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Optimization of Time Division for TOU Pricing Based on Equivalent Load of Power Systems with High Proportion of Renewable Energy

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ABSTRACT: As the installed capacity for renewable energy continues to expand and the cost of electricity generation decreases, we are entering an era of building a modern power system. There is a growing need to optimize timeofuse (TOU) pricing to effectively manage the volatility and intermittency of these sources. This paper presents a new method for optimizing the time division of TOU pricing based on equivalent load. The equivalent load is calculated using the typical load curve of the power grid and incorporates the weight of renewable energy consumption responsibility as the equivalent coefficient. By considering the consumption of renewable energy and the interaction between supply and demand, the method aims to achieve a balance between electricity supply and demand while promoting the utilization of renewable energy. The method is validated by using power load data of a certain period in a northern region of the State Grid of China. The results demonstrate that the optimized time division based on the equivalent load can effectively reduce the peak load, significantly narrow the gap between peak-valley loads on the power grid side, and promote the consumption of renewable energy.

KEYWORDS:time division, renewable energy, equivalent load, time of use (TOU) pricing

I. INTRODUCTION

To achieve a low-carbon energy structure is animportant part of China's "dual carbon" strategy. In recent years, the construction process of modern power systemhas been accelerating. There have been some new changes in the power supply and demand structure: firstly, the proportion of uncertain renewable energy on the generation side has increased, and the power structure on the consumption side has changed rapidly, leading to increased bidirectional volatility in power production and consumption; secondly, with the large-scale integration of renewable energy, the marginal cost of power supply has changed significantly due to the changing output structure of power sources at different times; in addition, the diversification of power consumption structure and the large-scale application of new energy storage devices in the electricity consumption process have improved the responsiveness of user demand[1].

However, renewable energy sources such as wind and photovoltaic power pose severe challenges to the safe and reliable operation of the new power system due to their output volatility and intermittency[2][3]. Wind and photovoltaic power curtailment phenomena occur frequently, and the utilization rate of power sources needs to be improved. It is urgent to use market incentives to mobilize demand-side resources, promote the consumption of renewable energy, and alleviate the pressure on system operation[4]. TOU pricing is an important market mechanism for demand-side management[5]. By dividing a day into sharp, peak, shoulder and valley periods and setting different price levels for each period, it fully utilizes the price signal to guide electricity users to minimize electricity usage during peak hours and maximize usage during off-peak hours, thereby ensuring the safe and stable operation of the power system, improving the overall utilization efficiency of the system, and reducing the overall electricity cost for society.

The division of peak and valley periods is the basis for the formulation and implementation of TOU pricing. However, in many areas where TOU pricing is currently implemented, the division of

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time periods has failed to adapt to the requirements of the new situation, and does not reflect the power supply and demand relationship mapped out by the characteristics of power output and load characteristics. Therefore, it is urgent to further improve the TOU pricing mechanism, scientifically carry out the division of TOU pricing periods, avoid price distortion, and improve the power supply and demand situation to promote green and low-carbon energy development.

The "Notice on Further Improving the TOU Pricing Mechanism"[6] proposes a scientific approach to dividing time periods, stating that "periods with tight supply and demand and high marginal cost of power supply should be designated as peak periods, while periods with relaxed supply and demand and low marginal cost of power supply should be designated as valley periods". There are generally several methods for dividing time periods, including clustering methods based on load characteristics, cost-based methods based on supply cost, and factor analysis methods[7]. Among them, clustering methods use membership or similarity functions to cluster points on the load curve based on the numerical characteristics of the load, evaluate the possibilities of being in each time period, and then determine the sharp, peak, shoulder, and valley periods. Clustering methods include fuzzy clustering[8], C-means clustering, and SOM neural network clustering[9]. These clustering methods are based on load values and ignore the time sequence, which can result in overly dispersed time periods and make it difficult for electricity users to adjust their electricity consumption behavior based on TOU pricing. Cost-based methods divide time periods by analyzing the variation characteristics of actual supply costs over time [10], including methods such as sudden change division based on daily load curve costs, cost time membership function method, and short-term marginal cost method, which involve complex cost calculation processes.

The paper proposes an equivalent load calculation method. Based on the typical load curve of the power grid, the equivalent load curve reflecting the power source structure is generated by introducing the weight of renewable energy power consumption responsibility which is provided by The National Development and Reform Commissionof China as the equivalent coefficient. Then, the hierarchical clustering method is used to divide the equivalent load curve into time periods. The results show that compared to the traditional typical load method, the time period division method based on equivalent load fully reflects the power source structure and will play an important role in guiding users to adjust their electricity consumption behavior, participating in power system balance, and promoting the consumption of renewable energy.

II. DEFINITION OF EQUIVALENT LOAD

2.1 Time division for TOU pricing

Traditional TOU pricing is mainly designed based on the typical load curve of the power supply side. It divides the 24 hours of each day into peak, shoulder, and valley periods, with higher electricity prices during peak periods and lower prices during off-peak periods. Some provinces also set sharp-period pricing, seasonal pricing, or abundance-scarcity pricing. Through differentiated pricing, it fully utilizes the price signal to guide users to reduce electricity usage during peak hours and increase usage during off-peak hours, achieving the goals of peak shaving, load balancing, and ensuring the security of the power system. Although electricity is a homogeneous commodity for users, the marginal generation costs of different energy sources vary greatly on the generation side. Compared to thermal power, renewable energy has significantly lower generation costs with the expansion of installed capacity and technological advancements, and the marginal cost may even approach zero.

If TOU pricing is designed solely based on the typical load curve of the power supply side, it is difficult to effectively transmit the power source structure and cost information to the demand side, and it may even result in cost inversion, where users consume cheaper electricity but pay higher prices. Figure 1 shows the multi-energy output curve of a certain region on the generation side, with higher total output from 10 am to 12 pm. If TOU pricing is designed based on the typical load method, the electricity price should be increased during this period to suppress electricity usage due to the high load. However, this period is the peak period for solar power generation, with lower marginal generation costs. Higher electricity prices are not conducive to the consumption of photovoltaicpower. Therefore, it is necessary to optimize the traditional TOU pricing time division method based on the typical load curve of the power grid, taking into account factors such as the consumption of renewable energy and generation-side costs.

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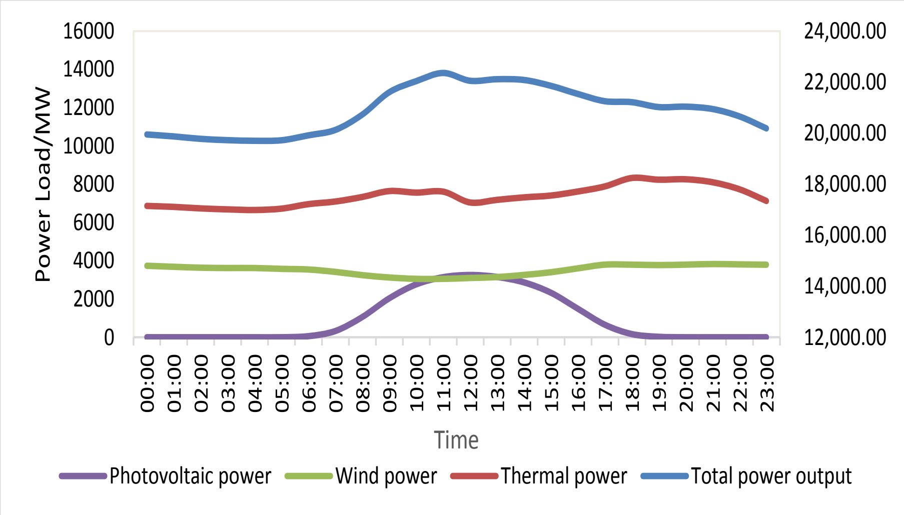

Fig.1 Multi-energy output curve at power generation side

2.2Why introduce Equivalent Load

Due to the volatility and intermittency of renewable energy generation, which is uncertain in terms of time and uneven in spatial distribution, it poses significant challenges to the balance of power supply and demand and the safe and reliable operation of new power systems.

Many scholars have designed TOU pricing based on net load[11][12][13], which has the advantage of directly corresponding the net load with high-cost non-renewable energy generation. In literature [12], the net load curve obtained by subtracting the wind and solar power generation from the local load curve, and it is used as the optimization target for TOU pricing. The net load curve is divided into time periods using fuzzy membership functions, and it is believed that implementing new TOU pricing will prompt consumers to change their electricity consumption habits and reduce their electricity usage, leading to a decrease in user comfort. The paper introduces the concepts of "load transfer rate" and "user comfort" and considers consumer psychology. It formulates two optimization objectives: minimizing the peak-valley difference and maximizing user comfort. These objectives are linearly weighted and transformed into a single optimization objective, which is solved using a genetic algorithm. However, the paper does not provide principles or methods for determining the weighting factors, nor does it compare the improvement in renewable energy consumption before and after optimization. In literature [13], a peak-valley TOU pricing optimization model is developed based on the contribution of load and renewable energy generation to the "duck curve" peak-valley membership degree. This method aims to maximize renewable energy consumption under the constraint that the total electricity cost change before and after optimization is within 0-1%. However, it does not consider the impact on the peak-valley load difference and generation-side costs.

The limitation of the net load method is that the net load is only a part of the grid supply load, so it is not suitable for time period division based on net load. Furthermore, improving the peak-valley difference of the net load does not necessarily indicate a better promotion of renewable energy consumption. Taking into account the advantages and limitations of various load curves, this paper designs an equivalent load indicator and provides its calculation method, and then TOU pricing can be optimized based on the equivalent load.

2.3Definition and calculation of equivalent load

"Equivalent" refers to a comprehensive indicator or quantity that is equivalent to a specific value. For example, "pollution equivalent" measures the environmental pollution caused by different pollutants, and "equivalent electricity price" combines capacity costs and electricity costs. Drawing on the basic idea of "equivalent," the load indicator that considers renewable energy consumption is defined as the "equivalent load." Unlike the typical load of the power grid, the equivalent load takes into account the power grid load, renewable energy consumption, and consumption responsibility weight. The total electricity consumption corresponding to the equivalent load curve is the same as that of the typical load curve, hence the term "equivalent load". The calculation method is as follows:

Step 1: Normalize the typical load of the power supply side using the min-max

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normalization method to obtain dimensionless values between 0 and 1:

$$L(t)' = \frac{L(t) - \min(L)}{\max(L) - \min(L)} \quad (1)$$

In equation (1), $L(t)'$ represents the normalized typical load of the power grid at time t. L represents the typical load of the power grid, and $L(t)$ represents the typical load of the power grid at time t. $\max(L)$ and $\min(L)$ are the maximum and minimum values of the typical load of the power grid, respectively.

Step 2: Normalize the power output of renewable energyon the generation side using the max-min normalization method to obtain values between 0 and 1:

$$L_r(t)' = \frac{\max(L_r) - L_r(t)}{\max(L_r) - \min(L_r)} \quad (2)$$

Where $L_r(t)'$ represents the normalized renewable energy consumption power at time t, $L_r(t)$ represents the renewable energy consumption power at time t, and $\max(L_r)$ and $\min(L_r)$are the maximum and minimum values of the renewable energy consumption power.

Step 3: Combine the two normalized values from steps 1 and 2 using an adjustable coefficient β and the weight of renewable energy consumption responsibility ω to obtain the normalized equivalent load, as shown in equation (3):

$$L_e(t)' = (1 - \beta\omega)L(t)' + \beta\omega L_r(t)' \quad (3)$$

Where $L_e(t)'$ represents the normalized equivalent load at time t, $L_e(t)' \in [0,1]$, ω is the coefficient of renewable energy equivalent, and β is the adjustment coefficient.

Step 4: Restore the normalized equivalent load $L_e(t)'$ to obtain the equivalent load $L_e(t)$ at time t using equation (4):

$$L_e(t) = \frac{L_e(t)' \times (\sum_t^N \Delta(t)L(t) - N\Delta(t)\min(L))}{\sum_t^N \Delta(t)L_e(t)'} + \min(L) \quad (4)$$

Where $L_e(t)$ represents the equivalent load at time t, $\Delta(t)$ is the time interval between load data sampling points, typically equals to 1 hour, and N = 24.

The typical load $L(t)$can be provided by the local power grid company or calculated based on the actual load of the power grid. There are several methods for calculating the typical load, including the maximum daily load method, the average method, the weighted average method, and the fuzzy C-means clustering algorithm[14]. Some scholars have also proposed methods that consider the grid load data and fit the typical load based on a normal distribution[15]. These methods can be complex and determining the typical load is not the focus of this study. For simplicity, this paper collects daily load data and calculates the typical load $L(t)$ using the average method.

III. HIERARCHICAL CLUSTERING TIME DIVISION METHOD BASED ON EQUIVALENT LOAD

3.1 Principle of time period division

Reasonable time period division is a prerequisite for implementing peak-valley TOU pricing. The division should not only follow the principles set by the pricing policy but also consider its own characteristics. The principles for dividing peak and off-peak periods are as follows:

(1) Reflect the actual peak and valley characteristics of the load

The time periods should exactly reflect the peak and valley characteristics of the load curve. This allows for the establishment of a reasonable relationship between peak and valley electricity prices, guiding power users to adjust their consumption patterns, reduce peak demand, improve power grid load rate, and achieve peak shaving and valley filling objectives.

(2) Reflect the electricity costs of each time period

Electricity generation and supplying involve costs. To meet the electricity demand during peak and valley periods, the power system needs to make adjustments, resulting in different electricity costs. Therefore, the time period division should fully reflect the cost differences between different time periods.

(3) Reflect the supply-demand relationship and achieve a win-win situation between supply and demand

Electricity cannot be easily stored. If supply exceeds demand, it leads to resource waste, while if supply falls short of demand, it disrupts normal social production and daily life. Therefore, it is necessary to reflect the supply-demand relationship in the time period division and provide accurate information to users to adjust their consumption patterns, ensuring the stable operation of the power system.

(4) Consider the flexibility of demand-side load adjustment

With the rapid development of the economy, the number of electricity users is increasing. Different users have different production and lifestyle patterns, resulting in

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significant differences in their electricity consumption patterns. The time period division should consider the characteristics of user electricity consumption to promote demand-side response.

3.2 A Hierarchical clustering method based on Equivalent Load

The hierarchical clustering method is simple and easy to use[16]. By clustering the hourly load data for each day, the time periods can be quickly divided and classified based on the actual load. The division can then be optimized by considering the load fluctuation trend.

Hierarchical clustering is a method of dividing a dataset into different levels, forming a tree-like clustering structure. The division methods include "bottom-up" aggregation and "top-down" splitting. AGNES is a hierarchical clustering algorithm that uses the bottom-up aggregation method to divide the dataset[17]. It starts by treating each sample in the dataset as an initial cluster, and then at each step of the algorithm, it merges the two closest clusters until the predefined number of clusters is reached. The key aspect here is calculating the distance between clusters. In fact, each cluster is a set of samples, so a method for calculating the distance between sets can be used. Given two clusters C_i and C_j, the distance can be calculated using the following formulas:

Minimum distance:

$$d_{min}(C_i, C_j) = \min_{x\in C_i, z\in C_j} dist(x,z) \quad (5)$$

Maximum distance:

$$d_{max}(\mathrm{C_i}, \mathrm{C_j}) = \max_{\mathrm{x\in C_i, z\in C_j}} \mathrm{dist}(\mathrm{x,z}) \quad (6)$$

Average distance:

$$\mathrm{d_{avg}}(\mathrm{C_i}, \mathrm{C_j}) = \frac{1}{|\mathrm{C_i}||\mathrm{C_j}|} \sum_{\mathrm{x\in C_i}} \sum_{\mathrm{z\in C_j}} \mathrm{dist}(\mathrm{x,z}) \quad (7)$$

Clearly, the minimum distance between the closest samples in two clusters represents the minimum distance between the clusters, the maximum distance between the farthest samples represents the maximum distance between the clusters, and the average distance between all samples in the two clusters represents the average distance between the clusters. When using $\mathrm{d_{min}}$, $\mathrm{d_{max}}$, or $\mathrm{d_{avg}}$ to calculate the distance between clusters, the AGNES algorithm is correspondingly referred to as the "single-linkage" algorithm, "complete-linkage"algorithm, or "average-linkage" algorithm.

By partitioning the tree-like structure created by the AGNES algorithm at specific levels, the corresponding division results of the clusters can be obtained. If the partition level is gradually increased, the clustering results with a gradually decreasing number of clusters can be obtained.

3.3 Influence of parameters in calculating Equivalent Load

According to equation (3), the value of the standardized equivalent load $\mathrm{L_e(t)'}$ is influenced by the parameters ω and β. The renewable energy equivalent coefficient ω is directly taken as the weight of renewable energy consumption responsibility published annually by the national energy regulatory authority. The calculation of ω is shown in equation (8):

$$\omega = \frac{\sum_{\mathrm{i}}^{\mathrm{m}} \mathrm{Q_{ri}}}{\sum_{\mathrm{j}}^{\mathrm{n}} \mathrm{Q_j}} \quad (8)$$

Where $\sum_{\mathrm{i}}^{\mathrm{m}} \mathrm{Q_{ri}}$ is the total annual consumption of m types of renewable energy, and $\sum_{\mathrm{j}}^{\mathrm{n}} \mathrm{Q_j}$ is the total social consumption of various power sources.

Generally, in China TOU pricing is designed on a provincial basis. When the geographical region of TOU pricing does not match the region of ω, the equivalent load can be adjusted based on the region's ω and the adjustment coefficient β to reflect the impact of renewable energy consumption. $\beta\omega \in [0,1]$. Each region can adjust β according to the actual needs of TOU pricing management, usually setting $\beta = 1$.

The renewable energy output is normalized using the max-min method in equation (2) with $\max(\mathrm{L_r}) - \mathrm{L_r(t)}$. If the renewable energy consumption power $\mathrm{L_r(t)}$ is larger at time t, then $\mathrm{L_r(t)'}$ will be smaller. Based on equations (3) and (4), under the same $\beta\omega$, the equivalent load will also be smaller when the renewable energy consumption is larger, and vice versa. This has a similar effect to the "duck curve" where more photovoltaic power generation leads to lower "net load". However, the "net load" in the "duck curve" deducts all photovoltaic output, while the "equivalent load" does not fully deduct the renewable energy output but uses a relative conversion method, with the degree of conversion determined by $\beta\omega$. If the values of β and ω are changed, a larger product of $\beta\omega$ will result in a greater deviation of the equivalent load curve from the typical load curve, and vice versa. When $\beta\omega = 0$, the equivalent load is equal to the typical load.

Figure 2 shows the equivalent load curves for$\beta = 1$ and ω values equal to 0.16 and 0.32, as well as $\beta = 0.5$ and $\omega = 0.16$. The dashed line represents the equivalent load, the solid black line represents the typical load curve, and the solid green line represents the actual renewable energy output.

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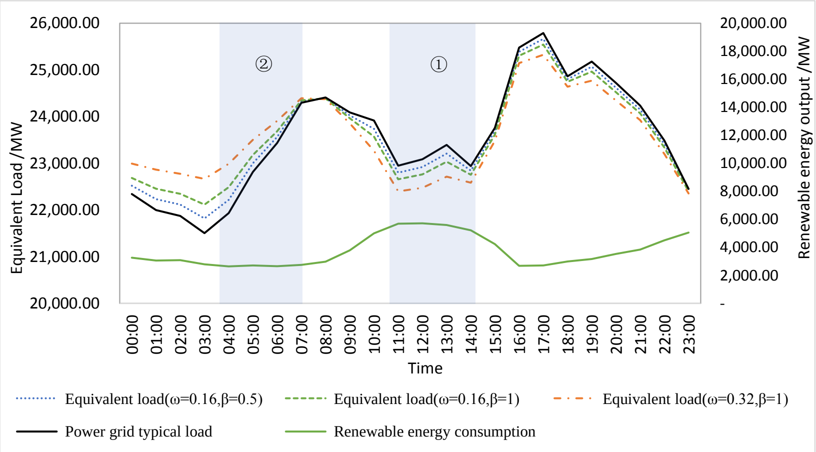

Fig.2 Equivalent load curve and renewable energy consumption curve

Based on Figure 2, during periods with high renewable energy output (such as the ① zone from 11 am to 2 pm), the equivalent load decreases. Since the equivalent load curve is below the typical load curve, optimizing TOU pricing based on the equivalent load curve should lower the average electricity price in the ① zone, thus result in stimulating electricity consumption during that period.

IV. CASE AND ANALYSIS

4.1 Data

In order to verify the effectiveness of the time division for TOU pricing based on equivalent load, we collect the daily load data of a certain period in a northern region of the State Grid of China. The renewable energy output and proportion data is shown in Table 1.

Table 1 Output and proportion of renewable energy in a certain power grid region

Time	Renewable energy output /MW	Non-renewable energy output /MW	Total electricity output /MW	Renewable energy proportion /%
00:00	3,275.90	19,069.97	22,345.87	14.66%
01:00	3,065.97	18,936.33	22,002.30	13.93%
02:00	3,094.89	18,779.87	21,874.76	14.15%
03:00	2,801.40	18,705.92	21,507.32	13.03%
04:00	2,645.10	19,289.05	21,934.15	12.06%
05:00	2,716.75	20,101.26	22,818.01	11.91%
06:00	2,657.42	20,780.86	23,438.28	11.34%
07:00	2,762.11	21,537.18	24,299.29	11.37%
08:00	2,984.25	21,426.30	24,410.55	12.23%
09:00	3,792.74	20,298.20	24,090.94	15.74%
10:00	5,007.10	18,909.44	23,916.54	20.94%
11:00	5,701.89	17,248.48	22,950.37	24.84%
12:00	5,730.08	17,358.32	23,088.40	24.82%
13:00	5,600.63	17,793.82	23,394.45	23.94%
14:00	5,220.15	17,722.74	22,942.89	22.75%
15:00	4,236.63	19,525.40	23,762.03	17.83%
16:00	2,683.14	22,796.19	25,479.33	10.53%
17:00	2,715.48	23,075.56	25,791.04	10.53%
18:00	3,005.72	21,857.56	24,863.28	12.09%
19:00	3,170.38	22,010.73	25,181.11	12.59%
20:00	3,536.35	21,185.57	24,721.92	14.30%
21:00	3,845.02	20,392.11	24,237.13	15.86%
22:00	4,516.13	18,973.24	23,489.37	19.23%

Time	Renewable energy output /MW	Non-renewable energy output /MW	Total electricity output /MW	Renewable energy proportion /%
23:00	5,056.85	17,397.96	22,454.81	22.52%

4.2 Resulting

(1) **Time period division**

The equivalent load is calculated based on equation (4). The traditional time period division based on the typical load is as follows: 3 hours of sharp period from 16:00 to 18:00 and from 19:00 to 20:00, 6 hours of peak period, 7 hours of shoulder period, and 8 hours of valley period. Keeping the duration of sharp, peak, shoulder, and valley periods unchanged, the time periods are redivided based on the equivalent load using the hierarchical clustering method. The time period division results are shown in Table 2.

Table 2 Typical load and Equivalent load and corresponding time period division

Time	Typical load /MW	Equivalent Load /MW	Time period based on Typical load	Time period based on Equivalent load
00:00-01:00	22,345.87	22,687.40	valley	valley
01:00-02:00	22,002.30	22,457.81	valley	valley
02:00-03:00	21,874.76	22,350.26	valley	valley
03:00-04:00	21,507.32	22,119.14	valley	valley
04:00-05:00	21,934.15	22,491.49	valley	valley
05:00-06:00	**22,818.01**	**23,179.97**	**valley**	**shoulder**
06:00-07:00	23,438.28	23,686.03	shoulder	shoulder
07:00-08:00	24,299.29	24,349.42	peak	peak
08:00-09:00	24,410.55	24,391.57	peak	peak
09:00-10:00	24,090.94	23,968.30	peak	peak
10:00-11:00	23,916.54	23,575.81	shoulder	shoulder
11:00-12:00	**22,950.37**	**22,661.71**	**shoulder**	**valley**
12:00-13:00	23,088.40	22,765.67	shoulder	shoulder
13:00-14:00	23,394.45	23,036.29	shoulder	shoulder
14:00-15:00	22,942.89	22,756.39	valley	valley
15:00-16:00	23,762.03	23,613.79	shoulder	shoulder
16:00-17:00	25,479.33	25,305.09	sharp	sharp
17:00-18:00	25,791.04	25,546.42	sharp	sharp
18:00-19:00	24,863.28	24,747.40	peak	peak
19:00-20:00	25,181.11	24,965.96	sharp	sharp
20:00-21:00	24,721.92	24,524.04	peak	peak
21:00-22:00	24,237.13	24,073.72	peak	peak
22:00-23:00	23,489.37	23,338.40	shoulder	shoulder
23:00- 00:00	22,454.81	22,402.05	valley	valley

Based on the time period division results shown in Table 2, the time variation chart in Figure 3 is plotted. It demonstrates that the time period division based on the equivalent load curve is generally consistent with the division based on the typical load, but there are some changes during the low renewable energy output period from 5:00-6:00 and the high output period from 11:00-12:00. Due to the higher equivalent load during 5:00-6:00, the period has changed from valley to shoulder, while the period from 11:00-12:00 has changed from shoulder period to valley period.

Although the typical load during 11:00-12:00 is higher than during 5:00-6:00, the equivalent load during 11:00-12:00 is lower. Therefore, charging valley electricity prices during 11:00-12:00 helps to release electricity demand. So, the time period division result reflects the level of renewable energy output on the power generation side.

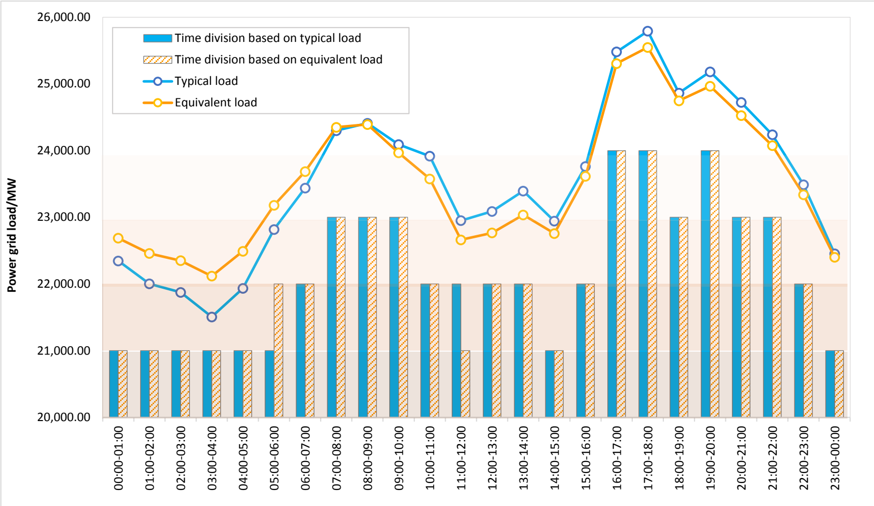

Fig. 3 Time period division comparison based on typical load and equivalent load

(2) **Power grid load**

The optimization of TOU pricing is a multi-objective planning problem. The optimization objectives include maximizing the utilization of renewable energy, minimizing environmental management costs, minimizing the purchasing costs of electricity generation, minimizing the peak-valley difference in grid load and so on. Some objectives are mutually consistent, while others may conflict with each other. Various optimization methods for TOU pricing were introduced in literatures[19][19][20].After optimizing TOU pricing using the typical load method, the minimum load of the power grid increased from 21,507.32 MW to 21,939.28 MW, achieving a valley filling of 431.96 MW. The equivalent load method achieved a valley filling of 435.62 MW. Both methods have valley filling effects.

The impact of the optimized typical load method and equivalent load method on the sharp-valley load difference of the power grid is shown in Figure 4. The sharp-valley load difference decreased from 4,283.72 MW before optimization to 2,976.75 MWand 2,965.24 MW respectively.

It is worth noting that during periods with high renewable energy output (Zone ① in Figure 4), the equivalent load method optimized the power grid load to be higher and more stable. This indicates that the output structure on the power generation side effectively transfers to the power supply side.

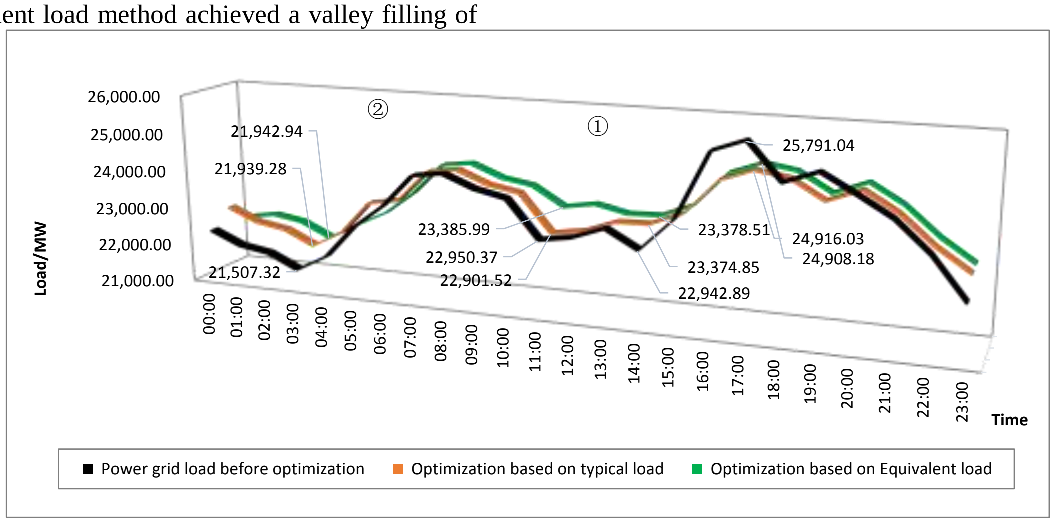

Fig. 4 Power grid load curve before and after TOU pricing optimization based on typical load and equivalent load

4.3 Discussion

The equivalent load provides a comprehensive indicator that incorporates the power grid load, renewable energy generation. It is calculated based on the typical load curve of the power grid and takes into account the weight of renewable energy consumption responsibility. By using the equivalent load, it becomes possible to assess the impact of renewable energy on the power system and optimize TOU pricing accordingly. In regions with higher renewable energy output, the utilization rate of renewable energy can be further increased.

Furthermore, The TOU pricing based on the equivalent load enables demand-side users to respond to renewable energy consumption in conjunction with the power generation side, consquently promotes the transition of the new power system from "generation following load" to "generation-load interaction".

V. CONCLUSION

Renewable energy sources such as wind and photovoltaic power pose significant challenges to the safe and reliable operation of new power systems due to their fluctuating and intermittent output. Timeofuse (TOU) pricing is an important market mechanism for demand-side management, and the time division of peak and valley periods is the foundation for implementing TOU pricing.

This paper has presented a method for optimizing the time division of TOU pricing based on the concept of equivalent load. By incorporating the weight of renewable energy consumption responsibility as the equivalent coefficient, the proposed method accurately reflects the output of renewable energy.The results demonstrate that the optimized time division based on the equivalent load can effectively stabilize the grid load, promote the consumption of renewable energy and create a win-win situation for power generation, supply, and consumption.

The findings of this research have practical implications for the development of strategies for managing the challenges associated with a high proportion of renewable energy in the power system and provides insights for policymakers and energy market participants in optimizing TOU pricing.

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