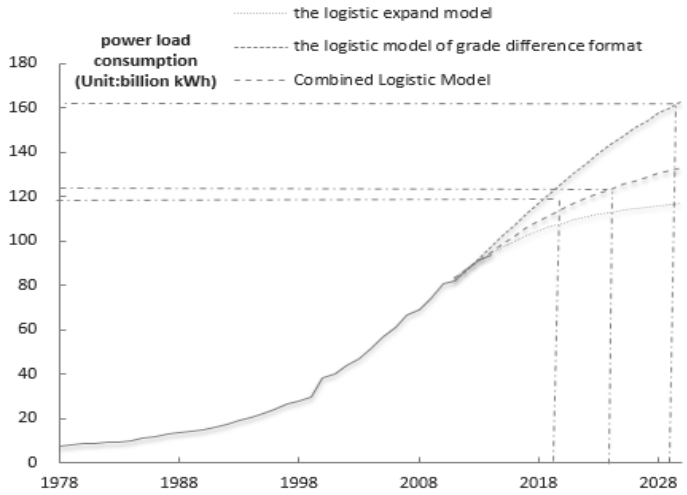

Fig. 2.Prection of the city saturation load

Reference for related studies, as long as the growth rate of electricity consumption is less than 2%, it indicates that the city electricity consumption has entered the saturation stage [8-9]. Three model predicted results show that the growth rate of Beijing electricity consumption is slowing from 2015. The logistic expand speed down rapidly and expects that Beijing would enter the saturation stage of development in 2019, whose saturated power consumption is 106.45 billion kWh. Predicted results of the logistic model of grade difference format grow most gently, the beginning of saturation stage is in 2029 and saturated power consumption is 160.49 billion kWh. The growth rate of combined logistic model is moderate. Since 2023, Beijing would enter saturation stage of power consumption and its saturated power consumption is 121.49 billion kWh (Fig.2).

III. CONCLUSIONS

Based on the development of power load in accordance with logistic curve change rule, logistic model of grade differential format is set up by combining with the accumulation generation sequence of grey theory of differential format. This method improves the integrated use of historical data and has strong anti-interference ability. Economy and population are the main factors which can effect on the power consumption, by establishing logistic expand model and functioning the parameters of the model are functional according to the factors. This paper analyzes the degree of changes in the rate of power load with the other factors change. Combination logistic model for the weight of error standard deviation is established. This model combines the advantages of two kinds of prediction model and improves the prediction accuracy. Finally, by using the model to forecast the future city power consumption in Beijing, what results that the paper gets show that, the power consumption of Beijing would be 121.49 billion kWh by 2023 and then Beijing would enter into power saturation stage.

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