An Adaptive Multi-Scene Single-User Flexible Negative Control Effect Evaluation Algorithm

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Abstract. Designing an evaluation algorithm that can adapt to the demand response of multiple scenarios can effectively reduce the cost of secondary development of the system and improve the willingness of users to participate in the regulation. In this paper, a self-oriented single user flexible negative control evaluation algorithm is proposed. In this algorithm, the determination method of target load curve is proposed first. On this basis, the generalized distance between curves is defined according to the characteristics of common evaluation indexes. Several parameters are reserved in the generalized distance. By adjusting the parameters, the evaluation scheme can be adapted to different scenarios. Then, this paper puts forward a method to set the initial value of parameters. By using this method and neural network, and combining with the existing evaluation samples, the parameters in the generalized distance can be determined automatically. Furthermore, an annual updating method of each parameter in the generalized distance is proposed by using the algorithm of neural network. Finally, the effectiveness of the algorithm is verified by the historical response data of Changzhou Lvjian district.

1. Introduction
In different scenarios, such as ensuring the stability of the power grid, absorbing new energy and improving energy efficiency, more and more attention has been paid to the flexible load control by intelligent means based on demand response technology [1]. Flexible load regulation mainly includes load prediction, event initiation, index decomposition, and instruction execution and regulation evaluation. Due to the potential risk that the flexible negative control may affect the normal power consumption, many users hold a certain psychology of rejection to this technology. This creates a certain obstacle for the promotion of flexible negative control. As the last link of flexible negative control, the regulation and evaluation is closely related to the subsidy to users, and directly affects the willingness and specific participation mode of users.

At the same time, in different regions and under different scenes, there are different evaluation criteria for the control effect of flexible load. This makes it necessary to design and develop distinct evaluation algorithms for the implementation of demand-response projects. This increases the cost of system development and the difficulty of managing different projects.

Therefore, it is imperative to study a set of self-driven evaluation algorithms that can not only improve users' willingness to participate, but also be applicable to multiple scenarios.
Existing evaluation algorithms include evaluation of single index, evaluation of comprehensive index, evaluation based on non-electric power index.

The evaluation of a single index is based on a key index in the flexible negative control. Literature [2] calculated the prediction curve and obtained the evaluation result through the difference between the prediction curve and the actual load curve. Literature [3] classifies according to the size of the cutting load. For different gears, the evaluation results are obtained according to the response speed.

The evaluation of the comprehensive index is to obtain the evaluation result by confirming the weight of each index considering various factors in the flexible negative control. Literature [4] classifies the generation models of prediction curve into expectation and weather, and takes 33 commercial and industrial users in California as research objects to carry out relevant calculations.

In general, existing evaluation algorithms can meet the requirements of demand response in different scenarios. However, with the popularization of technology, different evaluation algorithms exist in different regions. These differences are not conducive to a unified analysis of response effects from a macro perspective, and are not conducive to improving users' willingness to participate. From the perspective of R&D cost of flexible negative control system, different evaluation algorithms need to be designed in different regions. This increases the enterprise's system development costs. Therefore, a new evaluation algorithm is needed to evaluate the response effect of a single user based on the local flexible negative control.

2. Target load curve and generalized distance

2.1. Determination of target load curve

For each regulation, there is in fact a target load curve. There are three main ways to determine the target load curve.

In the simplest form, it is assigned directly by the manager. The closer the actual load curve is to the specified load curve, the better the performance. This is the mode used for virtual peak regulation [13].

The second way is to reduce the load. Before the instruction is executed, the flexible load control system makes load prediction for the user. On the basis of the predicted load curve, the required control amount is subtracted to get the target load curve.

As shown in FIG. 1, assuming that a system conducts 48 measurements (one measurement point in half an hour) every day, the system issues the index of cutting off 50kW load during the 22nd to 28th measurements. In this scenario, the target curve can be obtained by predicting load minus regulation. Accurate load control [14] can be summarized as this mode.

The third way is to limit the load. That is, the user's load must not exceed a certain range, or direct excision. In this case, the target load is the value of the limited load. Conventional orderly electricity consumption [15] is equivalent to limiting the load value to 0 in this mode.

![Figure 1. The target load of reduction mode](image-url)
In general, most of the flexible negative control can get the target load curve through one of the above three ways.

2.2. Generalized distance to load curve

Through the target load curve, the evaluation of the system response to the single user load can be obtained.

Most evaluation models obtain evaluation results based on several indicators, such as response speed, response time length, response load, total power reduction, peak load, etc. [16]. Therefore, this paper focuses on these indicators. For clean energy consumption, economy and other indicators that are not directly related to flexible negative control, this paper does not discuss. Among the five indexes such as response speed, some of them take the extreme value as the best. For example, the response speed, the faster the better.

Other indicators, however, are optimal in terms of appropriateness. Taking the response load as an example, too high response load can reduce the load on the power grid, but at the same time, it reduces the electricity sold, causing economic losses to the power grid and reducing the comfort level of users. For the index of response time length, there is a similar situation. If it is too short, the target will not be reached; if it is too long, both the power grid and users will suffer losses.

Table 1 shows the analysis of common indicators. Among them, "whether threshold is involved" refers to the identification of corresponding indicators, and whether a threshold is needed as a reference. Take the response speed as an example. After the start of flexible negative control, the response can be regarded as the beginning of the response if the load value does not decrease. It is only when the load is reduced to a certain extent that the response can be considered to begin. The right-most column of Table 1, "Modification of Formula (1)"s, will be explained later.

Table 1. The optimal situation of each indicator on demand response

| The response indicators | The optimal trend | Whether thresholds are involved | Revision of formula (1) |
|-------------------------|-------------------|--------------------------------|-------------------------|
| Response speed          | The sooner the better | Yes                          | $w_i$ diminishing       |
| Response time length    | advisable to appropriate | Yes                          | $w_i$ decrease first and then increase |
| Response load           | advisable to appropriate | No                           | $M$ is great           |
| Total power cut         | advisable to appropriate | No                           | $w_i$ Remain the same   |
| Peak load               | advisable to appropriate | No                           | $M$ is great           |

It can be seen from Table 1 that the calculation of various indicators in flexible negative control is a complex process, the essence of which is to extract some information from the load curve as a judgment basis. From this point of view, if the actual load curve is directly compared with the target load curve, and different weights are used in the comparison, it is an equivalent calculation method.

$$d(p, \bar{p}) = \sqrt{\frac{1}{n} \sum_{i=1}^{n} w_i \| p_i - \bar{p}_i \|^p}$$  \hspace{1cm} (1)

2.3. Item distance correction

In some demand response scenarios of power rationing, it is required that the user's power load should not exceed a certain value. In this scenario, if the user load exceeds the target load, the response will be poor. If the user does not reach the target load, the response is not affected at all. Therefore, compared with the target load, the positive and negative convergence of the actual load have different effects on the response effect.
There are many similar flexible negative control scenarios. However, formula (1) does not reflect the positive and negative convergence. Therefore, it is necessary to introduce the itemized distance function \( \varphi(p_i, \bar{p}_i) \).

Formula (1) can be rewritten as follows

\[
\begin{align*}
    d(p, \bar{p}) &= \sqrt{\frac{1}{n} \sum_{i=1}^{n} w_i \varphi(p_i, \bar{p}_i)} \\
    \varphi(p_i, \bar{p}_i) &= |p_i - \bar{p}_i|
\end{align*}
\]  

(2)

3. Initialization of each parameter by neural network

3.1. Parameter initialization

Response speed, response time, response load, total power cut and peak load are the key evaluation indexes.

The weight vectors of response speed, response time length and total reduced electric quantity are respectively set as \( W_{\text{speed}}^T, W_{\text{duration}}^T, W_{\text{kWh}}^T \).

\[
W_{\text{speed},i} = \begin{cases} 
    w_{\text{base}} - \frac{w_{\text{base}}}{d} i, & i \leq d \\
    0, & i > d
\end{cases}
\]  

(3)

Formula (4) represents the initial weight vector that only considers the response speed, and the weight of each point will be adjusted later to adapt to various scenarios including nonlinear. Where, is the benchmark weight value, which is specified by the user and is generally set to 1. The weight value will not be greater than this number. D is the number of measurement points corresponding to the response speed. Take the measurement every 5 minutes. If the user is required to respond within 10 minutes after the instruction is issued, the value of D is 2. The above is the weight matrix considering only the response speed.

3.2. Construction of parameter correction model

The basic principle of neural network is used to modify the parameters of each system based on the data. Specifically includes the total weight vector \( W \), and the magnification index M.

For the existing system of historical evaluation data, the historical data is directly used for the first revision. For the newly launched system, the simulation data can be used for verification, or the system can be modified for the first time after experiencing the response regulation.

The value \( n \) in formula (1) varies in each event due to the different length of time it takes to respond to each event. In order to facilitate the calculation of neural network, a larger \( N \) value is specified and the load data of each flexible negative control is extended to \( N \) in equal proportion.

As amplification exponent M is involved, implicit layers \( h_i \) need to be designed to support nonlinear relationships. Let the node representing the hidden layer and 0 represent the final output. \( w_i \) is not only the weight factor in formula (1), but also the weight from the hidden layer \( h_i \) node to the output layer node O.
3.3. Back propagation of neural network

In the case of flexible negative events that have occurred, the system administrator sets an expected evaluation value for each event. The evaluation value is expressed as $O_{\text{tar}}$. The variance of evaluation value and expectation obtained by design calculation is $E$.

$$E = \frac{1}{2} (O_{\text{real}} - O_{\text{tar}})^2 \quad (4)$$

4. Numerical Examples

In this paper, the relevant data of Changzhou Green construction area are selected for example analysis. The flexible negative control in the green zone is mainly about improving energy efficiency and protecting the stability of the power grid. In the scenario of energy efficiency improvement, it is equivalent to the system specifying a target load curve, according to which the user executes the response strategy. In this scenario, the user's focus is equivalent to a total power cut. At the same time, if the load value deviates too much from the target curve at a certain moment, it will have an impact on the subsequent energy strategy. Therefore, the indicator responding to load is also an important aspect of users' attention.

In Changzhou Green construction zone, the regulation with energy optimization as the goal is generally no more than 4 hours. If the data is collected every five minutes, the value of $n$ in the neural network model is 48. Select 129 users for analysis. Among these users, they experienced three energy efficiency improvements in 2017. In each case, the users participating in the promotion are individually evaluated. These 3 incidents, total user evaluation 267 times.

5. Conclusion

The effect evaluation of single user's demand response is directly related to the user's enthusiasm to participate in the regulation. The design of self-oriented evaluation algorithm is conducive to reducing the secondary development cost of the demand response system and improving the willingness of users to participate.

This paper firstly analyzes the identification of target load curve, and then defines the generalized distance between curves. The generalized distance between the actual load curve and the target load curve is directly related to the evaluation result. Then, this paper proposes the initialization algorithm of generalized distance correlation parameter, constructs the correlation model by using the neural network, and calculates the correlation parameter according to the evaluation sample. Due to the constant need to improve the accuracy of parameters, this paper designed the annual update algorithm. Finally, the validity of the proposed algorithm is verified by an example in Changzhou Green construction area.

Acknowledgments

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