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The prediction model for electrical power system using an improved hybrid optimization model

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ABSTRACT

In this paper, an improved hybrid optimization model based on grey GM (1,1) model is proposed to develop the prediction model in power systems. To realize more accurate prediction, the regression model is firstly integrated into GM (1,1) through compensation for the residual error series. The improved model is defined as RGM (1,1). Furthermore, Markov chain model is applied to RGM (1,1) to enhance the prediction performance. We call the proposed model as MC-RGM (1,1). Finally, Taylor approximation method is presented MC-RGM (1,1) for achieving the high prediction accuracy. The improved model is defined as T-MC-RGM (1,1). A real case of thermal electric power generation in Japan is used to validate the effectiveness of proposed model.

1. Introduction

The power prediction models have been researched by many researchers in order to provide useful information for the real-time power generation, efficient energy management, and economic cost saving [1]. In electric power production, the thermal power generation is one of the conversion to the electric power of the reaction fever energy of fuel, such as oil, coal, natural gas, and waste, i.e. Now, thermal power generation occupies about 70% of the electric power production in Japan [2]. Therefore, the accurate prediction for thermal power generation can help the decision making of Japan's future energy policy. The conventional power prediction models can be roughly divided into four types: time series method [3], regression method [4], expert-based method [5] and neural network based method [6]. However, the prediction accuracies of time series method and regression method rely on a law for the distribution of original series as well as a large amount of observed data. The drawback of fuzzy theory is that its analysis model is established based on human's experience as well as the amount of training data. The successes of neural network based method needs a large amount of training data [7]. In many practical situations, because of limitation for many reasons, it is very difficult to obtain the complete information from analyzed system [8]. In order to realize the analysis and prediction for uncertain systems accurately, Professor Deng [9] proposed the grey model based on grey system theory. As the prediction model, GM (1,1) has made an important role to make accurate prediction in power systems prediction fields [10–15]. However, GM (1,1) only s only a first order single variable grey model, the forecasted accuracy is unsatisfactory when original data show great randomness [16].

In this paper, we propose an improved GM (1,1) model, then it is applied to perform the power generation prediction. We first integrate second order polynomial regression model into GM (1,1) to enhance its prediction capability by compensation for the residual error between the actual output and prediction value from GM (1,1). We call the improved model as RGM (1,1). Then, Markov chain model is combined with RGM (1,1) to further enhance the prediction performance. We call the proposed model as MC-RGM (1,1). Finally, Taylor approximation method is presented to MC-RGM (1,1) for achieving the high prediction accuracy. The improved model is defined as T-MC-RGM (1,1). A real case of thermal electric power generation in Japan is used to validate the effectiveness of proposed model. The experimental results show that the proposed improved model has good performance for power generation prediction.

This paper is organized as follows: Section 2 describes preliminaries which include some definitions in grey system theory and GM (1,1) model which stand for first-order grey model with single variable. Section 3 discusses the improved RGM (1,1) prediction model by compensation for the residual error between the actual

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output and prediction value from GM (1,1). Section 4 describes the hybrid model which is combined Markov chain model with RGM (1,1). The optimization model to find the optimal whitening coefficient of MC-RGM (1,1) by Taylor approximation method is described in Section 5. Case study is presented in Section 6. Finally, conclusions are drawn in Section 7.

2. Preliminaries

In recent years, grey system theory has become a very effective method of solving uncertainty problems under discrete data and incomplete information. The grey system theory have also been successfully employed in many prediction applications with the use of grey model GM (1,1), such as geosciences, engineering, agriculture, medicine, meteorology, natural sciences, and bioscience [17–26].

2.1. Basic definitions

Definition 1. According to the concept of black box, a grey system is defined as a system containing uncertain information presented by grey number [9].

Definition 2. A grey number is one of which the exact value is unknown, while the upper and/or the lower limits can be estimated. Generally grey number is written as $\otimes X_g$ [16]:

$$\otimes X_g = [X_d, X_u] \tag{1}$$

where X_d is the lower limit and X_u is the upper limit. Based on some means (or research), when we know some more information, then the $\otimes X_g$ may be transformed into a exact number. The exact number is called as whitening number.

Definition 3. The whitening method for the grey number $\otimes X_g$ is given as [16]

$$X_g = \Lambda X_d + (1-\Lambda)X_u \tag{2}$$

where $\Lambda \in [0,1]$; is called the whitening coefficient. For example, the statement that a product's weight is possibly between 1.5 and 2.0 is a number $\otimes X_g = [1.5,2.0]$. Through some other means, we can know his exact weight as $X_g = 1.6$. Here, the used means is called as whitening method.

2.2. Grey GM (1,1) model

In recent years, the methodologies of grey prediction based on grey system theory have been successfully used in many fields. In terms of information availability degree, grey prediction walks out the shadow of large-sample statistics. The grey prediction model bases on the method of accumulated generating operation (AGO) rather than finding the statistics features to preprocess the original data so that the after processed data will become regular. Based on the processed data, we can use the differential equation to approximate such a regularity and hopefully to predict the next output from the system [27].

For the original series $x^{(0)}(t)$, $t = 0, 1, \ldots, n$, a new series $x^{(1)}(t)$, $t = 0, 1, \ldots, n$ can be generated by the AGO as

$$x^{(1)}(t) = \sum_{i=0}^{t} x^{(0)}(i) \tag{3}$$

From $x^{(1)}(t)$, we can form the grey prediction model GM (1,1) which is expressed by one variable, and first order differential equation as

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \tag{4}$$

where the coefficients a and b are called the grey development and grey input coefficients, respectively.

The grey derivative for the first order grey differential equation with AGO is conventionally represented as

$$\frac{dx^{(1)}(t)}{dt} = \lim_{\Delta t \to 0} \frac{x^{(1)}(t+\Delta t) - x^{(1)}(t)}{\Delta t} \tag{5}$$

Let $\Delta t \to 1$ and obtain

$$\frac{dx^{(1)}(t)}{dt} \cong x^{(1)}(t+1) - x^{(1)}(t) = x^{(0)}(t+1) \tag{6}$$

Then the discrete form of GM (1,1) differential equation model is expressed as

$$x^{(0)}(i) + az^{(1)}(i) = b \tag{7}$$

where $z^{(1)} = \{z^{(1)}(1), z^{(1)}(2), \ldots, z^{(1)}(n)\}$ is called background value of $\frac{dx^{(1)}}{dt}$ and calculated by

$$z^{(1)}(i) = \frac{1}{2}(x^{(1)}(i-1) + x^{(1)}(i)) \tag{8}$$

By least-square method, the coefficients a and b can be obtained as follow

$$\begin{bmatrix} a \\ b \end{bmatrix} = (\mathbf{A}^\top \mathbf{A})^{-1} \mathbf{A}^\top \mathbf{X_n} \tag{9}$$

$$\mathbf{A} = \begin{bmatrix} -z^{(1)}(1) & 1 \\ -z^{(1)}(2) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \tag{10}$$

$$\mathbf{X_n} = \begin{bmatrix} x^{(0)}(1) \\ x^{(0)}(2) \\ \vdots \\ x^{(0)}(n) \end{bmatrix} \tag{11}$$

Then, the modelling value of Eq. (4) is obtained as

$$\hat{x}^{(1)}(i) = \left(x^{(0)}(0) - \frac{b}{a}\right)e^{-ai} + \frac{b}{a} \tag{12}$$

The prediction series for original time series can be obtained as

$$\hat{x}^{(0)}(i) = \hat{x}^{(1)}(i) - \hat{x}^{(1)}(i-1) = \left(x^{(0)}(0) - \frac{b}{a}\right)(1-e^{a})e^{-ai} \tag{13}$$

where the data series $\{\hat{x}^{(0)}(0), \hat{x}^{(0)}(1), \cdots, \hat{x}^{(0)}(n)\}$ are called fitting series, while series $\{\hat{x}^{(0)}(n+1), \hat{x}^{(0)}(n+2), \ldots, \hat{x}^{(0)}(n+k)\}$ are called prediction series. Usually, the number of data set used in GM (1,1) is rather small because only two coefficients are requited to be identified in Eq. (9). In other words, GM (1,1) is often used as a short-term prediction scheme [28]. The GM (1,1) model realizes the prediction based only a set of the most recent data in a time series. Predictions of this kind are to establish a curve for the most recent data, and then make predictions based on the established curve.

3. RGM (1,1) model

The residual error between the real value $x^{(0)}(i)$ and the model prediction value $\hat{x}^{(0)}(i)$ of GM (1,1) is still exists. In order to minimize the residual error further, we present second order polynomial regression model based on statistical method to compensate