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A Coordinate Method between the System and Bus Load Forecasting in Electricity Market Environment

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Abstract. In view of the problems such as excessive tensile load factor of nodal bus and overload of load flow section that often occur during the trial operation of Guangdong Electric Power Spot Market, the coordination mechanism between the system and bus load forecasting results is studied in this paper. Firstly, the time-sharing credibility coordination model of the system-bus is established based on the least square method, so as to achieve the goal of load balance between upper and lower grades and the minimum overall error. Secondly, the different classification of the time-sharing credibility model is studied to adapt to different kinds of situation. Finally, a province is taken as an example to verify the effectiveness of the proposed method, and the results show that it has certain engineering application value.

1. Introduction

Load forecasting is the basis of the safe and economic operation of power system. With the new round of power reform and the continuous improvement and development of China's power market, the role of load forecasting is becoming more and more important[1-4]. At present, the Guangdong Electric Power Spot Market has entered the simulation operation stage. However, the experience shows that there are still many problems in the trial operation stage, such as the excessive tensile load factor of nodal bus and overload of load flow section. In view of these problems, this paper intends to discuss the improvement plan from the perspective of load forecasting.

The existing load forecasting researches mainly focus on the forecasting methods, which can be roughly divided into the traditional methods and the new intelligent methods. The traditional methods mainly include regression analysis, time series method, similar day method, etc[5-7]; the new intelligent methods mainly include artificial neural network method, support vector machine method, random forest method, etc[8-10]. However, the above methods are all proposed in the traditional power grid environment, so their accuracies in the power market environment remain to be verified. For this, some relevant researches are carried out by some experts and scholars. Literature [11] considers the impact of real-time electricity price on load, and proposes a load forecasting model combining quantile regression of support vector machine and kernel density estimation; Literature [12] takes into account both the electricity price and the historical load factors, and establishes a load prediction model by combining grey system and neural network; Literature [13] analyzes the correlation between electricity price, historical load and current load, and proposes a load forecasting model based on Attention-LSTM. Although the above researches have improved the load forecasting accuracy in the



electricity market environment effectively, but it does not consider the rationality between the multi-level load forecasting results.

The system load forecasting and bus load forecasting will be made at different times (cycles) according to different attributes and different structures, and obtain their own results respectively. Their prediction results should satisfy the ‘direct addition’ characteristic essentially, that is, after deducting the plant electric consumption and line loss, the system load should be equal to the sum of each bus load. However, there are obvious differences between their prediction results frequently, due to the difference in the calculation model, calculation method and characteristics. After deducting the plant electric consumption and line loss, there will be a large deviation in the power balance of the system if the total system load differs greatly from the sum of each bus load[14]. Therefore, it can be said that this is also one of the causes, which resulting in the excessive tensile load factor of nodal bus and overload of load flow section during the trial operation of the power market.

In view of the above problems, this paper further studies the coordination mechanism between the system load and the bus load based on their prediction results, so as to achieve the goal of load balance between the system and the bus and the minimum overall error. In this regard, the time-sharing reliability coordination model of the system-bus is established based on the least square method firstly, which can be applicable to the power market environment. Then, the different kinds of the time-sharing credibility model is studied. Finally, the validity of the proposed method is verified by taking the actual data of a province as an example.

2. The coordination model

2.1. The representation of the coordination values

During the construction of the coordination model, the coordination mechanism is mainly discussed based on the predicted results of all buses and system, and the historical value of load is hardly involved. Therefore, in order to facilitate the subsequent description, the predicted result is represented by $\hat{P}$, and the coordination value is represented by P in this paper. Its scalar representation is as follows.

The coordination value of the coordination day is set as $P_{b,t}$, where b represents the number of the system or bus, t represents the certain time of the coordination day. In order to keep the form tidy, $b=0$ is used to represent the total load coordination value of the system specially, therefore $b=0,1,\dots,B$, where B is the total number of bus bars. At the same time, $t=1,\dots,T$, where T is the total number of samples collected of the load curve every day.

2.2. The basic condition of coordination

For the coordination value, it should meet the load balance ideally, i.e

$$\sum_{b=1}^B P_{b,t} = P_{0,t}, t=1, 2, \dots, T \quad (1)$$

Considering that there is a certain amount of line loss between the sum of all bus bars and the total system load, it is necessary to correct the equation (1). Normally, the ratio of the sum of plant electric consumption and line loss can be obtained through statistics and estimation. Therefore, the coefficient λ_t ($0 < \lambda_t \leq 1$) is introduced to correct the constraint equation, i.e

$$\sum_{b=1}^B P_{b,t} = \lambda_t P_{0,t}, t=1, 2, \dots, T \quad (2)$$

where, λ_t represents the ratio of the total bus load to the system load after deducting plant electric consumption and line loss, which can be obtained through statistics or fitting of historical data. For example, for a certain time in a day in history, the following methods can be used for statistics:

$$\lambda_t = \frac{\sum_{b=1}^B P_{b,t}}{P_{0,t}} \quad (3)$$

2.3. The time-sharing credibility model

During the construction of the coordination model between the load of the system and bus, there is a basic principle. In which, the bus with high historical forecast accuracy should be adjusted as little as possible, while those with low historical prediction accuracy should be adjusted more.

Set the load forecast value of bus b at time t is $\hat{P}_{b,t}$, then the unbalanced load between all the busses and the system is $\Delta = \sum_{b=1}^B \hat{P}_{b,t} - \lambda_t \hat{P}_{0,t}$. If the value of the unbalanced load is 0, it is clear that the equilibrium condition is satisfied, and there is no need to coordinate between the system and buses. Coordination calculation is required only when the value of the unbalanced load is not 0. At this case, set the adjustment amount of bus b at time t is the difference between the coordination value and the forecast value, therefore $\Delta_{b,t} = P_{b,t} - \hat{P}_{b,t}$.

The adjustment load between the bus and the system at time t is described by using the weighted least squares method, and the model is established as

$$\begin{aligned} \min f_t &= \sum_{b=0}^B \omega_{b,t} \left(\frac{\hat{P}_{b,t} - P_{b,t}}{\hat{P}_{b,t}} \right)^2 \\ \text{s.t. } \sum_{b=1}^B P_{b,t} &= \lambda_t P_{0,t} \end{aligned} \quad (4)$$

where, $P_{b,t}$ is the coordination value of bus b at time t, which is also called as the decision variable; $\omega_{b,t}$ is the credibility of the forecast value of bus b at time t, which is an important parameter in the coordination model and determines the adjustment amount at different times.

3. The research of credibility model

3.1. The influencing factors of credibility

The prediction error is directly related to the credibility. The larger the prediction error, the less "credible" the prediction will be. So it can be seen that the prediction error should be negatively correlated with the credibility. Generally speaking, the measurement and prediction errors always satisfy the normality, so the reciprocal of the historical error is usually chosen as the weight, whether in state estimation or in a prediction model.

In addition to the prediction error, the load level is also an influencing factor of credibility, whose influence should be treated dialectically. From the perspective of prediction mechanism, on the one hand, the higher the load level, the greater the inertia of the load curve, and the higher the credibility will be. On the other hand, the load level itself will also affect the level of prediction error. Therefore, if the prediction error has been selected, the load level may not be introduced into the expression of credibility. In summary, the impact of various factors on the coordination results is complex, and one factor may have both beneficial and adverse effects.

3.2. The classification of credibility

The credibility model can be divided into 'the model irrelevant to the load level' (category A) and 'the model relevant to the load level' (category B). In category A, it can be further divided into average weighted credibility model and credibility model linked to historical prediction accuracy. In category B, it can be divided into three models: the credibility of system load is far more than that of both buses,

the credibility is positively correlated with the load level, and the credibility is proportional to the load level multiplied by the inverse of the error square.

3.2.1. The credibility model irrelevant to the load level

(1) The average weighted credibility model. Without considering the influence of any factors, the basic way to choose the credibility model is to think that all credibility is equal and equal to 1, i.e

$$\omega_{b,t} = 1, \forall b, t \quad (5)$$

(2) The credibility model linked to historical prediction accuracy. If only the load prediction accuracy is considered, regardless of the load level, the credibility can be designed as the reciprocal of the square of the prediction error, i.e

$$\omega_{b,t} = \sigma_{b,t}^{-2}, \quad \forall b, t \quad (6)$$

3.2.2. The credibility model relevant to the load level

(1) The credibility of system load is far more than that of all the buses. When the load level is taken into establish the credibility model, the simplest way is to consider the magnitude order relationship of the load level between the system and buses. Generally speaking, there is not much difference at the magnitude of each bus load, so their credibility is the same; but the magnitude of the system load is much larger, thus its credibility is much greater. In view of the importance of the system load, the difference in credibility can be further amplified. In this way, the credibility of system load is regarded as infinite, while the credibility of each bus is set as 1, i.e

$$\omega_{b,t} = 1, \forall t, 1 \leq b \leq B \quad (7)$$

$$\omega_{0,t} \rightarrow \infty, \forall t$$

(2) The credibility is positively correlated with the load level. If the difference in load level is considered more carefully, the simplest way is to consider the credibility is related to the load level linearly. So the credibility can be designed as

$$\omega_{b,t} = k_1 \hat{P}_{b,t}, \forall b, t \quad (8)$$

where, k_1 is positive.

(3) The credibility considers both the prediction accuracy and load level at the same time. At this credibility model, the credibility can be designed as

$$\omega_{b,t} = k_2 \hat{P}_{b,t}^2 \sigma_{b,t}^{-2}, \forall b, t \quad (9)$$

where, k_2 is positive.

4. Case studies

The actual and predicted load data of the system and each bus in a province during 2018.10.11-2018.11.11 are collected in this paper. Then, the proposed method is used to simulate and coordinate the 7-day prediction results from 2018.11.05 to 2018.11.11. In the process of simulation, the historical data of 21 days before the coordination date is used to calculate the percentage coefficient of total bus load value λ_t and historical prediction error $\sigma_{b,t}$.

4.1. The coordination results of the percentage coefficient of total bus load λ_t

The values of the percentage coefficient of total bus load λ_t before and after the coordination are calculated separately, and a statistical comparison is made in the paper, as shown in Table 1. Where, the average value is the average value of λ_t at 96 moments of the coordination day; the maximum value is the maximum value of λ_t at 96 moments of the coordination day; the minimum value is the minimum value of λ_t at 96 moments of the coordination day; the range is the difference between the maximum value and the minimum value.

As shown in Table 1, the percentage coefficient of total bus load λ_t is more stable after the coordination. The average value is basically stable at around 0.95, and the fluctuation range is relatively stable, which is basically within 0.025. In contrast, the percentage coefficient of total bus load is divergent before the coordination. In some extreme cases, it was even greater than 1, which is not reasonable at a provincial power grid. However, this unreasonable phenomenon could be basically eliminated after the coordination.

Table 1 The statistical comparison of λ_t before and after the coordination

	date	average value	maximum value	minimum value	range
before the coordination	20181105	1.0008	1.0490	0.9701	0.0789
	20181106	0.9663	1.0101	0.9294	0.0807
	20181107	0.9582	0.9955	0.9242	0.0713
	20181108	0.9521	0.9971	0.9110	0.0861
	20181109	0.9665	0.9834	0.9456	0.0378
	20181110	0.9894	1.0194	0.9607	0.0587
	20181111	0.9846	1.0303	0.9484	0.0819
after the coordination	20181105	0.9539	0.9623	0.9415	0.0208
	20181106	0.9534	0.9618	0.9406	0.0212
	20181107	0.9529	0.9614	0.9405	0.0209
	20181108	0.9520	0.9608	0.9394	0.0214
	20181109	0.9511	0.9603	0.9381	0.0222
	20181110	0.9499	0.9590	0.9367	0.0223
	20181111	0.9488	0.9580	0.9349	0.0231

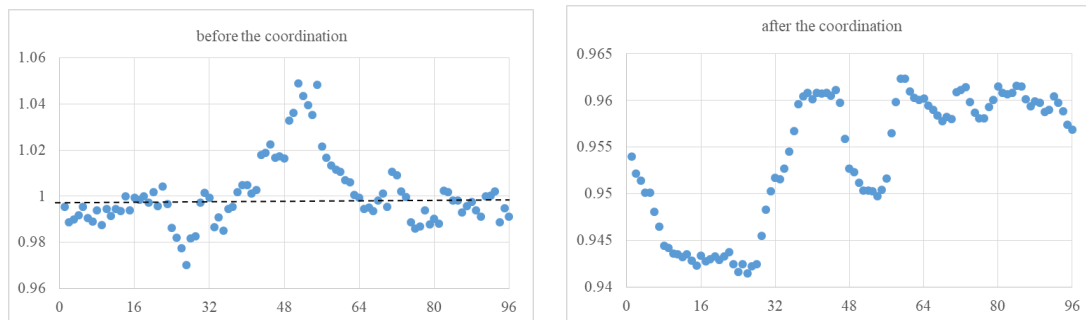


Figure 1. November 5, 2018

In order to make the comparison of λ_t before and after the coordination more intuitively, the scatter diagram of λ_t on November 5, 2018 is shown as Figure 1.

4.2. The influence of the proposed method on prediction accuracy

In order to analyse the influence of the proposed method on prediction accuracy, a credibility model related to prediction accuracy in the above is selected for testing. At the same time, it is also set that: the system does not participate in the coordination process, whose prediction accuracy is extremely high by default.

The other instructions during the test:

- (1) For the convenience of reading, the chosen credibility model is shown again here:

$$\text{Model : } \omega_{b,t} = k_2 \hat{P}_{b,t}^2 \sigma_{b,t}^{-2}, \forall b, t$$

- (2) The relative error is chosen as the predictive accuracy index, i.e

$$\varepsilon = \frac{1}{T} \sum_{t=1}^T \frac{|\text{the predicted load value} - \text{the actual load value}|}{\text{the actual load value}} \quad (10)$$

- (3) If the system does not participate in the coordination process, its credibility can be set as

$$\omega_{b,t} = \inf, \quad \forall t \quad (11)$$

The test is carried out, and the prediction accuracy before and after the coordination is statistically compared, as shown in Table 2.

Table 2. The comparison of the prediction accuracy after the coordination

date	difference	number 1	number 2	number 3	number 4
20181105	-0.0133	332	1	719	25
20181106	-0.0062	276	0	772	14
20181107	-0.0036	497	0	554	10
20181108	-0.0073	357	0	681	15
20181109	-0.0013	505	0	547	4
20181110	-0.0045	485	2	569	14
20181111	-0.0042	566	0	494	11

where, the difference=sum (relative error before the coordination - relative error after the coordination) / the total number of buses; number 1 is the number of the buses whose relative error has reduced after the coordination; number 2 is the number of the buses whose relative error has reduced more than 0.1 after the coordination; number 3 is the number of the buses whose relative error has increased after the coordination; number 4 is the number of the buses whose relative error has increased more than 0.1 after the coordination.

It can be seen from Table 2, the average prediction accuracy of the total buses has decreased a little after the coordination. However, the degree of the reduction is not much, basically within 1%.

5. Conclusions

In view of the problems such as excessive tensile load factor of nodal bus and overload of load flow section that often occur during the trial operation of Guangdong Electric Power Spot Market, a time-sharing credibility coordination model between the system and buses is proposed in this paper. The case study shows that although the proposed method will sacrifice a small amount of prediction accuracy, but it can better meet the ‘direct addition’ characteristics of the system and bus load after the coordination. At the same time, the percentage coefficient of total bus load becomes more stable and reasonable after the coordination. In addition, the proposed method can eliminate some unreasonable phenomena- the percentage coefficient of total bus load is greater than 1.

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