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Short-term nodal load forecasting method considering redundant information

Si Yang[1], Long Zhao[1], Xueshan Han[2], Yong Wang[2], Wenbo Li[3], Donglei Sun[1] and Junxiong Wang[2]

[1]Economic & Technology Research Institute of State Grid Shandong Electric Power Company, Jinan, China
[2]Key Laboratory of Power System Intelligent Dispatch and Control of Ministry of Education, Shandong University, Jinan, China
[3]State Grid Shandong Electric Power Research Institute, Jinan, China

wajxng@163.com

Abstract. The most existing short-term nodal load forecasting methods only focused on the application of separate historical data, ignoring the abundant redundant information in power system. In this paper a new nodal load forecasting method considered physical redundancy and measurement redundancy was proposed. Firstly, the effect of redundant information on short-term nodal load forecasting was analysed and the forecasting principle was given. Secondly, in order to form additional state variable measurement equations, two kinds of existing redundant information between state variable and measured values were analysed deeply. Then based on the forecasting principle and the analysis results, the forecasting model mainly imitated the form of state estimation was established and the specific forecasting process was given. Case studies demonstrated that compared with traditional support vector machine model, the proposed method could effectively decrease forecasting errors and improve forecasting results.

1. Introduction

Load forecasting is the key and basis of power system operation and decision. In recent years, to deal with the energy and environmental crises and to meet the growing social demand for electricity, the concept of Energy Internet has been proposed and rapidly recognized [1]. As the core carrier of Energy Internet, power transmission network also shows a complex, different, multiple, flexible, associated form[2-3]. And the inherent uncertainty and flexibility of passive power supply make it more and more difficult to grasp the load law of all kinds of nodes in the power grid [4]. Therefore, it is necessary to predict and analyze the load of any node involved in grid regulation.

Nodal load forecasting techniques have evolved from initial time series extrapolation methods to non-linear regression methods and the artificial intelligence algorithm. And now nodal load forecasting technology is gradually expanding toward big data [5-6]. However, most of these researches focus on the mining of the variation of single nodal load itself from the perspective of time series. In fact, subject to the network physical laws, each load node is not isolated and there is a close physical relationship between layers and layers. At present, there are some researches on applying this kind of physical relationship to nodal load forecasting. For example, references [7-8] proposed and demonstrated that the multi-nodal load forecasting model is better than node prediction alone. In [9], according to the relationship between nodes, using the strong physical regularity that the total load is equal to the sum of all individual loads, the multi-nodal load forecasting is realized. Reference [10] refers to the idea of power system state estimation to solve the problem of uncoordinated multistage load forecasting results, which essentially utilizes the physically associated redundant information between nodes. Generally speaking, the current researches cannot sufficiently utilize the physical association of load nodes and the redundant information provided by modern measurement technology.

Aiming at the shortcomings of existing research, a short-term nodal load forecasting method considering redundant information is proposed. First of all, the principle of forecasting method is analyzed, and the physical relation of state variable is further revealed by the redundant characteristics of measured data. Then, the specific prediction models and methods are given, and the multi-group measurement equations obtained are used to realize the nodal load forecasting with the estimated correction characteristics. Finally, an actual example is used to verify the effectiveness of this forecasting method.

2. Analysis of the forecasting principle

2.1. The principle of the forecasting method

Traditional load forecasting methods usually analyze historical load data, which is actually redundant information of time series. Since nodal load forecasting uses only time-series redundant information, the prediction results will inevitably have errors. In fact, the historical information of each time section can be regarded as the measurement value [10], but these independent and redundant measurement equations are not closely related to the object to be predicted. The state estimation of the power grid is based on the assumption that all the measurements are conducted at the same time, and the state variables are estimated using the measured redundancy. The shorter the time, the higher the accuracy. Therefore, under the premise of inherited time series redundancy, nodal load forecasting can draw lessons from state estimation to deal with the correlation and redundancy information of the same time section so as to improve the prediction accuracy of nodal load.

With the idea of state estimation, nodal load is the state variable to be estimated. It is the key point of this study that how to characterize the time series and the physical correlation measurement information of each time section as the estimation function of this state variable.

Power transmission network consists of many components, is a complex network with multi-layer structure. A load node (except the terminal) exists in both the upper and lower power grids, which can be equivalent to the load of the upper grid and the power of the lower grid. Therefore, the nodal load naturally has a physical correlation and its state can be described by a number of independent measurement equations.

With the continuous deepening of power grid smart and digital transformation, many transmission and distribution components (such as transmission and distribution lines and transformers) have been able to carry out multi-terminal and high-precision measurement of transmission power, and the measurement processes are independent from each other. Therefore, it is necessary to introduce the measured values of transmission and distribution components into the nodal load forecasting system to improve the traditional nodal load forecasting methods. According to the relationship between the nodal load state and measured values, a set of measurement equations that express the state variable directly or indirectly can be extracted from independent measurements. This is the core idea of this study.

2.2. Two types of redundant information

Combined with the actual situation of power system, two kinds of redundant information between state variables and measured values are analyzed.

2.2.1. Physical correlation redundant information. The past researches on nodal load correlation prediction is based on the law of conservation of energy, that the upper load and the sum of lower nodes load are equal.

However, this process is a little rough. And because of the strong physical laws, this type of method must collect the data of all associated nodes to make a unified prediction, which cannot meet the requirements of grid flexibility in the new situation. In reality, although the network structure of the power grid is very complicated, it will spontaneously follow the constraint of node injection power balance during the operation of power system. It means that there is an additive characteristic between the nodal load state variable and the power measurement of the transmission and distribution components.

Therefore, if the transmission and distribution line power measurements are also introduced to the forecasting process, considering the physical correlation of transmission and distribution elements measurements could decouple the strong physical laws between the total load and the part. Then the nodal load forecasting can be more flexible and can sufficiently utilize the original measurement information such as line power measurements and transformer power measurement, which will be helpful to improve the load forecasting results.

2.2.2. Measurement redundancy information. In modern power system, there are multi-terminal and independent measuring devices for the same transmission and distribution components, which produces sufficient redundancy information of measurements. The distribution diagram of transmission and distribution components measuring devices is shown as figure 1.

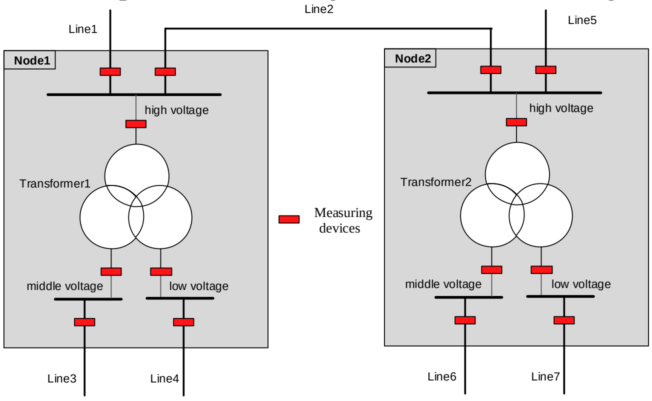

Figure 1. Distribution diagram of transmission and distribution components measuring devices

When analyzing the redundancy characteristics, the nodal load is a complete vertical structure when considering only the state variables association. There is no measurements at this time to describe the direct correlation between nodes in the same layer, which is not in accordance with the actual situation of the power grid. As the Line2 in figure 1, after the introduction of the line power measurements, the line power could be measured and predicted simultaneously on both nodes (ignoring the loss on the line). This feature can make the state variables of nodes in the same layer correlate, to make up for the deficiencies of the past researches.

In summary, this section analyzes two kinds of redundant information about nodal load state variables and power measurement values of transmission and distribution components, explains the physical rules of grid load nodes at a deeper level, and provides the following nodal load forecasting model more abundant redundant information.

3. Forecasting model and method

3.1. Nodal load forecasting model

The forecasting model mainly imitates the form of state estimation. Based on the analysis in the previous section, we choose the nodal load as the state quantity, then the previous predicted values of the transmission and distribution elements are equivalent to the measured values in the state estimation model.

Nodal load forecasting model considering redundant information:

$$\begin{aligned} \min\ f &= w_{\mathrm{u}}(z_{\mathrm{u}}-x)^2 + w_{\mathrm{d}}(z_{\mathrm{d}}-x)^2 \\ &\quad + w_{\mathrm{u}}'(z_{\mathrm{u}}'-x)^2 + w_{\mathrm{d}}'(z_{\mathrm{d}}'-x)^2 \\ &\quad + w_{\mathrm{h}}(z_{\mathrm{h}}-x)^2 + w_{\mathrm{ml}}(z_{\mathrm{m}}+z_{\mathrm{l}}-x)^2 \\ \text{s.t.}\quad & z_{\mathrm{u}} = \sum_{ku=1}^{M} z_{ku},\ z_{\mathrm{d}} = \sum_{kd=1}^{N} z_{kd}, \\ & z_{\mathrm{u}}' = \sum_{ku=1}^{M} z_{ku}',\ z_{\mathrm{d}}' = \sum_{kd=1}^{N} z_{kd}', \end{aligned} \tag{1}$$

where x is an estimate of the nodal load state variable, M is the number of lines connected to the node in the upper grid, N is the number of lines connected to the node in the lower grid, z_{ku} and z_{kd} are the upper and lower grid line measurements of local terminals, z_{ku}' and z_{kd}' are the nodal load calculated from the upper and lower grid line measurements of opposite terminals, z_{h}, z_{m} and z_{l} are the transformer high, middle and low voltage port measurements, z_{u} and z_{d} are the nodal load calculated from the upper and lower grid line measurements of local terminals, z_{u}' and z_{d}' are the nodal load calculated from the upper and lower grid line measurements of opposite terminals, w is the reliability of each measurement, which means the accuracy of the previous forecasting.

In the model shown in equation (1), there is only one state variable for nodal load of the node to be predicted, which has been described by a set of six measurement equations. The whole model can encompass the relationship between state variables and independent measurement values, and make full use of the two types of redundant information generated to correct the state variables

3.2. Nodal load forecasting method

Based on the established estimation model considering redundant information, the steps of nodal load forecasting are as follows:

(1) Retrieve historical power data and forecast reliability information of multi-terminal measurement of transmission and distribution components;

(2) According to the variation characteristics of the historical power data of transmission and distribution components, select the appropriate previous forecasting model. In this study, the previous forecasting model is support vector machine (SVM) model [11];

(3) According to SVM model, respectively forecast the transmission power of transmission and distribution components;

(4) According to the constraints of equation (1), process the pre-forecasting values of transmission and distribution components and generate multiple sets of measurement equations;

(5) Use the forecasting model to correct and estimate the nodal load state and get the final forecast value of nodal load;

(6) Collect the actual value information of the nodal load, compare the actual load with the predicted results, assess and record the reliability of each measurement;

(7) return to step (1) to carry out the next stage of nodal load forecasting.

4. Case studies

The actual operation data of some grids in Shandong Province on July 2017 are used as an example to verify the nodal load forecasting method which takes into account the redundant information. The data set covers the power measurement data of the high, middle and low voltage ports of the three-winding transformer in the substation, and the power measurement data of the transmission lines connected to the high-voltage busbar of the local and opposite nodes. The time resolution of the data set is 1h. The regional node topology is shown in figure 2.

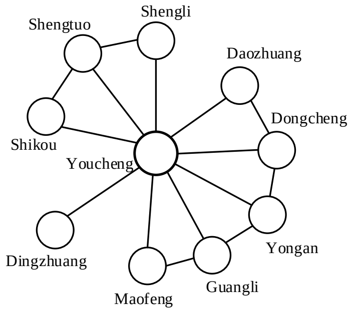

Figure 2. Regional node topology

The power measurements of the transformer high voltage port are selected as the nodal load criterion. Two models are used to predict the nodal load on July 27. On the one hand, only the nodal load criterion is selected as the historical data, and the SVM model is used to directly predict the nodal load. On the other hand, the SVM model is used to predict the power of lines and all transformer ports respectively. Then, the load forecasting method based on physical connection and redundant information proposed in this paper is used to correct and estimate the forecasting results. Taking Shikou Station as an example, the forecasting results of these two forecasting models are shown in figure 3. As can be seen from figure 3, the forecasting results of the proposed model are closer to the actual nodal load.

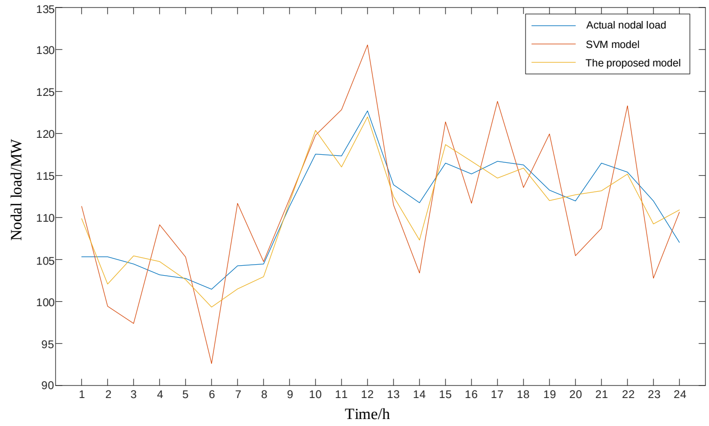

Figure 3. Comparison of nodal load forecasting results

The mean absolute percent error (MAPE) and root mean square error (RMSE) are chosen as the evaluation criteria to compare the predictive effects of the two models. The comparison of forecasting results is shown in table 1.

Table 1. Comparison of forecasting results

Node name	MAPE(%)		RMSE(MW)	
	SVM model	The proposed model	SVM model	The proposed model
Dongcheng	11.337	8.984	9.772	5.532
Yongan	9.193	6.243	9.428	6.223
Guangli	8.359	5.731	7.228	4.262
Maofeng	10.288	7.561	8.144	6.591
Dingzhuang	10.392	9.791	8.400	7.330
Shengli	6.152	5.598	10.136	5.417
Shikou	8.068	6.318	10.519	7.762

As can be seen from table 1, compared with the traditional prediction methods, the proposed method has a decline in the prediction error, and the nodal load forecasting accuracy has improved significantly.

5. Conclusions

In view of the fact that the existing nodal load forecasting methods cannot discover the physical association of the nodes deeply and utilize the redundant information provided by the modern measuring technology sufficiently, a nodal load forecasting method with the estimation and correction characteristic and considering the redundant information is proposed. The advantages of this method are the sufficient utilization of the rich original information provided by modern measuring technology, no requirement for the previous prediction model, the distributed prediction process, the flexible control of the nodal load forecasting scale and so on. The actual grid operation data are selected to validate the proposed method. The results show that the load forecasting method based on redundant information has a significant decrease compared with the SVM forecasting error. It can be seen that this method considers the actual situation of power grid in the context of Energy Internet, makes full use of the redundant information provided by modern measurement system, and based on the idea of traditional prediction methods, explores the promotion effect of redundant information on improving nodal load forecasting effect. It is helpful to improve the accuracy of nodal load forecasting results.

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