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ScienceDirect

Energy 32 (2007) 1670–1675

ENERGY

www.elsevier.com/locate/energy

Grey prediction with rolling mechanism for electricity demand forecasting of Turkey

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Received 7 August 2006

Abstract

The need for energy supply, especially for electricity, has been increasing in the last two decades in Turkey. In addition, owing to the uncertain economic structure of the country, electricity consumption has a chaotic and nonlinear trend. Hence, electricity configuration planning and estimation has been the most critical issue of active concern for Turkey. The Turkish Ministry of Energy and Natural Resources (MENR) has officially carried out energy planning studies using the Model of Analysis of the Energy Demand (MAED). In this paper, Grey prediction with rolling mechanism (GPRM) approach is proposed to predict the Turkey's total and industrial electricity consumption. GPRM approach is used because of high prediction accuracy, applicability in the case of limited data situations and requirement of little computational effort. Results show that proposed approach estimates more accurate results than the results of MAED, and have explicit advantages over extant studies. Future projections have also been done for total and industrial sector, respectively.

Keywords: Electricity demand; Forecasting; Grey prediction

1. Introduction

A good demand forecasting is the essential prerequisite of an energy system study for not only aiming at cost-efficient investments in the capacity expansion planning, but also plays an effective role in monitoring environmental issues as well as setting tariffs and relevant plans for demand side management studies. As a result of these, energy demand forecasting studies constitutes the vital part of energy policy of countries, especially for those countries whose energy demand is growing relatively quickly, as the case of Turkey. With its developing economic structure, Turkey is a virtually net energy importer and its demand for energy, especially for electricity, is growing relatively quickly as a result of the growth in its economy in the recent years. Gross electricity consumption was 163.2 TWh in 2005. According to the projections, that will be 500 TWh in 2020 [1]. This situation shows that electricity sector in Turkey is in a dynamic change. Furthermore, Turkish economy is extremely sensitive to the internal and external political, economic and market development. Due to these negative or positive impacts, its energy consumption pattern also fluctuates even in a short period. For this, the economic crises of 2001 can be given as an example. Therefore, this kind of structure of energy demand in Turkey requires a detailed effort for an accurate prediction.

In literature, considerable efforts have been made for energy demand forecasting. Box–Jenkins models, regression models, econometric models, neural networks are the most commonly used techniques in energy forecasting studies [2]. In Turkey, energy forecasting studies have been officially carried out by the Turkish Ministry of Energy and Natural Resources (MENR) by using Model of Analysis of the Energy Demand (MAED) [3]. Using a bottom–up methodology, MAED is a simulation model designed to evaluate medium and long-term demand for energy in a country, and has being implemented for the last two decades in the country. Nevertheless, to run the model,

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doi:10.1016/j.energy.2006.11.014

one needs too much of versatile input data as well as experimental knowledge. These can be regarded as virtual disadvantages of the model [4]. It is also criticized in a number of studies that demand projections of MAED are higher than real values owing to the effects of government policies on the results [5]. Effect of government interventions primarily due to the reasons that each government pursues its own energy policies, unexpected economic fluctuations frequently take place caused by political instability, perceived shortages in the natural gas supplies and high dependency of the power generation system on this resource, resulting in an unexpected partial black-outs. Therefore, it will be useful to use a different technique apart from that of MENR's to obtain more reliable results with the least accurate forecast errors as much as possible.

Except for the MENR, there are studies about energy demand forecasting studies for Turkey. Ediger and Tatlıdil [5] applied cyclic pattern method for forecasting primary energy demand in Turkey. Canyurt et al. [6] modelled Turkey's future energy demand using genetic algorithm approach based on gross domestic product, population, import and export figures. Ozturk and Ceylan [7] utilized from genetic algorithm to forecast electricity demand for Turkey based on socio-economic indicators. Gorucu et al. [8] modelled gas consumption by using artificial neural networks (ANN). Sozen et al. [9] used ANN for forecasting net energy consumption in Turkey. Tunc et al. [10] predicted Turkey's electricity consumption rates with regression analysis for the years of 2010 and 2020 and, developed a linear mathematical model to predict the distribution of future electrical power supply investments in Turkey.

The aim of this study is to present a new methodology for electricity demand forecasting for Turkey using Grey prediction (GP). As mentioned before, Turkey's energy demand structure can be characterized as both unstable and chaotic. In this sense, GP is an alternative forecasting tool for those systems whose structure is complex, uncertain and chaotic. GP has been widely used in forecasting studies due to its advantages, requiring low data items to build forecasting models and higher forecasting accuracy when compared with other forecasting techniques. There are lots of studies using GP in energy demand forecasting in literature. Dong [11] has forecasted energy demand of China for the next 25 years using GP. Yao et al. [12] proposed an integrated grey-fuzzy based electricity management for enterprises. Yao and Chi [13] developed taguchi-grey based predictor to forecast the demand value of electricity on line. Hsu and Chen [14] forecasted power demand of Taiwan using an improved grey model (GM). The results of these given studies show that the GP is a practical and reliable tool in energy demand forecasting.

Although there are studies relating to energy demand forecasting for Turkey based on socio-economic indicators such as gross domestic product, population and import–export figures [6–7], those studies have certain deficiencies and disadvantages. In these studies, future predictions have been achieved under different scenarios of those indicators without predicting future values of indicators. But, for the developing countries, especially for Turkey, aforementioned indicators have neither stable nor predictable trends, even in a long term, owing to politic and economic uncertainties or fluctuations taking place in international markets. In other words, it is rather difficult to incorporate quantitatively and handle the uncertain factors such as socio-economic indicators for the energy demand projections in Turkey. Yet, using socio-economic indicators for future energy demand forecasting, estimation of these indicators seem to be another problem that should additionally be studied on them. However, GP only needs recent year's data for reliable and acceptable accuracy for future prediction. This is one of the considerable advantages of GP over previous studies. Besides, it is more practicable and user friendly when compared to Box–Jenkins models and artificial intelligence techniques which require more effort and time for parameter identification and model building phases.

In this paper, GP with rolling mechanism (GPRM) approach is suggested for the electricity demand forecasting for Turkey. The rolling mechanism is an efficient technique to increase forecasting accuracy of GP in case of having exponential and chaotic data. The electricity consumption data for Turkey from 1970 to 2004 is modelled using the GPRM. The model is applied separately to forecast total and industrial sector electricity consumption. Rest of the paper is structured as follows. GP and GPRM approaches are introduced shortly in Section 2. Results of electricity demand forecasting obtained by GPRM are presented in Section 3 in addition to future projections. Finally, the study has been concluded in Section 4 with comments on future researches.

2. Grey prediction

Grey Theory (GT) deals with systems having uncertain and imperfect information [15–16]. In real life, systems are modelled and decisions are made under the assumptions of insufficient and imperfect information, which are basic properties of GT [17]. The GP adopts the essential part of the GT and it has been successfully used in forecasting problems in many disciplines and obtained very successful results as it requires as few as four lagged inputs to constructs a prediction model [18–21]. Moreover, the method is straightforward and little computational effort is needed to constitute the prediction model. Review and applications of GP and GT have been presented by Lin and Lin [22].

GP has three basic operations: accumulated generating operator (AGO), inverse accumulating operator (IAGO) and grey model (GM). GM(1,1), i.e. first order grey model with one variable. The steps of GP are shown below [17].

Step 1: Original time sequence with n samples (time point) is expressed as

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)). \tag{1}$$

AGO operator, Eq. (2), is used to convert chaotic series $x^{(0)}$ into monotonically increasing series $x^{(1)} = (x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n))$, where $x^{(1)}$ is derived as follows:

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

Step 2: Form the GM(1,1) model by establishing a first order grey differential equation

$$x^{(0)}(k) + az^{(1)}(k) = b, \tag{3}$$

where

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1). \tag{4}$$

In Eq. (3), k ($k = 2,\ldots,n$) is a time point. a is called the development coefficient and b is called driving coefficients. Using least mean square estimation technique coefficients, $[a\ b]^{\mathrm{T}}$ can be estimated as

$$\begin{bmatrix} a \\ b \end{bmatrix} = [B^{\mathrm{T}}B]^{-1}B^{\mathrm{T}}Y, \tag{5}$$

where

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \ldots & 1 \\ -z^{(1)}(n) & 1 \end{bmatrix}, \quad Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}.$$

Step 3: According to the estimated coefficients a and b, GP equation can be obtained by solving differential equation in Eq. (3).

$$\hat{x}^{(1)}(k+1) = \left[x^{(1)}(0) - \frac{b}{a}\right]e^{-ak} + \frac{b}{a}, \tag{6}$$

where $\hat{x}(k)$ denotes the prediction of x at time point k and $x^{(1)}(0)$ is taken to be $x^{(0)}(1)$. By performing IAGO on $\hat{x}^{(1)}(k+1)$ elements of the estimated series $\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1)$ for $k = 2,3,\ldots,n$ can be extracted.

In GM(1,1), the whole data set is used for prediction. It is, however, recommended using only recent data to increase forecasting accuracy in future prediction in case of having chaotic data. GPRM is such a technique used in GP for ensuring this approach. In GPRM, $x^{(0)}(k+1)$ is predicated by applying GM(1,1) to $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(k))$ where $k<n$. After the result is found, procedure is repeated, but this time the newly predicted entry $x^{(0)}(k+1)$ is added to at the end of data, and the oldest data $x^{(0)}(1)$ is removed from data. Next, $x^{(0)} = (x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(k+1))$ is used to predicate $x^{(0)}(k+2)$. When $k = 4,5,6,\ldots,n-1$, mean absolute percentage error (MAPE) for the $(k+1)$ instant of GM(1,1) is defined as

$$e(k+1) = abs\left(\frac{x^{(0)}(k+1) - \hat{x}^{(0)}(k+1)}{x^{(0)}(k+1)}\right) * 100\%, \tag{7}$$

where $k+1 \leqslant n$. And, the average rolling error of GM(1, 1) is

$$e = \frac{1}{n-4}\sum_{k=4}^{n-1} e(k+1) * 100\%. \tag{8}$$

3. Electricity demand forecasting for Turkey with GPRM

The main goal of this study is to forecast electricity demand forecasting for Turkey using GPRM. The electricity consumption data for Turkey from 1970 to 2004 were obtained from the MENR (Table 1) for building GPRM model [3].

It is seen in Fig. 1 that electricity consumption shows an exponential trend. Due to the instable economic structure of the country, demand fluctuates especially in the last five year period. There is also an ongoing increase in the power consumption as well as resulting in irregular changes due to the changes occurring in the social and economic factors. Therefore, GPRM appears as a consistent technique for an accurate demand forecasting for the electricity demand in Turkey.

In case, a prediction series performs a substantial versatility, it is preferred to study with rolling mechanism having small values for k. Thus, recent four years data ($k-3$, $k-2$, $k-1$, k) are selected to predict $(k+1)$th point, i.e. $k = 4$ is used in rolling mechanism in this study. For the period of 1970–2004, starting from 1970, each fifth year's consumption value is computed based on the consumption data of its prevailing four years. For example, the value of 1974 is predicted by executing the model GM(1,1), which is, in turn, constructed by using the data for 1970, 1971, 1972, and 1973. $\hat{x}^{(0)}(k+1)$, i.e. estimation of total electricity consumption in 1974 is obtained as 11.89 using prediction equation and IAGO. Then, predicting value was compared with measured data so that predicting accuracy, i.e. MAPE, could be inspected. MAPE for total electricity consumption in 1974 is 3.66%. These steps were repeated for the rest of the years (1974–2004). The average rolling error of GM(1,1) for total electricity consumption was calculated using Eq. (8).

$$e = \frac{1}{35-4}\sum_{k=4}^{35-1} e(k+1) * 100\%$$
$$= \frac{1}{31}(4.66 + 7.90 + 6.0 + \cdots + 1.32) * 100\% = 3.69.$$

Prediction accuracy for total electricity consumption for 1974–2004 is 100−3.69 = 96.31%, which is a satisfactory result. In the same manner, all the computations are carried out for the industrial electricity consumption. For the period of 1974–2004, industrial sector's MAPE value is determined as 5.7%. Prediction accuracy of industrial electricity consumption is 94.93%. The difference, that the error value of industrial sector's electricity consumption is found slightly greater than that of total electricity, would

Table 1
Total and industrial sector electricity consumption from 1970 to 2004

Years	Industrial sector electricity consumption (TWh)	Total electricity consumption (TWh)	Years	Industrial sector electricity consumption (TWh)	Total electricity consumption (TWh)
1970	4.69	7.31	1988	25.26	39.72
1971	5.34	8.29	1989	27.60	43.12
1972	6.19	9.53	1990	29.21	46.82
1973	7.09	10.53	1991	28.51	49.28
1974	7.58	11.36	1992	31.54	53.98
1975	8.75	13.49	1993	34.25	59.24
1976	10.51	16.08	1994	34.14	61.40
1977	11.98	17.97	1995	38.01	67.39
1978	12.41	18.93	1996	40.64	74.16
1979	12.54	19.63	1997	43.49	81.88
1980	13.01	20.40	1998	46.14	87.70
1981	14.21	22.03	1999	46.48	91.20
1982	15.20	23.59	2000	48.84	98.30
1983	15.58	24.47	2001	46.99	97.07
1984	18.03	27.64	2002	50.49	102.95
1985	19.61	29.71	2003	55.10	111.77
1986	20.89	32.21	2004	59.57	121.14
1987	23.87	36.70			

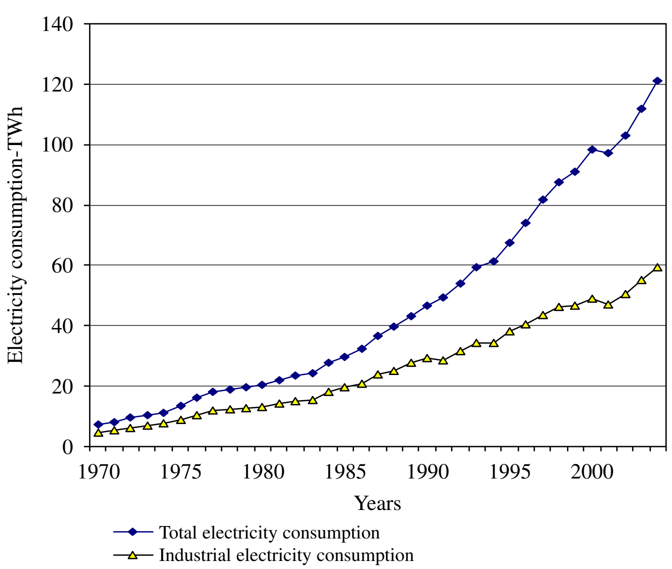

Fig. 1. Electricity consumption from 1970 to 2004.

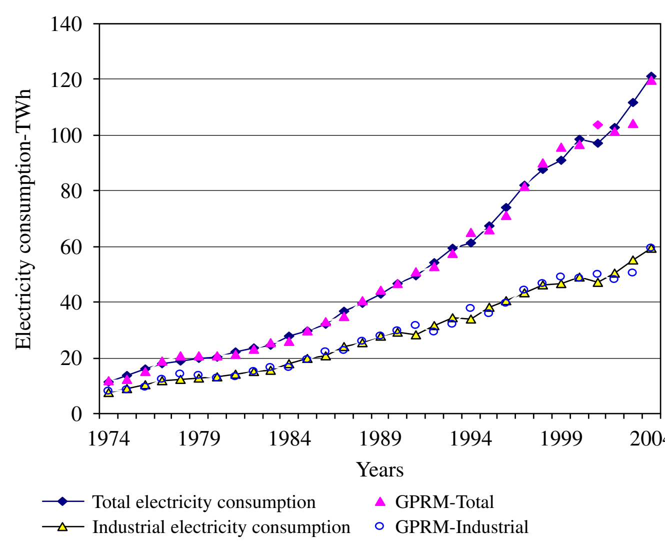

Fig. 2. Actual and fitted values for electricity consumption.

be explained due to the reason that the former is much more sensitive to changes in the economic structure.

Actual and fitted values for both total and industrial electricity consumptions are also presented in Fig. 2. As Fig. 2 is closely investigated, it can be seen that the results obtained with the GPRM reflect the trend of electricity consumption.

Results of GPRM were also compared to MAED's results for the period 1994–2004. Demand forecasting of MAED was taken from the WEC-TNC [23]. The results of the comparison based on the total and industrial level are presented in Tables 2 and 3, respectively. The GPRM gives much better results than the MAED model in the comparison of electricity consumption values of both total and the industrial sector. As it can be seen from the given tables, there are substantial differences between the results of the both models. The reason in that difference is that the MAED model uses too many indicators, and in case of the existence of a high level of variability in them, this simply brings about error effect on the results. On the other hand, GPRM uses only the consumption data of the last four years. In this respect, it has both simplicity and much better prediction accuracy, and can be implemented reliably.

Using GPRM, future projections have also been done for both total and industrial consumption for the period 2006–2015 (Fig. 3). Results show that electricity consumption will increase approximately 50% for the next

Table 2
Comparison of MAED and GPRM for total electricity consumption (TWh)

Years	Actual	MAED	Error (%)	GPRM	Error (%)
1994	61.40	66.82	8.83	64.88	5.66
1995	67.39	74.57	10.65	65.93	2.17
1996	74.16	81.23	9.54	71.34	3.80
1997	81.88	88.48	8.05	81.40	0.59
1998	87.70	96.38	9.89	90.13	2.76
1999	91.20	104.99	15.12	95.63	4.86
2000	98.30	114.37	16.35	96.60	1.72
2001	97.07	123.60	27.33	103.56	6.68
2002	102.95	133.58	29.76	101.45	1.46
2003	111.77	144.36	29.16	104.23	6.74
2004	121.14	156.01	28.78	119.53	1.33
Average MAPE			17.59		3.43

Table 3
Comparison of MAED and GPRM for industrial electricity consumption (TWh)

Years	Actual	MAED	Error (%)	GPRM	Error (%)
1994	34.14	39.66	16.18	37.58	10.09
1995	38.01	44.74	17.71	35.95	5.41
1996	40.64	49.30	21.31	39.46	2.90
1997	43.49	54.26	24.76	44.51	2.33
1998	46.14	59.70	29.39	46.49	0.77
1999	46.48	65.66	41.26	49.20	5.84
2000	48.84	72.20	47.82	48.41	0.88
2001	46.99	77.97	65.93	49.93	6.27
2002	50.49	84.22	66.81	47.94	5.05
2003	55.10	90.96	65.08	50.48	8.39
2004	59.57	98.24	64.93	59.52	0.08
Average MAPE			41.93		4.36

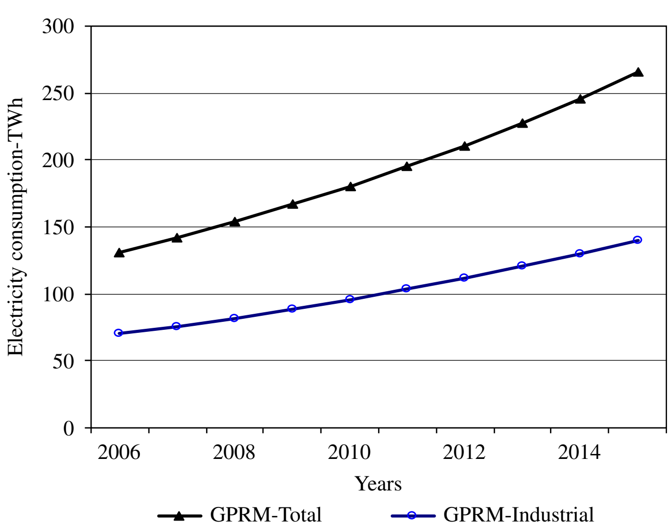

Fig. 3. Electricity demand projection from 2006 to 2015.

decade. It is expected that industrial and total consumption will be 140.37 and 265.7 TWh in 2015, respectively. However, due to the unstable and uncertain economic and social structure of the country, for the each next five year period, it is strictly recommended revising the results using GPRM for obtaining more accurate outcomes.

4. Conclusions and future research

In this paper, it is attempted to model and forecast total and industrial electricity forecasting for Turkey based on GPRM. Results have revealed that GPRM performs better results than official results of MENR for both total and the industrial sector. These results have solicited that GPRM can be used safely for future electricity projection. Future projections have also been carried out for both total and industrial consumption using GPRM for the period 2006–2015.

Based on this study, following works using GPRM may focus on two areas, namely electricity forecasting for various sectors and short-term load forecasting. The usage of GPRM can also be extended to forecast various sectors such as residential, agriculture and transportation. Besides, it has not yet encountered any research related with short-term load forecasting for Turkey which is also a critical and urgent aspect for operational concerns. Therefore, GPRM can be used as a useful tool for short-term load forecasting for Turkey.

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