Combined Extension Theory and Multi-Regression Analysis Method for Long-Term Load Forecasting

Mang-Hui Wang  
Associate Professor  
National Chin-Yi Institute of Technology Institute of Information and Electrical Energy  
35, Lane 215, Sec. 1, Chung-Shan Rd., Taiping, Taichung, 411  Taiwan, R.O.C.  
TEL:+886-4-23924505ext 7233, FAX:+886-4-23924419  
E-mail: wangmh@chinyi.ncit.edu.tw

Chih-Yung Ho  
Student  

ABSTRACT

In this paper, forecasting models of yearly peak load and electricity demand are built according to the gross domestic product (GDP) and economic growth rates. First, a novel extension clustering method based on the extension theory is introduced to recognize the load types of yearly peak load (YPL) and yearly electricity demand (YED), and to build the Matter-Element Model of every load type, then the changed range of YPL and YED at the forecasting time can be forecasted according to correlation degree between the built models and the forecasting models. Second, according to the load data of every load type, using the multi-regression analysis method (MRAM) to build the load forecasting models of every load type, then the forecasting models can be used to forecast the values of YPL and YED at the forecasting time. To verify the proposed forecasting methods, the statistics of YPL and YED in Taiwan have been tested. The compared forecasting results with the grey GM (1,1) model show that the proposed methods have better accuracy for both YPL and YED forecasting.

Keywords: yearly peak load, yearly electricity demand, extension theory, multi-regression method, grey GM (1,1) model.

I. INTRODUCTION

Power load forecasting is one of the most important subjects for power systems. The amount of power load in a country is an index of national economics and progress. In general, the more civilization the more power is required in a country. So, correct power load forecasting is one of the most important techniques in a progressing country. According to statistical data, the higher the GDP of a country, the higher electricity demand for each person. Comparing the economic growth and the electricity demand growth in Taiwan shows roughly a straight line after B. C.1997 [1].

Various models for load forecasting have been reported in the literature based on statistical methods [2], the time series model [3], rule-based methods [4,5], neural networks (NN) [6],
and grey theory [7]. Artificial neural networks are currently established as a promising approach to load forecasting since they are able to cope with the non-stationary nature of the load and provide accurate forecasts, learning by themselves the functional relationship between system inputs and outputs, through a training process. However, a limitation of the neural network (NN) approach is its inability to produce linguistic output, because it is difficult to understand the content of network memory, the neural network approaches need large amounts of training data on load, and thus require heavy computational efforts to create satisfactory models. Grey forecasting models do not need large amounts of data. They have been successfully applied in YPL forecasting [8], but the accuracy of grey forecasting models still needs further improvement.

In light of the above developments, this paper applies a novel extension clustering method based on the extended theory and the Multi-Regression analysis method to forecast both the YPL and YED. First, this paper uses the proposed extension clustering method to recognize the load type of the forecasted year, then the changed range of the forecasted year can be forecasted according to the matter-elements in a similar load type. Second, this paper uses MRAM to build load forecasting models of every load type, then the forecasting models can be used to forecast the load values at the time of forecast. The main advantage of the proposed method is that it not only can predict maximum and minimum values but also the load value at the time of forecast, and the proposed forecasting methods are adopted to correct for the problems in the aspects of forecasting accuracy and computational efforts associated with the prediction of long-term YPL and YED. Therefore, it can provide more information on the power system plan.

II. SUMMARY OF EXTENSION THEORY

In the standard set, an element either belongs to or does not belong to a set. Therefore, the range of the standard set is also either 0 or 1, which can be used to solve a two-valued problem. In contrast to the standard set, the fuzzy set enables the description of concepts where the boundary is not explicitly a value between 0 and 1. It concerns not only whether an element belongs to the set but also to what degree it belongs. The extension set extends the fuzzy set from \([0, 1]\) to \((\infty, \infty)\) [9]. In other words, the extension set theory can map each element to a membership grade between \(-\infty\) and \(\infty\). It can describe the degrees to which an element belongs to the set or does not belong to the set, the higher the degree; the more closely the element belongs to the set.

2.1 Matter-Element Theory

In extension theory, a matter-element contains fundamental elements. If we define the name of the matter \(N\), one of the characteristics of the matter by \(c\), and the value of \(c\) by \(v\).
The matter-element can be described as follows:

\[ R = (N, c, v) \]

(1)

On the other hand, if we assume that \( R = \{N, C, V\} \) is a multidimensional matter-element, \( C = \{c_1, c_2, \cdots, c_n\} \) a characteristic vector and \( V = \{v_1, v_2, \cdots, v_n\} \) a value vector of \( C \), then a multidimensional matter-element is defined as follows:

\[
R = (N, C, V) = \begin{bmatrix}
N, c_1, v_1 \\
R_2 \\
\vdots \\
R_n
\end{bmatrix} = \begin{bmatrix}
c_2, v_2 \\
\vdots \\
c_n, v_n
\end{bmatrix}
\]

(2)

2.2 Summary of Extension set

Definition 1: Let \( U \) be a space of objects and \( x \) a generic element of \( U \), then an extension set \( \tilde{E} \) in \( U \) is defined as a set of ordered pairs as follows:

\[
\tilde{E} = \{(x, y) | x \in U, y = K(x) \in (-\infty, \infty)\}
\]

(3)

Where \( y = K(x) \) is called the correlation function for extension set \( \tilde{E} \). The \( K(x) \) maps each element of \( U \) to a membership grade between \(-\infty\) and \( \infty \).

Definition 2: If \( X_o = [a, b] \) and \( X_d = [f, g] \) are two intervals in the real number field, \( X_o \in X_d \), \( X_0 \) and \( X_d \) are the classical (concerned) and neighborhood domains, respectively. Based on the concept of left-right-sided distance, the correlation function in the extension theory can be defined as follows:

\[
K(x) = \begin{cases}
-\rho(x, X_o) & x \in X_o \\
\rho(x, X_o) - \rho(x, X_o) & x \notin X_o
\end{cases}
\]

(4)

Where

\[
\rho(x, X_o) = \left| x - \frac{a + b}{2} \right| - \frac{b - a}{2}
\]

(5)

\[
\rho(x, X_d) = \left| x - \frac{f + g}{2} \right| - \frac{g - f}{2}
\]

(6)

The correlation function can be used to calculate the membership grade between \( x \) and \( X_o \).
The correlation function is shown in Fig. 1. When $K(x) \geq 0$, it indicates the degrees to which $x$ belongs to $X_o$. When $K(x) < 0$, it describes the degree to which $x$ does not belong to $X_o$. When $-1 < K(x) < 0$, it is called the extension domain, which means that the element $x$ still has a chance to become part of the set if conditions change.

![Fig. 1 The correlation function in the extension set theory.](image)

### III. MULTI-REGRESSION ANALYSIS METHOD

Traditionally, the multi-regression method was used frequently to forecast the change of something to another thing [10-11]. The details of multi-regression analysis are shown in the following:

A. The firsthand information is $n$, $p+1$ lines of matrix those labeled $p$ are independent variables and those labeled $p+1$ are dependent variable, they can be written as:

\[
\begin{array}{cccc}
  x_{11} & x_{12} & \cdots & x_{1p} \\
  x_{21} & x_{22} & \cdots & x_{2p} \\
  \vdots & \vdots & \ddots & \vdots \\
  x_{ni} & x_{n2} & \cdots & x_{np} \\
\end{array}
\]

\[
y_1 = x_{1p+1} \\
y_2 = x_{2p+1} \\
\vdots \\
y_1 = x_{np+1}
\]

(7)

B. The average of all variables calculated by Eq. (7), can be written as

\[
\bar{x}_i = \frac{1}{n} \sum_{k=1}^{n} x_{ki} \quad (i = 1, 2, \cdots, p+1)
\]

(8)
C. The coefficient can be calculated as follows:

\[
I_{ij} = \sum_{i=1}^{n} (x_{i} - \bar{x}_i)(x_{j} - \bar{x}_j) \\
\sum_{i=1}^{n} x_{ij} \frac{1}{n} \sum_{i=1}^{n} x_{i} \left( \sum_{i=1}^{n} x_{i} \right) \text{ (i,j=1,2,...,p+1)}
\] (9)

According to the Eq. (9), it can be simplified as follows:

\[
\begin{bmatrix}
I_{11} & I_{12} & \cdots & I_{1p} & I_{1p+1} \\
I_{21} & I_{22} & \cdots & I_{2p} & I_{2p+1} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
I_{p1} & I_{p2} & \cdots & I_{pp} & I_{pp+1} \\
I_{p+11} & I_{p+12} & \cdots & I_{p+1p} & I_{p+1p+1}
\end{bmatrix}
\] (10)

D. Eq. (10) can be translated into the following linear equation:

\[
\begin{bmatrix}
I_{11} & I_{12} & \cdots & I_{1p} & b_1 \\
I_{21} & I_{22} & \cdots & I_{2p} & b_2 \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
I_{p1} & I_{p2} & \cdots & I_{pp} & b_p
\end{bmatrix}
\begin{bmatrix}
b_1 \\
b_2 \\
\vdots \\
b_p
\end{bmatrix}
= \begin{bmatrix}
I_{1p+1} \\
I_{2p+1} \\
\vdots \\
I_{pp+1}
\end{bmatrix}
\] (11)

After solving the linear equation (11), the value of \( b_1 \ b_2 \ \cdots \ b_p \) can be obtained.

E. Calculating the Eq. (12)

\[
b_0 = \bar{y} - b_1 \bar{x}_1 - b_2 \bar{x}_2 - \cdots - b_p \bar{x}_p
\] (12)

We can have the regression equation as follows:

\[
y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_p x_p
\] (13)

**IV. THE PROPOSED FORECASTING METHOD**

In this paper, GDP growth and economic growth rates are the input factors of the forecasting model, and the YPL and YED are the output values. Due to the nonlinear relation between input factors and output values, the forecasting of the YPL and YED is not easy work.
The main ideas of the proposed forecasting method divide into two parts. First, we use the extension clustering method to recognize the type of every year and to build the matter-element model of every load type. When the GDP growth and economic growth rates are given, the changed ranges of YPL and YED at the forecast times can be forecasted according to the relation a degree between the built models and forecasting models. Second, using the multi-regression analysis method to build the forecasting model of every load type, when the GDP growth and economic growth rates are given, the forecasting values can be calculated according to the most similar load model. Therefore, the proposed forecasting method can simultaneously use both the changed range and forecasting value. The structure of the proposed load forecasting method is shown in Fig. 2.

Let \( F_i (i = 1, 2, \cdots, m) \) is an \( m \) pieces extension set of \( F \) and \( F_i \subset F \), the forecasting subject \( F_x \) can decide whether it belong to the set of \( F_i \) or not by the extension clustering.
method, then the forecasting range and value of $F_i$ can be estimated by the similar load model. The proposed forecasting method is described in the following steps:

Step 1: According to the yearly peak load and electricity demand growth rates delimit some load types.

Step 2: Building the matter-element model and forecasting model of every load types as follows:

A. The matter-element model of i-th load type can be written as follows:

$$R_i = (F_i, C, X_i) = \left[ F_i, C_1, X_{i1}, C_2, X_{i2} \right]$$

(14)

Where $C_1$ is the GDP growth rate, $C_2$ is the economic growth rate, $X_{i1} = \langle a_{i1}, b_{i1} \rangle$ and $X_{i2} = \langle a_{i2}, b_{i2} \rangle$ are the changed ranges (classical domain) of the GDP growth and economic growth rates in i-th load type, respectively. The neighborhood domain of entire models in the extension set theory is defined as follows:

$$R_n = (F_n, C, X_n) = \left[ F_n, C_1, \langle f_1, g_1 \rangle, C_2, \langle f_2, g_2 \rangle \right]$$

(15)

Where $X_{d1} = \langle f_1, g_1 \rangle$ are the maximum and minimum values of the GDP growth rates in the entire models, and $X_{d2} = \langle f_2, g_2 \rangle$ are the maximum and minimum values of the economic growth rates in the entire models.

B. The forecasting model of every load type can be calculated by the multi-regression analysis method as in section III, the typical forecasting model of i-th load type in our problem can be written as:

$$y_i = b_{i0} + b_{i1}x_1 + b_{i2}x_2$$

(16)

Step 3: Formulating the matter-element of the forecasting data as follows:

$$R_x = (F_x, C, x) = \left[ F_x, C_1, x_1, C_2, x_2 \right]$$

(17)

where $x_1$ and $x_2$ are the GDP growth and economic growth rates of the forecasting data, respectively.

Step 4: Calculating the degrees of correlation of the forecasting data with the characteristic by
the proposed extended correlation function as follows:
\[
K_i(x_j) = \begin{cases} 
-0.5\rho(x_j,X_j), & \text{if } x_j \in X_{ij} \\
\|y_j-a_j\|, & \text{if } \rho(x_j,X_j) \\
\rho(x_j,X_j) - \rho(x_j,X_{ij}), & \text{if } x_j \notin X_{ij} 
\end{cases}
\]
(18)

Step 5: Setting the weights of every correlation degree, \(W_{i1}, W_{i2}\), depend on the importance of every characteristic in the recognition process. Because the importance of all characteristics is the same, all weights in this paper are set to 1/2.

Step 6: Calculating the indexes of correlation for every forecast type \(\lambda_i\).

\[
\lambda_i = \sum_{j=1}^{2} W_{ij} K_i
\]
(19)

Normalizing the indexes of correlation into an interval between –2 and 1 as Eq. (20).

\[
\lambda_i = \frac{3\lambda_i - \lambda_{\text{min}} - 2\lambda_{\text{max}}}{\lambda_{\text{max}} - \lambda_{\text{min}}}
\]
(20)

Where \(\lambda_{\text{max}} = \max_{1 \leq i \leq n} \{\lambda_i\}\), \(\lambda_{\text{min}} = \min_{1 \leq i \leq n} \{\lambda_i\}\). This process will be beneficial for recognition.

Step 8: Determining the load type of the forecasting data. The rule is that if \(\lambda_{iP} = 1\) then the forecasting data belongs to the \(P\)-th type.

Step 9: Using the range of load growth rates of \(P\)-th type to calculate the forecasting maximum and the minimum values of forecasting data.

Step 10: Using the forecasting model of \(P\)-th type with Eq. (16) to calculate the YPL and YED of the forecasting data.

V. CASE STUDIES AND DISCUSSIONS

To verify the proposed forecasting methods, Taiwan power (Taipower) system YPL, YED, GDP and economic growth rate data form 1982 to 2003 [12-13], twenty-two years data are utilized for experimentation. The historical data is shown in Table I. This paper uses the historical data from 1982 to 2001 to build the forecasting models, and the forecasting models to forecast the YPL and the YED from 2002 to 2003. Comparisons of forecasting results using the grey GM (1,1) model are also conducted [7,8,14].

5.1 The non-linear nature of this forecasting problem

According to the historical data in Table I, the forecasting models use the GDP and
economic growth rates for input factors, the YED and the YPL growth rates are the output values. Figs. 3 and 4 show the relation between the input factors and output values. It is clear that the relations between the input factors and output values are highly non-linear curves. So if the forecasting models are directly to use the MRAM, the forecasting error will be large, which is the main reason in the proposed method to delimit some load types (or some sections) in the related curves. When the load types are delimited, every load type (or section) can be seen as approximately linear, thus the sectioned forecasting models will provide higher accuracy.

Table I
The YED, YPL, GDP and Economic growth data in Taiwan.

<table>
<thead>
<tr>
<th>Year</th>
<th>YED (KLOE)</th>
<th>YPL (MW)</th>
<th>GDP (NT$)</th>
<th>Economic growth rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>10,130,800</td>
<td>6,918</td>
<td>1,899,971</td>
<td>3.55</td>
</tr>
<tr>
<td>1983</td>
<td>11,308,300</td>
<td>7,808</td>
<td>2,100,005</td>
<td>8.45</td>
</tr>
<tr>
<td>1984</td>
<td>12,365,800</td>
<td>8,517</td>
<td>2,343,078</td>
<td>10.6</td>
</tr>
<tr>
<td>1985</td>
<td>12,988,600</td>
<td>8,716</td>
<td>2,473,786</td>
<td>4.95</td>
</tr>
<tr>
<td>1986</td>
<td>14,551,900</td>
<td>9,900</td>
<td>2,855,180</td>
<td>11.64</td>
</tr>
<tr>
<td>1987</td>
<td>16,100,100</td>
<td>11,113</td>
<td>3,237,051</td>
<td>12.74</td>
</tr>
<tr>
<td>1988</td>
<td>17,838,000</td>
<td>12,331</td>
<td>3,523,193</td>
<td>7.84</td>
</tr>
<tr>
<td>1989</td>
<td>19,449,500</td>
<td>13,422</td>
<td>3,938,826</td>
<td>8.23</td>
</tr>
<tr>
<td>1990</td>
<td>20,857,500</td>
<td>14,511</td>
<td>4,307,043</td>
<td>5.39</td>
</tr>
<tr>
<td>1991</td>
<td>23,107,900</td>
<td>15,321</td>
<td>4,810,705</td>
<td>7.55</td>
</tr>
<tr>
<td>1993</td>
<td>26,075,200</td>
<td>17,666</td>
<td>5,918,376</td>
<td>7.01</td>
</tr>
<tr>
<td>1994</td>
<td>27,888,000</td>
<td>18,610</td>
<td>6,463,600</td>
<td>7.11</td>
</tr>
<tr>
<td>1995</td>
<td>29,629,700</td>
<td>20,000</td>
<td>7,017,933</td>
<td>6.42</td>
</tr>
<tr>
<td>1996</td>
<td>31,449,800</td>
<td>22,000</td>
<td>7,678,126</td>
<td>6.1</td>
</tr>
<tr>
<td>1997</td>
<td>34,137,700</td>
<td>22,900</td>
<td>8,328,780</td>
<td>6.68</td>
</tr>
<tr>
<td>1998</td>
<td>36,590,800</td>
<td>23,830</td>
<td>8,938,967</td>
<td>4.57</td>
</tr>
<tr>
<td>1999</td>
<td>39,867,800</td>
<td>24,206</td>
<td>9,289,929</td>
<td>5.42</td>
</tr>
<tr>
<td>2000</td>
<td>44,162,100</td>
<td>25,854</td>
<td>9,663,388</td>
<td>5.86</td>
</tr>
<tr>
<td>2001</td>
<td>45,135,400</td>
<td>26,290</td>
<td>9,506,624</td>
<td>-2.18</td>
</tr>
<tr>
<td>2002</td>
<td>47,467,200</td>
<td>27,117</td>
<td>9,748,811</td>
<td>3.59</td>
</tr>
<tr>
<td>2003</td>
<td>49,623,300</td>
<td>28,129</td>
<td>9,847,555</td>
<td>3.24</td>
</tr>
</tbody>
</table>

Power: 1 KWH=956 KLOE
KLOE: kiloliters Oil Equivalent
5.2 The forecasting results of YED.

In Table I, the YED data from 1982 to 2001 is between 2.2% and 12.03% and can be divided into five types. Every load type with the related year is shown in Table II, then the matter-element model of every load type can be built according to ranges of the GDP and the economic growth rates as shown in Table III. In Table IV, according to the proposed forecasting method, both 2002 and 2003 belong to the second load types, thus the electricity demand growth forecasting is between 3.5% and 6.0%. Table V shows the compared results in years 2002 and 2003 with the different forecasting methods. The electricity demand is 45,135,400 KLOE in year 2001, so the electricity demand is between 46,715,139 KLOE and 47,843,524 KLOE in year 2002. When using the forecasting model of the second load type to calculate the forecasting value in year 2002, the forecasting value is 46,862,100 KLOE. In
fact, the electricity demand in year 2002 is 4,746,200 KLOE and the growth rate is 5.17%, the error of the forecast value is only 1.28%. Oppositely, the forecast value of grey GM(1,1) method is 49,291,500 OECD that the error is 3.843% in year 2002. Similarly, the electricity demand in year 2003 is 4,962,300 KLOE. The forecasting range of the proposed method is between 49,128,552 KLOE and 50,315,232 KLOE, and forecasting value is 49,135,000 KLOE, the forecasting error of the proposed method is only 0.99%, but the error of grey GM(1,1) method is 6.57%. The compared forecasting results with the grey GM (1,1) model show that the proposed method has better accuracy in year 2002 or 2003. Moreover, the proposed forecasting method can also forecast maximum and minimum values, simultaneously, which is the most important information for the long-term power system plan.

Table II
The load types of YED growth rates.

<table>
<thead>
<tr>
<th>Type No.</th>
<th>YED growth rates $P_R$ (%)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_1$</td>
<td>$1.0 &lt; P_R \leq 3.5$</td>
<td>2001</td>
</tr>
<tr>
<td>$F_2$</td>
<td>$3.5 &lt; P_R \leq 6.0$</td>
<td>1982 - 1985</td>
</tr>
<tr>
<td>$F_5$</td>
<td>$11.0 &lt; P_R &lt; 13.5$</td>
<td>1983 - 1986</td>
</tr>
</tbody>
</table>

Table III
The Matter-element models of YED growth rates.

Matter-element models

<table>
<thead>
<tr>
<th>Matter-element models</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1 = (F_1, C, X_1) =$</td>
</tr>
<tr>
<td>$F_1, C_1, &lt; -1.62, -1.46 &gt;$</td>
</tr>
<tr>
<td>$C_2, &lt; -2.18, -1.96 &gt;$</td>
</tr>
<tr>
<td>$R_2 = (F_2, C, X_2) =$</td>
</tr>
<tr>
<td>$F_2, C_1, &lt; 5.58, 7.11 &gt;$</td>
</tr>
<tr>
<td>$C_2, &lt; 3.55, 4.95 &gt;$</td>
</tr>
<tr>
<td>$R_3 = (F_3, C, X_3) =$</td>
</tr>
<tr>
<td>$F_3, C_1, &lt; 7.33, 10.98 &gt;$</td>
</tr>
<tr>
<td>$C_2, &lt; 4.57, 7.49 &gt;$</td>
</tr>
<tr>
<td>$R_4 = (F_4, C, X_4) =$</td>
</tr>
<tr>
<td>$F_4, C_1, &lt; 3.93, 13.37 &gt;$</td>
</tr>
<tr>
<td>$C_2, &lt; 5.42, 12.74 &gt;$</td>
</tr>
<tr>
<td>$R_5 = (F_5, C, X_5) =$</td>
</tr>
<tr>
<td>$F_5, C_1, &lt; 10.53, 15.42 &gt;$</td>
</tr>
<tr>
<td>$C_2, &lt; 8.45, 11.64 &gt;$</td>
</tr>
</tbody>
</table>
### Table IV
Correlation Indexes of the YED with different years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Correlation Indexes</th>
<th>Recognized Types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda_1'$</td>
<td>$\lambda_2'$</td>
</tr>
<tr>
<td>2002</td>
<td>-1.43</td>
<td>1</td>
</tr>
<tr>
<td>2003</td>
<td>-1.54</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table V
The forecasting results in years 2002 and 2003 with the different methods.

<table>
<thead>
<tr>
<th>Items</th>
<th>Forecasting methods</th>
<th>YED (KLOE)</th>
<th>YPL (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2002</td>
<td>2003</td>
</tr>
<tr>
<td>Actual Data</td>
<td></td>
<td>47,467,000</td>
<td>49,623,000</td>
</tr>
<tr>
<td>Grey GM(1,1) method</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forecasting values</td>
<td></td>
<td>49,291,500</td>
<td>52,882,000</td>
</tr>
<tr>
<td>Forecasting error (%)</td>
<td></td>
<td>3.84</td>
<td>6.57</td>
</tr>
<tr>
<td>Proposed method</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forecasting Max. values</td>
<td></td>
<td>47,843,524</td>
<td>50,315,232</td>
</tr>
<tr>
<td>Forecasting Min. values</td>
<td></td>
<td>46,715,139</td>
<td>49,128,552</td>
</tr>
<tr>
<td>Forecasting values</td>
<td></td>
<td>46,862,000</td>
<td>49,135,000</td>
</tr>
<tr>
<td>Forecasting error (%)</td>
<td></td>
<td>1.28</td>
<td>0.99</td>
</tr>
</tbody>
</table>

### 5.3 The forecasting results of YPL

In Table I, the YPL growth rates from 1982 to 2001 are between 1.57% and 13.58% and can be divided into five types. The load types of YPL with the related year are shown in Table VI. The matter-element model of every load type can be built according to ranges of the GDP and the economic growth rates as shown in Table VII. The forecasting results of the proposed method can be seen in Tables V and VIII. The forecasting growth rates of YPL are between 1.5% and 4.0%. The year 2002 was a type 1 year. The YPL is 26,290 MW in year 2001, so the forecasting YPL is between 26,684.35 MW and 27,341.6 MW in year 2002. In fact, the peak load demanded data is 27,117 MW and the growth is 2.55% that error of the forecast value is only 1.32%, but the forecast value using grey GM(1,1) method is 29,388 MW and the error is 8.38% in year 2002. Similarly, in year 2003, the YPL real value is 28,129 MW, the forecasting range of the proposed method is between 27,524 MW and 28,201 MW, the forecasting value is 27,586 MW that the error is only 1.93%. In opposition, the forecast value of grey GM(1,1) method is 31,097 MW that the error is 10.55% in year 2003.
The forecasting results, compared with the grey GM (1,1) model, show that the proposed method has better accuracy on YPL in years 2002 and 2003.

Table VI
The load types of YPL growth rates.

<table>
<thead>
<tr>
<th>Type No.</th>
<th>YPL growth rates $p_p$ (%)</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_1$</td>
<td>$1.5 &lt; p_p \leq 4.0$</td>
<td>1982，1985，2001</td>
</tr>
<tr>
<td>$I_3$</td>
<td>$6.5 &lt; p_p \leq 9.0$</td>
<td>1989，1990，1995，2000</td>
</tr>
<tr>
<td>$I_4$</td>
<td>$9.0 &lt; p_p \leq 11.5$</td>
<td>1984，1988，1992，1996</td>
</tr>
<tr>
<td>$I_5$</td>
<td>$11.5 &lt; p_p \leq 14.0$</td>
<td>1983，1986，1987</td>
</tr>
</tbody>
</table>

Table VII
The Matter-element models of YPL.

<table>
<thead>
<tr>
<th>Matter-element models</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1 = (I_1, C, X_1) = { I_1, \ C_1, &lt; -1.62,7.11 &gt; }$</td>
</tr>
<tr>
<td>$R_2 = (I_2, C, X_2) = { I_2, \ C_1, &lt; 7.33,11.69 &gt; }$</td>
</tr>
<tr>
<td>$R_3 = (I_3, C, X_3) = { I_3, \ C_1, &lt; 4.02,11.8 &gt; }$</td>
</tr>
<tr>
<td>$R_4 = (I_4, C, X_4) = { I_4, \ C_1, &lt; 8.84,11.57 &gt; }$</td>
</tr>
<tr>
<td>$R_5 = (I_5, C, X_5) = { I_5, \ C_1, &lt; 10.53,15.42 &gt; }$</td>
</tr>
</tbody>
</table>

Table VIII
Correlation Indexes of the YPL forecasting data.

<table>
<thead>
<tr>
<th>Year</th>
<th>Correlation Indexes $\hat{\lambda}$</th>
<th>Recognition Types $\hat{\lambda}_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>$-1.4887$ $-1.414$ $-1.7536$ $-2$</td>
<td>$I_1$</td>
</tr>
<tr>
<td>2003</td>
<td>$-1.487$ $-1.2877$ $-1.7538$ $-2$</td>
<td>$I_1$</td>
</tr>
</tbody>
</table>

5.4 Comparison of modeling accuracy

The compared results of modeling accuracy are shown in Fig. 5 and Fig. 6. As we can see in Fig. 5 and 6, promising results were obtained by using the proposed forecasting method not only in the YED model or in the YPL model (1982 to 2001) but also in the forecasting model (2002 to 2003). The average error of all methods is shown in Table IX. The average errors of
the proposed method in both the YED and YPL are only 0.365% and 0.572%, respectively. On the other hand, the average errors of the grey GM(1,1) model are 3.18% and 6.569%. Therefore, the compared results also show that the proposed forecasting method has the higher accuracy than the grey GM(1,1) method.

![Fig. 5](image1.png)  
**Fig. 5** The comparison between the actual YED data and the modeling data with the different methods.

![Fig. 6](image2.png)  
**Fig. 6** The comparison between the actual YPL data and the modeling data with the different methods.
Table IX
Average error between the actual data and the modeling data with the different modeling methods.

<table>
<thead>
<tr>
<th>Modeling methods</th>
<th>YED average error (%)</th>
<th>YPL average error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed method</td>
<td>0.36479%</td>
<td>0.5717%</td>
</tr>
<tr>
<td>GM(1,1) method</td>
<td>3.1788%</td>
<td>6.5693%</td>
</tr>
</tbody>
</table>

VI. CONCLUSIONS

Economic development is based the electricity. The growth of electrical demand reflects the economic development and the industrial development at that time. This paper presents a novel forecasting method combining both the extension theory and the MRAM. The proposed method not only can be used to forecast the values of YED and YPL, it also can be used with multi-input factors in highly non-linear forecasting problems. The main advantage of the proposed method is that it can give the forecasting range and forecasting value at the same time. Moreover, the proposed method does not need learning time and artificial parameters, and the computing time is also short. Using practical numerical comparisons with the grey GM (1,1) model show that the proposed forecasting method has better accuracy and provides more information to planners on both YED and YPL forecasting.

REFERENCES


