Study on Association Rules Based on Multiple Types of Flexible Loads

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Abstract. At present, the comprehensive consideration of multiple types of flexible loads and the complementary characteristics in time and space are less considered, which results in the user's response potential cannot be further explored. This paper takes flexible load as the research object, and proposes a method for the research of association rules based on multiple types of flexible loads. An association rule mining and evaluation model is established to form an intelligent offline database and a relative connection degree database. As a result, the correlation of various types of flexible loads is discovered through the cooperation of the two, so as to provide guidance for dispatching.

1. Introduction
With the large-scale development of new energy today, problems such as difficulty in peak shaving and insufficient consumption have gradually emerged, restricting the development of wind power. People have been studying various types of loads in detail. Literature [1] did not consider the consumption of wind power in the grid on the load side. Literature [2] only considers the consumption of wind power by the system when the wind power fluctuates the most, which makes the result conservative. Literature [3] only considers the optimal scheduling of interruptible loads. Literature [4] does not involve the role of flexible load excitation. In summary, this paper proposes an association rule based on multiple types of flexible loads, which further provides a more reasonable and reliable decision-making basis for the smooth operation of the power grid, and better promotes the automation of smart grids.

2. The contribution of the flexible load to the demand side response
There is a coupling effect between a variety of flexible loads. This effect may be positive coupling or reverse repulsion, so that the flexibility condition is not the sum of the total contribution of the double load and the contribution of the two single loads. equal[5]. Here is the traditional connection degree model:

$$\lambda_{xy} = \Delta \varepsilon_{xy} - \left(\Delta \varepsilon_y + \Delta \varepsilon_x\right)$$  

(1)

The traditional connection degree model does not consider the order of magnitude difference in the contribution degree of the flexible load participating in the absorption under different flexible conditions, so it may cause difficulty in comparing the degree of connection between different factors.
Therefore, it is necessary to improve the traditional connection degree model and define the relative connection degree model $\lambda_{xy}$:

$$\lambda_{xy} = \gamma \left[ \Delta e_{xy} - (\Delta e_x + \Delta e_y) \right]$$  \hspace{1cm} (2)

In the formula, $\gamma = \frac{1}{\Delta e_x + \Delta e_y}$ is the relative coefficient. Based on the relative connection degree model to express the relative effects of different factors can effectively reduce the difficulty of comparison caused by the difference of orders of magnitude. The interaction between multiple flexible loads can be judged based on $\lambda_{xy}$.

| $\lambda_{xy}$ | Type of interaction |
|----------------|---------------------|
| $\lambda_{xy} > 0$ | Connection          |
| $\lambda_{xy} < 0$ | Repulsion           |
| $\lambda_{xy} = 0$ | Infinite interaction|

For the flexible condition of dual flexible loads X and Y, the contribution of RMSE renewable energy consumption depends on 4 components:

| Component       | Definition                                                                 |
|-----------------|-----------------------------------------------------------------------------|
| $\Delta e_{x+y}$ | The contribution of any flexible load in X and Y to the demand side response |
| $\Delta e_{xy}$  | The X and Y two flexible loads cooperate to participate in the response to the demand side response volume |
| $\Delta e_{x-y} = \Delta e_x - \Delta e_{x+y}$ | Only a single flexible load X participates in the response to the contribution of the demand side response volume |
| $\Delta e_{y-x} = \Delta e_y - \Delta e_{x+y}$ | Only a single flexible load Y participates in the response to the contribution of the demand side response volume |

In order to reflect the impact of nonlinear factors in the power grid, the contribution model is optimized based on the RMSE index to obtain an improved demand-side response supply-end contribution model based on the RMSE index:

$$\Delta e_x = \sqrt{\frac{1}{n} \sum_{k=1}^{n} (Q_k - Q_k')^2}$$  \hspace{1cm} (3)

In the formula, $n$ is the number of points, which is determined by the step length of all-weather daily load recording; $Q_k$ is the response index of the simulated k-point running in the sequence before response; $Q_k'$ is the response index of the simulated k-point running in the sequence after the response. The larger the value, the better the contribution of the flexible load to the demand side response.

According to the definition, it can also be expressed as:

$$\lambda_{xy} = \gamma \left[ \Delta e_{xy} - (\Delta e_x + \Delta e_y) \right] = \gamma (\Delta e_{xy} - \Delta e_{x+y})$$  \hspace{1cm} (4)

$$\Delta e_{xy} = \Delta e_{x+y} + \Delta e_{x-y} + \Delta e_{y+x} + \Delta e_{y-y} = \sqrt{\frac{1}{n} \sum_{k=1}^{n} (Q_k - Q_k')^2}$$  \hspace{1cm} (5)
3. Results & Discussion

In this chapter, the actual measurement data of the power grid in a certain area of Liaoning will be used as the input to analyze the calculation examples. First, carry out data selection and data enhancement. Explain the sampling data to clarify the sampling frequency and increase the data intensity to ensure the accuracy of the results. Secondly, set up a simulation environment to adjust the algorithm parameters to achieve the best results. Finally, a calculation example is analyzed and related indicators are introduced to evaluate the results.

The relative degree of connection between flexible loads is not a fixed value, and is affected by the response target. Since the value of the relative degree of connection is small, it is processed as a percentage, and is accurate to two decimal places. This article establishes a relative connection degree database according to different scenarios.

| Flexible load | H     | R     | S     |
|---------------|-------|-------|-------|
| H             | -     | -4.39%| -0.06%|
| R             | -4.39%| -     | 0.15% |
| S             | -0.06%| 0.15% | -     |

Table 3. Scenario 1: Night

| Flexible load | H     | R     | S     |
|---------------|-------|-------|-------|
| H             | -     | 7.03% | -0.05%|
| R             | 7.03% | -     | 0.32% |
| S             | -0.05%| 0.32% | -     |

Table 4. Scenario 1: All day

| Flexible load | H     | R     | S     |
|---------------|-------|-------|-------|
| H             | 11.92%| -     | 0.46% |
| R             | 11.92%| -     | -0.05%|
| S             | 0.46% | -0.05%| -     |

Table 5. Scenario 1: Day

It can be seen from the table that the heating load has a large response at night, the rotating load fluctuates throughout the day, and the storage load has a small schedulable capacity and almost no connection with the heating and rotating loads.

Through the above constraints and the demand-side response objective function, the non-response value in different situations is solved. The pre-response values under three different scenarios are shown in the figure below. It is divided into three situations: large response volume during the day, large response volume at night, and large response volume throughout the day.
4. Conclusions
It can be seen from the above simulation results that the response contribution of nonlinear factors and the performance of the relative connection quantification evaluation model are better than the existing methods. The combination of the two has a great guiding effect on the flexible load dispatching of the power grid, which can improve the measured response of the flexible load, which is very beneficial for optimizing the dispatching strategy of the power grid.

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