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# Power Precise Load Shedding Control Strategy Considering User Demand Response Clustering

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# Power Precise Load Shedding Control Strategy Considering User Demand Response Clustering

**Qin Li[1] Zhiqiang Xu[1] HuiFang Zhang[1] Yi Liu[1] Jun Lu[2] Zesheng Hu[2]**

[1] Hunan Transmission and Transformation Survey and Design Consulting Co, Ltd State Grid Hunan Electric Corporation Hunan Changsha, China

[2] School of Electrical and Electronic Engineering North China Electric Power University Beijing, China

[*]lujun@ncepu.edu.cn

**Abstract.** Load shedding control is one of the key technologies for stable operation and efficiency optimization control of power system. Aiming at optimized load overcut rate optimization problem for second/minute level precision load shedding efficiency, a precise load shedding control method based on user demand response clustering is proposed. Firstly, based on the analysis of the characteristics of the precise load control system, the authors construct the optimal mathematical model of the precision load shedding control strategy with minimum load overcut rate using the user load clustering. Secondly, the particle swarm algorithm is used to achieve the minimum load overcut rate control strategy model. Finally, through the analysis of the example, the proposed method can reduce the 30% load over-cut rate and the load over-cut rate volatility compared with the traditional method, and verify the effectiveness of the proposed method.

## 1. Introduction

In recent years, there have been many large-scale power outages in the world, causing huge economic losses. In order to reduce and avoid the losses caused by such accidents, it is necessary to put forward new requirements for the safety and stability of the power system. Power system safety and stability emergency control is an effective means to ensure that the system maintains stable operation under sudden conditions. Precise load shedding is one of the commonly used measures. After a serious fault in the power grid or loss of a large amount of power, a part of the load is cut off to reduce the power imbalance in the network and maintain the stable operation of the system. According to different control requirements, the precise load shedding is divided into a millisecond-level control system for fast load control and a second- and minute-level control system with more friendly interaction. The millisecond-level control system is required for frequency emergency control. The first time limit can be interrupted by the quick cut-off part; the second/minute-level control system can interrupt the load and realize the power balance. This paper focuses on the control strategy of the second- and minute-level control systems.

For precise load shedding control, domestic and foreign scholars have carried out research from different aspects. The [4] considers the uncertainty of wind farm output, and proposes the application of robust linear optimization theory to study the calculation of small shear load with multiple wind farms in power grid planning. For the optimal load shedding control problem with transient stability constraints, the parallel pattern search algorithm is used to solve the problem effectively. The validity and correctness of the method are verified by testing three different scale systems [5]. The [6] proposes an emergency load shedding optimization model that takes into account transient safety and economy, and designs an efficient solution method. The reliability evaluation of micro-grid island operation was carried out [7]. The source-source fluctuation and actual load-cutting strategy during islanding were analysed.

At present, some scholars take the new energy grid connection as the background, consider the load shedding operation to reduce the risk of grid connection, and also analyse the load shedding operation in the island operation of the micro grid. However, few scholars have adopted the overcut rate as the entry point and considered the problem of excessive load shedding in the precise load shedding control. This paper implements the precise load shedding control through the user side demand response strategy, and proposes a clustering grading precision load shedding control strategy considering the user demand response. Compared with the traditional unloaded load superposition method with no demand response clustering, this method effectively reduces the overcut rate, realizes the efficient control of the load shedding control, improves the load utilization rate and reduces the adverse impact of the load shedding operation.

The rest of this paper is organized as follows. In Section II, the optimal mathematical model of the precision load shedding control strategy with minimum load overcut rate using the user load clustering is constructed. In Section III, the model solving is proposed. In Section IV, the performance of the proposed is evaluated through simulations. The conclusion is drawn in Section V.

## 2. Precision load shedding modeling

### *2.1. Load shedding control strategy applicable scenario*

The application scenario of this paper is shown in Figure 1. The control system consists of the main station and the control terminal. The control process includes the second-level main station to control the large-area network to deliver the load-shedding command to the control terminal through the provincial-level marketing control. The control main station is generally located in the dispatching machine room of the provincial power company, and the control terminal is generally located in the power distribution room of the large user, and the convergence point is generally located in the city, county company or hub substation. The functions of main station and the control terminal are as follows,

(1) The main station collects the loadable load uploaded by the control terminal, calculates the release control command according to the demand side management target, and performs load distribution;

(2) The control terminal collects the user's loadable load, uploads it to the control master station, and executes the control command. The precise cut-off part can interrupt the load. The data communication between the primary station and the terminal is carried by the marketing control area network, and the marketing control area network can be divided into two levels, namely, provincial level and regional level, and the aggregation point is set according to the network condition.

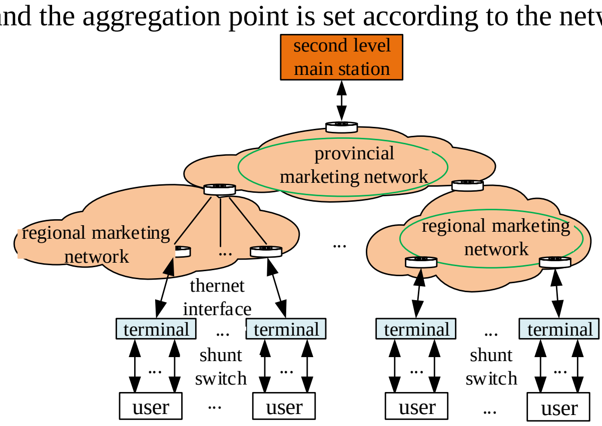


Figure. 1 Load shedding control strategy applicable scenario

*2.2. Modeling*

This part mainly introduces the precise load shedding control strategy model based on demand response. This section of load shedding modeling is divided into user load clustering hierarchical modeling and minimum over-cut rate modeling in load shedding control.

- User load clustering hierarchical modeling

Assume that the set of users participating in load shedding control is $UserSet=[U_1,U_2,\cdots U_k,\cdots U_N]$: A total of N users participate in the load-shedding demand response control. The expected start time of the grid load shedding operation is defined as $t^s$, and the end time is defined as $t^e$. The time interval is equally divided into T time periods in units of s, and $\mathrm{T}=\left[t^s,t^s+1,\cdots,t^s+T-1,t^e\right]$ is the time set.

Firstly, this section evaluates the total number of N users participating in load shedding control. The load usage of all users during the load shedding scheduling period is as follows.

$$Y=[\mathrm{X}_1,\mathrm{X}_2,\cdots,\mathrm{X}_k,\cdots,\mathrm{X}_n] \tag{1}$$

In the Equation(1), where Y is a $T\times\mathrm{n}$ dimensional matrix, which is the overall load and $X_k$ is a T-dimensional vector, which is the load of the user k. For any user, the load can be expressed by the following Equation.

$$X_k=[X_k(t^s),\cdots,X_k(t),X_k(t^e)],\ \forall k\in[1,n] \tag{2}$$

$$0\le X_k(t)\le X_k^{\max}(t) \tag{3}$$

In the formula (2), $X_k(t)$ represents the load arrangement of the user k at time t. And $X_k^{\max}(t)$ is the maximum value of the load shedding at time t. Calculate the total amount of load $Y(t)$ that can be cut at time t as Equation 4.

$$Y(t)=\sum_{k\in N}X_k(t) \tag{4}$$

Then, the user is ranked according to the size of the load. Then $UserSet=\{User_I,User_{II},User_{III},\}$, for the user $U_k\in User_i(i\in I,II,III)$ according to the size of $X_k(t)$ of all the users participating in the load-cutting at time t, the users can be ranked.

$$X_{i,\mathrm{k}}^{\min}(t)\le X_{i,k}(t)\le X_{i,\mathrm{k}}^{\max}(t) \tag{5}$$

where $X_{i,\mathrm{k}}^{\min}(t)$ and $X_{i,\mathrm{k}}^{\max}(t)$ are the user $User_i$ loadable upper and lower limits. .

Calculate the total amount of load that can be cut at time t as Equation 6.

$$Y_i(t)=\sum X_{i,k}(t) \tag{6}$$

$$0\le Y_i(t)\le Y(t) \tag{7}$$

Finally, this section calculates the total amount of load that can be cut at time t as follows.

$$Y(t)=\sum_{i\in I,II,III}Y_i(t)=\sum_{i\in I,II,III}\sum X_{i,k}(t) \tag{8}$$

- Minimum over-cut rate modeling

Set the load-cutting load $\mathrm{X}_k\left(t^\Delta\right)$ of user k at the actual load-cutting operation start time $t^\Delta$, and the total load of all users participating in the load-cut control is as Equation 9.

$$Y\left(t^\Delta\right)=\sum\mathrm{X}_k\left(t^\Delta\right) \tag{9}$$

The over-cut rate is an important indicator in the precise load shedding control of the power grid. The greater the over-cut rate, the greater the degree to which the load exceeds the target load shedding at this time. The greater the impact on the daily operation of the user, the smaller the user satisfaction. The over-cut rate mainly includes the instantaneous overcut rate and the mean overcut rate. The instantaneous overcut rate is defined as the ratio of the actual shear load to the target shear load for a certain load shedding operation, as shown in the following Equation,

$$\theta\left(t^{\Delta}\right)=\frac{Y(t^{\Delta})^{'}}{Y^{'}}\times 100\% \tag{10}$$

$$Y(\mathrm{t}^{\Delta})\geq Y^{'} \tag{11}$$

Where $Y^{'}$ is the target load shedding amount, and the mean over-cut rate $\bar{\theta}$ is defined as the mean value of the instantaneous over-cut rate in the set of load shedding time.

$$\bar{\theta}=\frac{1}{T}\sum_{t=t^{s}}^{t^{e}}\theta\left(t\right) \tag{12}$$

- Objective function

In this paper, the user selects the minimum value of the mean value of the over-cut time set as the objective function as shown in the following Equation.(13).

$$\min \quad \bar{\theta} \tag{13}$$

Constraints are from (1) to (12).

## 3. Optimization process

The model solving flowchart of this paper is shown in Figure 2. The specific process is as follows,

- The main station issues the load shedding command, which mainly includes the pre-start time of the load shedding, the duration, and the total load shedding.
- The control terminal quickly clusters the loadable users in the load shedding period according to the command.
- Calculate the pre-contribution ratio according to the load-cutting amount of users at all levels. The pre-contribution of $User_i(i\in I,II,III)$ is as $F_{\mathrm{i}}=\frac{Y_{\mathrm{i}}}{Y}$.
- Oversaturated load shedding according to $F_i\left(1\pm\chi_i\right)$ as its actual contribution ratio
- Calculate the optimal solution of the objective function by particle swarm optimization, and modify the constraint condition (7) to (14).

$$F_i\left(1\text{-}\chi_i\right)\bullet Y_i(t)\leq Y_i(t)\leq F_i\left(1\text{+}\chi_i\right)\bullet Y_i(t) \tag{14}$$

- The control terminal is ready to start the load shedding operation.

## 4. Experiment and Analysis

### *4.1. parameter setting*

Experimental parameter setting: The basic user load data in this paper is derived from [8], and the commercial large user data set is provided by the Office of Energy Efficiency & Renewable Energy (EERE); the number of users selected is 50, and when the load is cut off at the grid side at 18:13, The cutting load target is 300 MW and the cutting load duration is 2 min.

Contrast algorithm: this paper considers the clustering DR strategy of user behaviour clustering (hereinafter referred to as this method), that is, clustering analysis of different users on a feeder according to their power consumption behaviour, establishing logical sub-regions, and scheduling. The contrast algorithm is disordered [8]. In this strategy, users use random loads according to their own preferences.

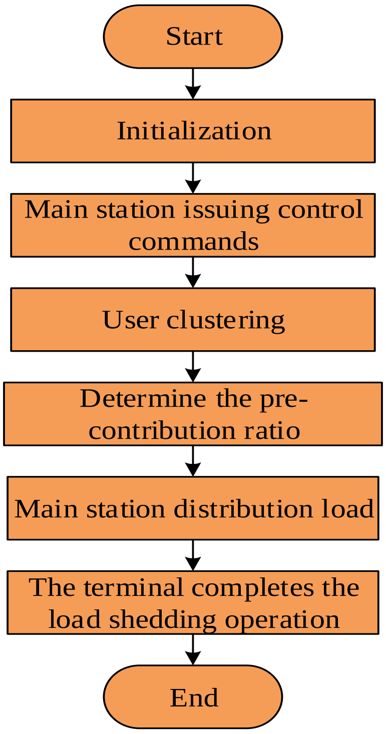


Figure. 2 algorithm flow chart

*4.2. Experimental results analysis*

- Comparison of total load results

Firstly, this part discusses the total load contrast of the method and the comparison method in this paper is discussed. The results of the comparison between the two methods at the time of 18:10-18:16 are shown in Figure 3, in which the horizontal axis represents time and the vertical axis represents the total load (MW).

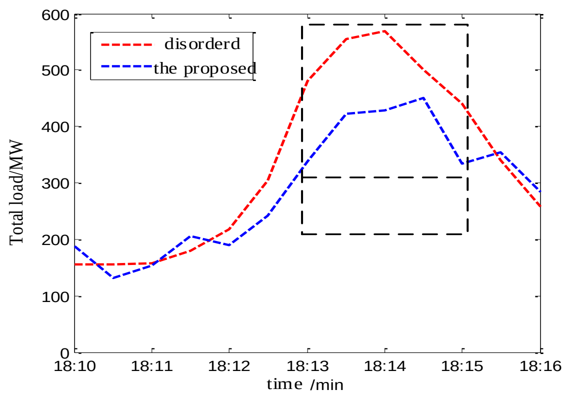


Figure. 3 18:10-18:16 load comparison

As can be seen from Fig.3, when the disorder power consumption and the method are in the range of 18:13 to 18:15, the disorder electric load curve is higher than that of the method, wherein the power peak load of the disorder power supply is 552.7MW at this time, the power consumption peak load of the method is 4206MW, and the peak-cutting effect of the method is better than that of the disorder method, and meanwhile, When the cutting load target is 300 MW, both methods can achieve the cutting load target, and the load exceeding the target in the method is less than that of the out-of-order power consumption.

- Comparison of over-cutting rate

The results of the over-cut rate of the two algorithms are shown in Table 1, and the comparison figure is shown in Fig.5.

Table 1 The results of the over-cut rate of the two algorithms

| | $\bar{\theta}$ (MW/min) | Maximum value of $\theta(t^{\Delta})$ (MW) | Minimum value of $\theta(t^{\Delta})$ (MW) | standard variance |
|---|---|---|---|---|
| disordered | 175.4% | 183.3% | 133.4% | 0.043 |
| the proposed | 122.6% | 139.5% | 112.6% | 0.012 |

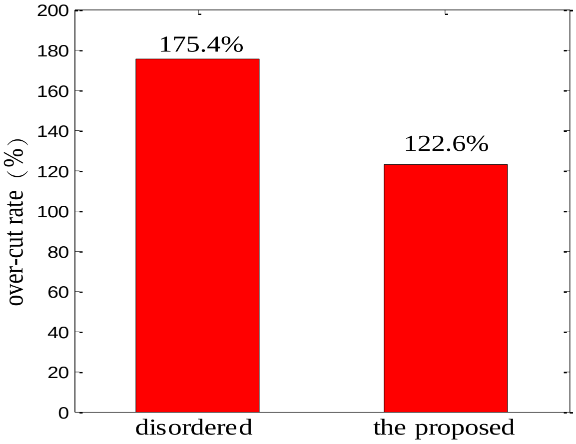


Figure. 4 the over-cut rate chart

As can be obtained from Table 1 and Fig. 5, in the 18:13 to 18:15 of the load instruction, the overcut rate (in short) is 175.4% and 122.6%, respectively, and the method is less than 30.1% of the out-of-order power utilization method. The instantaneous maximum over-cutting rate of the out-of-order electric power and this method is 183.3%, 139.5%, the instantaneous minimum passing rate is 133.4%, 112.6%, and the variance of the over-cut ratio is 0.043 and 0.012, respectively. Smaller load overcut rate, that is, users cut more than the target load of the program smaller.

- Multi-group cutting load experiment

In order to eliminate the randomness of simulation experiments, 10 groups of experiments are carried out under the same conditions. In this paper, mean value and variance are used as indicators to measure the volatility of over-cut rate of the two methods. The results are shown in Figure 5, Table 2, and comparison figures are shown in Figure 6 and Figure 7.

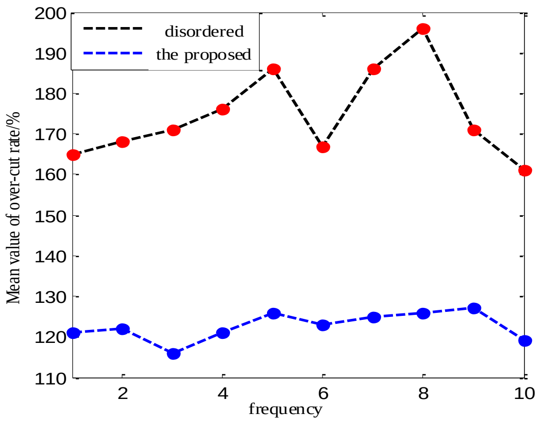


Figure. 5 multiple experiment over-cut rate results

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Table 2. multiple experiment over-cut rate results

| | the mean value (MW/min) | standard variance |
|---|---|---|
| disordered | 173.2% | 0.014 |
| the proposed | 124.7% | 0.011 |

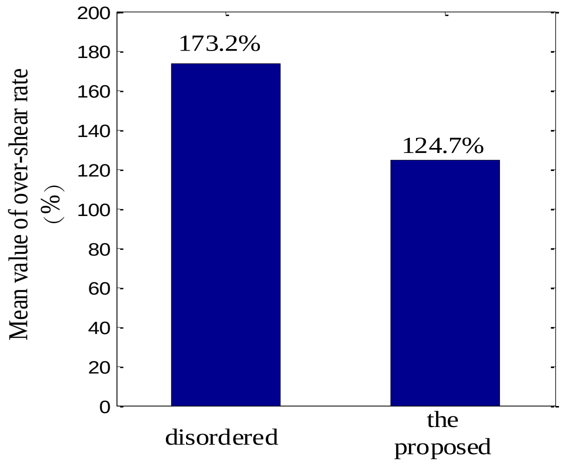


Figure. 6 the mean value of over-cut rate results

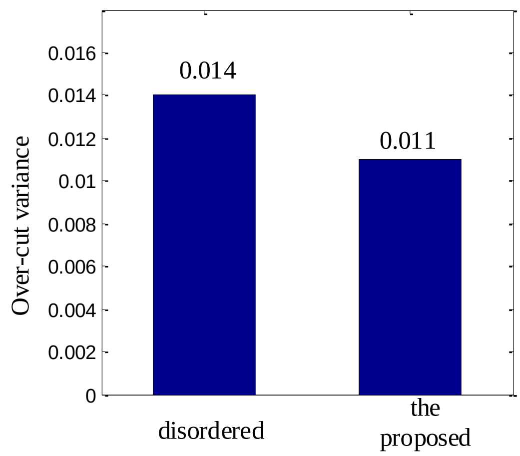


Figure 7 standard variance of over-cut rate results

As can be seen from Table 2, Fig. 7 and Fig. 8, the average value of the method in this paper is 173.2%, 124.7%, and the variance is 0.014, 0.011, respectively. The experimental results show that the fluctuation of the 10 groups of experiments is relatively small, and the average value of the method is 173.2%, 124.7% and 0.011, respectively. The experimental conclusions are reliable.

In conclusion, the method in this paper can ensure that the load-cutting target can be achieved at the same time, compared with the disordered power consumption, it can greatly reduce the amount of the total load cut over the target total.

## 5. Conclusion

The paper proposed a precise load shedding control method based on user demand response clustering. Through the user load clustering, the optimal mathematical model of the optimal load-cutting control strategy for the minimum load overcut rate is constructed. Then, the authors realized the minimum load overcut rate control strategy model. The analysis of the example shows that Compared with the traditional minimum overcut rate precision control method, the load over-cut rate and the load over-cut rate volatility can be reduced, and the effectiveness of the proposed method is verified.

**Acknowledgments**
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