A prediction method of residential load transformer demand factor based on time series

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Abstract. The use of residential transformer in distribution network directly affects the assessment result of the feeder installed capacity. With the development of power system reform and the improvement of power supply economy, it is more and more important to evaluate the demand factor of these transformers scientifically. In this paper, a method based on time series is proposed to predict the demand factor of residential load transformer in distribution network. Firstly, the actual current data of distribution transformer is collected. After data pre-processing, the maximum value of monthly demand factor is calculated, and the historical data based on time series can be obtained. Then, the general development trend of demand factor is predicted through gray model. Finally, more accurate demand factor prediction value can be obtained by using neural network model training. The data of a distribution transformer in a capital city of China is selected to illustrate the practicability and effectiveness of the proposed algorithm. The proposed algorithm can fully consider the dynamic characteristics of the demand factor changing in time, and will greatly improve the accuracy of the feeders installed capacity assessment.

1. Introduction

In recent years, with the rapid development of economy, the power consumption has increased sharply. Because of the improvement of users’ power quality requirements, the capacity usage of residential power transformers in the distribution network has been widely concerned. In the actual operation of distribution network, the reported installed capacity of residential load transformer may not be all connected to the distribution network, and the capacity connected to the distribution network is changing in time. The parameter reflecting the load usage condition of distribution transformer is called load demand factor [1, 2]. Load demand factor is the ratio between the actual access capacity and the reported installed capacity of distribution transformer. On the one hand, studying the demand factor can guide the dispatching of power grid scientifically and reasonably, and ensure the safe operation of power grid. On the other hand, it can be used to evaluate the power supply capacity of existing power grid and improve the accuracy of the feeder installed capacity calculation, which is of great significance for distribution network planning and transformation.

At present, research on the load demand factor is mainly focused on the relationship between the load and the number of households in residential communities. The Code for Electrical Design of Residential Buildings gives the range of demand factors for different households in residential buildings. However, the demand factors given in the above specifications are too large. There are
some related research using numerical regression analysis method, mathematical statistics method and kernel density estimation Parzen window method to modify the values.

In the Literature [3], the regression analysis method was used to fit the nonlinear relationship between the demand factor and the number of households in the house, but the influence of different users' power consumption on the demand factor is not considered. Literatures [4] and [5] used the kernel density estimation method and the mathematical statistics method to obtain the demand factor, but the calculation results were relatively rough. According to the literature research, the current literature has not discussed the dynamic characteristics of the demand factor changing in time, nor does it involve the load demand factor prediction. Therefore, in order to assess power supply capacity scientifically and reasonably and to make a more accurate prediction of its future development trend, it is necessary to propose a load demand factor evaluation method based on the historical acquisition data time series of the distribution transformer.

The load demand factor is affected by many factors, such as regional geographical and climatic conditions, social and economic development level, types of users' electricity consumption and electricity consumption habits. The trend is quite different. It is difficult to get more accurate prediction and analysis results by using a single prediction method. In this paper, a method based on time series to predict the demand factor of residential load transformer in distribution network is proposed. First of all, according to the historical current data of distribution transformer, the maximum value of monthly demand factor is obtained by data preprocessing, and the historical data based on time series is obtained. Then, the general development trend of demand factor can be predicted using the gray prediction model. Finally, the more accurate demand factor prediction is obtained by using the neural network model. The rest of the paper is organized in the following order. The demand factor is defined in Section 2. And in the prediction methods are introduced in Section 3. In Section 4, we present a case study and then in Section 5, we conclude our work.

2. Definition of demand factor

When users apply for access capacity to the power company, they need to consider the demand for power consumption growth over a period of time. The actual access capacity does not usually reach its reported capacity. At the same time, the actual capacity is affected by various factors such as the nature of power consumption, user access time and economic development level. The actual access capacity is fluctuating and it is related to the access time. Therefore, it is necessary to introduce a demand factor $F$ to characterize the inequality relationship, which is defined as follows:

$$F_i = \frac{l_i}{L_i}$$

(1)

Where $l_i$ is the maximum month load of power user $i$, and $L_i$ is the reported installed capacity of power user $i$.

Data to be collected includes the reported installed capacity of each residential power distribution transformer, monthly three-phase maximum current $I_{A_{\text{max}}}$, $I_{B_{\text{max}}}$, $I_{C_{\text{max}}}$, phase voltage $U$ and current transformer transformation ratio $k_{CT}$. According to the load current monitoring data of the distribution network transformer in the power consumption acquisition system, Formula (1) is used to calculate the time series of the monthly maximum demand factor. The formula for calculating the maximum monthly load is:

$$l = U \times (I_{A_{\text{max}}} + I_{B_{\text{max}}} + I_{C_{\text{max}}}) \times k_{CT}$$

(2)

It should be noted that due to the large number of power users in the distribution network, most of the users, such as industrial users, can access to the reported installed capacity within a short time after accessing the distribution network. Calculating the demand factor $F$ for each user is time-consuming and unnecessary. In practical application, the access capacity data of users are collected and the monthly maximum value is counted. If the actual capacity of users accessing the distribution network can reach 80% or more of the installed capacity within one year, it is defined as the saturated power user load. It is considered that the access capacity is approximately equal to the reported installed
capacity. Otherwise, it is defined as the unsaturated power user load, and its demand factor $F$ will be calculated by Formula (1).

3. Prediction of demand factor

3.1. Forecast of change trend

The development time of distribution automation in China is short and the input time of distribution transformer data acquisition and monitoring equipment is not long. Therefore, the amount of data is less and the historical time series of load demand factor is short. According to the actual data collection, calculated by preprocessing, there are at most 3–4 years of historical data of demand factor $F$. Some automatic monitoring equipment of distribution transformer is only put into operation for less than 1 year. Besides, the distribution of time series of demand factor sample data is irregular, and there is no obvious trend. In view of the above actual situation, firstly, gray model (GM) is employed to obtain the general trend of the demand factor changing in time [6-9].

The gray system can be regarded as an uncertain system in which "some information is known and some information is unknown". It can be used to predict for small samples. In order to reduce the volatility of the data, the gray model uses the cumulative generation method to obtain an increasing sequence, and then the prediction data is restored by the subtraction method. To construct a gray prediction GM (1, 1) model, firstly, the original time series data is accumulated one by one to generate a new series. Then, the least squares parameter estimation method is used to calculate the parameters of the differential equations. After that, the solution of the above differential equation, i.e. the fitting value of the accumulated generating sequence, is obtained. Finally, the fitted values of original time series can be obtained by successively reducing the fitting values of accumulative sequence.

3.2. Optimization of BP network algorithm based on SCG algorithm

BP algorithm is a kind of learning algorithm with tutors [10-14]. The whole learning process is composed of the forward propagation of signals and the reverse propagation of errors. BP neural network consists of input layer, output layer and hidden layer. A large number of applications show that BP neural network has the advantages of low structure complexity, mature algorithm, strong practicability and accurate mapping of the nonlinear relationship between input and output. But the convergence speed of the conventional BP neural network is slow. For some complex problems, the training time may be very long. And it is easy to fall into local minimum convergence. Therefore, it is necessary to optimize the BP algorithm.

The Scaled Coherent Gradient (SCG) algorithm is a variable gradient algorithm, which does not need to search linearly in every iteration. So, it can avoid the time-consuming problem of search direction calculation. Its basic idea adopts the principle of model trust interval approximation. SCG algorithm is an improvement of the variable gradient algorithm, which changes the linear search method of the variable gradient algorithm when calculating the search step length, and uses special skills. It can not only calculate the step size accurately, but also take into account the positive definiteness of Hessian matrix. The convergence speed is fast and the numerical stability is good. In this paper, SCG algorithm is used to train the BP neural network. In Matlab neural network toolbox, trainscg function is used as the training function of SCG algorithm.

3.3. Combination forecasting

The gray model can predict under the condition of small sample size, but the accuracy is low. The artificial neural network has strong learning ability. By building a complex network, it can be trained to obtain the nonlinear mapping correlation between input and output. The prediction error is small, and it is widely used in the field of time series prediction.

The combination method of gray prediction and neural network prediction is used to get the forecast month demand factor. The prediction data obtained from the gray model in Section 3.1 can reflect the value of the demand factor to a certain extent. The correlation is strong between the actual
sequence and the sequence obtained by the gray model. Therefore, the neural network can be trained taking the above time series as the input vector, and the actual time series as the output vector. In order to reduce the amount of iterative calculation and improve the learning efficiency, the SCG (scaled coherent gradient) algorithm with good numerical stability is used to train the model.

To sum up, the combination method proposed in this paper is as follows:

**Step 1.** Calculate the maximum monthly load of distribution transformer according to the Formula (2), and obtain the monthly demand factor by the Formula (1).

**Step 2.** Use the gray model of Subsection 3.1 to get the prediction series with the lower precision.

**Step 3.** Using SCG algorithm and the trainscg function in Matlab toolbox, train the demand factor prediction model taking the predict value obtained by the gray model as the input vector, and the actual time series as the output vector.

**Step 4.** Predict the demand factor using the BP network model obtained from the previous training (Step 3), in which the input data is the prediction value of the gray model.

The algorithm flow of demand factor prediction proposed in this paper is shown as in Figure 1.

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**Figure 1.** The flow draft of the demand factor prediction method based on time series.

### 4. Case study

The example data is taken from a residential distribution transformer in a provincial capital city. The effectiveness of the proposed algorithm is illustrated by constructing a demand factor combination prediction model. In order to verify the accuracy of the proposed combined prediction algorithm, the gray model and neural network prediction method are used to predict the demand factor for contrast.

After the data acquisition and preprocessing from the distribution SCADA system, using Formulas (1) - (2), the monthly maximum demand factor time series of the example distribution transformer from the 12th month to the 48th month can be obtained. It should be noted that the load data cannot be obtained until the 12th month due to the time limit of distribution automation equipment operation.

#### 4.1. Input and output settings and prediction results of three models

**1. Gray prediction**

Firstly, according to the demand factor from the 12th month to the 47th month, the original data series can be constructed. Then, the data series for the gray model is accumulated. The gray prediction model is built by the least square parameter estimation. Finally, the demand factor fitting value from the 13th month to the 47th month is restored by the incremental generation. The approximate change curve and the demand factor prediction value of the 48th month can be obtained.
(2) Neural Network prediction
Taking the data of every four months as the input data and the demand factor of the next month as the output data, the neural network prediction model can be trained. Taking the data from the 44th to the 47th month as input, the demand factor of the 48th month will be obtained by neural network prediction model.

(3) Combination prediction
The fitting value of the demand factor from the 13th month to the 47th month is obtained by the gray prediction model. Taking the fitting value of every four months as the input data, and the measured value in the next month as the output data, the combination prediction model is obtained. Taking the gray fitting data from the 44th to the 47th month as the input, the demand factor of the 48th month can be obtained through the combined forecasting model.

4.2. Evaluation of the three prediction model results

![Figure 2. Demand factor forecast results.](image2)

![Figure 3. Comparison chart of demand factor prediction error.](image3)
Through the model solution, the prediction results from the 19th to the 48th month of the above three prediction methods are shown in Figure 2. It can be seen from Figure 2 that the accuracy of gray prediction is low, the prediction results of neural network prediction and combined prediction method are similar, and the prediction results of the proposed algorithm are better than the other two algorithms. In order to show the advantages of the proposed algorithm more intuitively, the relative error index $e_{RE}$ (relative error, RE) is used to evaluate the calculation accuracy of the prediction algorithm:

$$e_{RE} = \left| \frac{s_{pre} - s_{real}}{s_{real}} \right| \times 100\%$$ (3)

Where $s_{pre}$ and $s_{real}$ are the predicted value and measured value of the demand factor respectively.

The relative error of gray prediction, neural network prediction and combination prediction methods from the 19th to the 47th month is shown in Figure 3. It can be seen from Figure 3 that the maximum prediction errors of the three algorithms are 30.20%, 24.63% and 19.88% respectively. The prediction errors of the gray model are generally higher, and the prediction accuracy of the proposed algorithm is generally higher than that of the gray prediction and neural network prediction methods. It can be seen from the analysis and comparison of the above three algorithms that the gray prediction algorithm is simple, but the error is large; the neural network prediction method improves the prediction accuracy, but the calculation error of individual months is still large; the combination prediction algorithm greatly improves the prediction accuracy.

Therefore, the algorithm proposed in this paper is practical and effective, and the prediction accuracy is higher.

5. Conclusions
This paper analyzes the historical data of demand factor based on time series, excavates its internal law, and then forecasts its future development trend. The dynamic characteristics of demand factor changing with time are fully considered in the proposed method. And the combined algorithm of gray model and neural network prediction is used to obtain the demand factor prediction value of residential load transformer in distribution network. As an important parameter for calculating the installed capacity of feeders, the prediction results of the proposed algorithm can improve the accuracy of the feeder installed capacity calculation, evaluate of the installed capacity of feeders dynamically. Thus, it can evaluate the power supply capacity of the existing power grid scientifically, and provide data support for the relevant work of the power grid department. It is of great significance for the distribution network planning and transformation.

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