Simulation and analysis on peak load regulation of office and living parks

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Abstract. With the rapid economic development and the rapid increase in human living demand, the load power is constantly increasing, and the range of change is also increasing substantially. The peak-valley difference of daily load is increasing, which brings challenges to the peak-shaving of the power grid. The microgrid can not only supply sufficient power to the load, but also track part load changes, and has good economic benefits. Due to both of the variety of load types and the capacities of loads, the problem of peak shaving in the microgrid has also emerged. Using “source load” peak shaving to relieve peak shaving pressure is a good approach. This paper takes the minimum load fluctuation rate as the objective function, and uses the improved particle swarm optimization algorithm to simulate the peak load regulation in office and living parks. The results show that the “source load” peak shaving can make the load curve smoother. It is effective for “source load” to participate in peak shaving.

1. Introduction
Fossil energy has made human development enter a new era, but as research has found that fossil energy is increasingly depleted, and the use of fossil energy will bring pollution to the environment, countries are committed to finding alternatives to fossil energy, wind power and photovoltaic power generation. Because of its clean and pollution-free advantages, it is favored by all countries. The proportion of wind power and photovoltaic power generation in the power generation of various countries has gradually increased, but the instability and randomness of the output of wind power and photovoltaic power generation have adversely affected the normal operation of the power system. How to coordinate the use of source and charge is an important direction of research today.

Due to the contradictory relationship between social demand and energy supply, fragmented energy demand is increasing, which brings challenges to centralized integrated energy services, such as electric vehicle charging load, air conditioning load and other random loads on the safety of the power system. Economic operation has brought about a large negative impact. However, this type of load has the advantages of fast response speed and great potential, and has become an important demand response resource under the smart grid. For example, the air conditioner[1-5] and the building environment to which it belongs have a certain cold storage capacity, and when the temperature is adjusted within a certain range, it will not affect the living comfort of the residents, thus creating conditions for load adjustment; the number of air conditioning load base is large. According to statistics, during the peak load period of summer in China's power grid, the air-conditioning load has accounted for 30-40% of the peak load, and it has shown an upward trend year by year. The number of air-conditioning loads after centralized control is considerable. The potential to participate in the system's peak and frequency modulation is huge. It can be incorporated into the power system operation scheduling; the development of electric vehicles equipped with batteries and their two-way charging technology means that electric vehicles have peak shaving capabilities, especially V2G[6]-
[10] and B2G of electric vehicles. The mode also provides convenient conditions for power system dispatching; the storage water heater itself has heat storage capacity, and the operation power of the water heater reaches several kilowatts, and the base is large, so the water heater[11-13] is also an effective means to participate in peak shaving.

This paper uses source charge to participate in peak shaving and researches on the load peak shaving ability, including electric vehicles, air conditioners, refrigerators, and water heaters. The next work arrangement of the thesis: Chapter 2 is the research of microgrid power output; Chapter 3 is the modeling of load peaking capacity; Chapter 4 is the case simulation and analysis; Chapter 5 is the conclusion.

2. Research on the power side of microgrid

2.1. Wind power output

The power of the wind turbine is related to the wind speed, and its power characteristic expression is expressed as expression (1).

\[
P_{\text{WT}} = \begin{cases} 
0 & (v \leq v_{ci}) \cup (v \geq v_{co}) \\
\alpha v^2 + \beta v + \gamma & v_{ci} \leq v \leq v_{cr} \\
P_{\text{Wr}} & v_{cr} \leq v \leq v_{co} 
\end{cases} 
\]

(1)

Where:
- \( P_{\text{WT}} \) - the actual power of the wind turbine;
- \( P_{\text{Wr}} \) - the rated power of the wind turbine;
- \( v \) - the actual wind speed;
- \( v_{ci} \) - the wind speed at which the wind turbine starts;
- \( v_{cr} \) - the wind speed at which the wind turbine reaches the rated power;
- \( v_{co} \) - the cut-out wind speed at which the wind turbine exits the operation.
The values of \( \alpha, \beta \) and \( \gamma \) are 3.4, -12, and 9.2, respectively.

2.2. Photovoltaic output

Assuming that the irradiation angle is the best angle at every moment, under the condition of ignoring the influence of other meteorological factors, the expression (2) of the power and light intensity of photovoltaic power generation is shown.

\[
P_{\text{PV}} = \begin{cases} 
P_{\text{PV,r}} & \text{for } S \leq S_r \\
P_{\text{PV,r}} & \text{for } S > S_r 
\end{cases} 
\]

(2)

Where:
- \( P_{\text{PV}} \) - photovoltaic power generation;
- \( P_{\text{PV,r}} \) - photovoltaic power rating;
- \( S \) - actual light intensity;
- \( S_r \) - rated light intensity.

3. Park load peaking

The load types of office and living parks are diverse, mainly including air conditioning load, water heater load, electric vehicle load, refrigerator load and various small power loads. Uncertainty modeling is carried out for the living characteristics of office and living parks.

3.1. Air conditioning peak shaving

3.1.1 Air conditioning load model. Basically, the modeling method of air conditioning is the cooling (heat) load calculation. The modeling method is based on the conservation of energy, that is, the energy change value of the building where the air conditioner is located at any time period is equal to the air conditioning cooling (heat) amount and the building. The difference in heat gain. The mathematical expression of the heat exchange principle is as follows:

\[
T(t+\Delta t) = T(t) - \eta PR - (T_{\text{ain}}(t+\Delta t) - \eta PR - T(t))e^{\frac{-\Delta t}{C}} 
\]

(3)

Where:
- \( T(t) \) is the temperature in the room at the \( t \) moment;
- \( T(t+\Delta t) \) is the indoor temperature after \( \Delta t \) passing;
- \( T_{\text{ain}}(t+\Delta t) \) is the ambient temperature outside the room at the moment;
- \( C \) is the heat capacity of the room;
- \( R \) is the thermal resistance of the room;
- \( P \) is the cooling/heating power of the air.
conditioner, $\eta P$ represents the cooling/heat of the air conditioner; $\eta$ represents the energy efficiency ratio of the air conditioner.

3.1.2 Air conditioning peak shaving model. Peak load and valley filling can be achieved by changing the set value during the load peak and valley period. The peak shaving ability of the air conditioner is calculated by the following formula.

$$P_{AC,PK} = \frac{n_0 \cdot \Delta t}{n_c \cdot \Delta t} N \cdot P_{AC}$$  \hspace{1cm} (4)

Where: $n_0 \Delta t$ indicates the control duration at the new set temperature; $n_c \Delta t$ indicates the operating cycle at the new set temperature; $N$ indicates the number of air conditioners participating in peak shaving; $P_{AC}$ indicates the power level of the air conditioner.

Outage time of air conditioning unit $\tau_{on}$:

$$\tau_{on} = RC \cdot \ln \frac{T_{on}^{t+1} - QR - T_{min}}{T_{on}^{t+1} - QR - T_{max}}$$ \hspace{1cm} (5)

Air-conditioning unit downtime $\tau_{off}$:

$$\tau_{off} = RC \cdot \ln \frac{T_{off}^{t+1} - T_{min}}{T_{off}^{t+1} - T_{max}}$$ \hspace{1cm} (6)

In summary, the available operating cycle is:

$$\tau = \tau_{on} + \tau_{off} = RC \cdot \ln \left( \frac{T_{on}^{t+1} - QR - T_{min}}{T_{on}^{t+1} - QR - T_{max}} \cdot \frac{T_{off}^{t+1} - T_{min}}{T_{off}^{t+1} - T_{max}} \right)$$ \hspace{1cm} (7)

3.2. Refrigerator peaking

3.2.1 Refrigerator load model. The equivalent thermal parameter modeling method can use the surrounding environment of the refrigerator as a circuit model for simulation calculations. Compared with the cold (heat) load conservation method, it requires fewer parameters and the calculation is simpler. This article uses ETP modeling method.

$$T_i^{t+1} = e^{-\frac{t+1}{m_c}} \cdot T_i^t + (1 - e^{-\frac{t+1}{m_c}}) \cdot \frac{\eta \cdot P(s)}{A}$$ \hspace{1cm} (8)

Where: $T_i^{t+1}$ represents the temperature of the refrigerator at time $t+1$, °C; $A$ represents the simulation duration; $m_c$ represents the thermal conductivity, kW/°C; $c$ is the thermal capacity of the refrigerator, kWh/°C; $P(s)$ represents the power of the refrigerator; $s$ represents the state of the refrigerator, when $T_i > T_{max}$, $P(s)=140$, otherwise equal to 0; $\eta$ represents the refrigeration efficiency of the refrigerator.

3.2.2 Peaking model of refrigerator. The peak shaving ability of the refrigerator is calculated by the following formula.

$$P_{R,PK} = \frac{n_0 \cdot \tau}{n_c \cdot \tau} \cdot N_0 \cdot P_R$$ \hspace{1cm} (9)

Where: $n_0 \cdot \tau$ represents the control duration at the new set temperature; $n_c \cdot \tau$ represents the operating cycle at the new set temperature, and its calculation method is similar to 4.1; $N_0$ represents the number of air conditioners participating in peak shaving; $P_R$ represents the power level of the refrigerator.
3.3. Peaking of water heater

3.3.1 Water heater load model. Assuming that the water temperature is $T_t$ at time $t$, if no hot water is used, the water temperature in the water tank of the water heater is expressed as follows:

$$T_{i+\Delta t} = T_{i+\Delta t}^\text{in} (1 - e^{\frac{\Delta t}{RC}}) + T_{i}^\text{out} e^{\frac{\Delta t}{RC}} + QR(1 - e^{\frac{\Delta t}{RC}})$$  \hspace{1cm} (10)

Where: $T_{i+\Delta t}$ represents the water temperature after passing $\Delta t$; $R$ represents the thermal resistance of the water tank, (m$^2$·C/W); $T_{i+\Delta t}^\text{in}$ represents the indoor temperature at the $t+\Delta t$ moment, °C; $C$ represents the heat capacity of the water heater, kWh/°C; $Q$ represents the heating power of the water heater, kW.

3.3.2 Peak model of water heater. The peaking capacity of the water heater is calculated by the following formula.

$$P_{\text{WH-PC}} = \frac{n_0 \cdot \tau}{n_c \cdot \tau} N_0 \cdot Q_{\text{WH}}$$ \hspace{1cm} (11)

Where: $n_0 \cdot \tau$ represents the control duration at the new set temperature; $n_c \cdot \tau$ represents the operating cycle at the new set temperature, similar to 4.1; $N_0$ represents the number of water heaters participating in peak shaving; $Q_{\text{WH}}$ represents the power of the water heater.

3.4. Electric car peak shaving

3.4.1 Influence factors. 1) Number of charge piles. The number of charging piles determines how many electric vehicles can be charged and discharged at the same time, that is, the number of charging piles determines the threshold value of electric vehicles participating in peaking power. The mathematical expression is as follows:

$$S = \begin{cases} n \times P_c^{n,1} & n \leq \bar{n} \\ n \times P_c^{n,1} & n > \bar{n} \end{cases}$$ \hspace{1cm} (12)

Where: $P$ represents the peaking power; $n$ represents the number of charging stations; $\bar{n}$ represents the number of charging stations; $l$ represents the state of the charging electric vehicle, 1 means fast charging, 0 means slow charging.  

2) Distance. Distance between electric vehicle and charging station is one of the influencing factors for electric vehicle users to decide whether to participate in peak shaving. It mainly considers two aspects, one is distance and car loss, and the other is distance and participation in peak shaving.

The relationship between distance and vehicle loss is described by mathematical expression (13).

$$F = F_i - F_o$$  \hspace{1cm} (13)

$$F_i = a + kL_1$$  \hspace{1cm} (13)

$$F_o = a + kL_0$$

Where: $F$ represents the maintenance cost incurred by the electric vehicle to participate in peak shaving, unit: yuan; $F_i$ represents the maintenance cost of the electric vehicle cumulative driving $L_1$, unit: yuan; $F_o$ represents the maintenance cost of the electric vehicle cumulative driving $L_0$, unit: yuan; $a$ represents the fixed maintenance cost of electric vehicles, unit: yuan; $k$ represents the electric vehicle loss factor, unit: yuan / km; $L_1$ represents the cumulative mileage of electric vehicles before peaking, unit: km; $L_0$ indicates electric vehicle participation Cumulative mileage after peak shaving, in kilometers.
The difference between the driving distance consumption and the income from participating in peak shaving is net income, and the net income can be described by mathematical expression (14).

\[
\begin{align*}
Q &= Q_1 - Q_2 \\
Q_2 &= (L_0 - L_i) \times D' \times \frac{P_c}{v}
\end{align*}
\]  

(14)

Where: \(Q\) indicates net income; \(Q_1\) indicates that electric vehicles participate in peaking gains, unit: yuan; \(Q_2\) indicates the cost of electric vehicles participating in peak-shaving travel consumption; \(D'\) indicates electricity price, unit: yuan/Kwh, \(i\) indicates different peaks Period, 1 represents the trough, 2 means the period, 3 means the peak; \(v\) means the electric car is the driving speed, the unit: km / hour.

The difference between the benefit of the electric vehicle participating in peak shaving and the maintenance cost and electricity consumption caused by the distance is equal to the total return, and the total return is expressed by equation (15).

\[M = Q - F\]  

(15)

3) Weather factors. The weather situation mainly considers the impact of electric vehicles participating in peak shaving. First, the weather affects human emotions. This kind of emotion can determine whether electric car users participate in peak shaving to a certain extent. Second, extreme weather conditions affect human safety, such as heavy snow, heavy rain or typhoon. It is a threat to electric car users to participate in peak shaving; the third point, the weather conditions of overheating or too cold will have certain damage to electric vehicles. In summary, the influence of weather conditions on the participation of electric vehicles in peak shaving can be expressed by mathematical expression (16).

\[\theta = e^{-\gamma}\]  

(16)

Where: \(\theta\) indicates the extent to which the weather affects the participation of electric vehicles in peak shaving. The greater the value, the greater the impact of the weather on the peak shaving; \(\gamma\) indicates the weather conditions.

3.4.2 Electric vehicle peak shaving model. From the factor analysis of section 3.4.1, the calculation method of peak shaving capacity of electric vehicles participating in peak shaving can be derived, as shown in equation (17).

\[
S(t) = \begin{cases} 
n' \times P_{c,i} & n' \leq n \\
n' \times P_{c,i} & n' > n \end{cases}
\]  

(17)

Where:

\[
n' = n^{i-1} + \sum_{i=1}^{N} f_{i}
\]  

(18)

\[
f_{i} = \begin{cases} 
1 & f_{M' \cdot f_{SOC'}} \cdot f_{\phi} = 1 \\
0 & f_{M' \cdot f_{SOC'}} \cdot f_{\phi} = 0
\end{cases}
\]  

(19)

\[
f_{M'} = \begin{cases} 
1 & M' \geq M_{\zeta} \\
0 & M' < M_{\zeta}
\end{cases}
\]  

(20)

\[
f_{SOC'} = \begin{cases} 
1 & SOC' \geq SOC_{\zeta} \\
0 & SOC' < SOC_{\zeta}
\end{cases}
\]  

(21)
\[ f_{i'} = \begin{cases} 1 & \text{if } \theta' \leq \theta_c \\ 0 & \text{if } \theta' > \theta_c \end{cases} \] (22)

Where: \( f_{i'} \) indicates the peaking state of the \( i \) electric vehicle at time \( t \); \( f_{i'}=1 \) indicates that it can participate in peak shaving; \( f_{i'}=0 \) indicates that it cannot participate in peak shaving; \( f_{d'} \) indicates the total return state of \( t \) in peak participation; \( f_{d'}=1 \) indicates the total return. It is worth to participate in peaking; \( f_{d'}=0 \) means not worthy of peaking in terms of total revenue; \( M'^t \) is the total return at the moment \( t \), \( M_c \) is the total return threshold; \( f_{soc'} \) indicates the \( SOC \) state of the \( i \) electric car at time \( t \); \( SOC'^t \) indicates the \( SOC \) the \( i \) electric vehicle is at \( t \) time, and \( SOC_c \) the \( SOC \) threshold of the electric vehicle; \( f_{\theta'} \) indicates the weather influence state at \( t \) time, \( \theta'^t \) indicates the weather influence degree value at time \( t \), and \( \theta_c \) indicates the weather influence threshold value.

4. Case simulation and analysis

4.1. Improved particle swarm algorithm

The weight coefficient of particle swarm algorithm determines its optimized global search and local search capabilities. In the early stage of particle swarm algorithm search, the weight coefficient needs to be larger, which can make the particle swarm algorithm have a stronger global search ability, can better avoid falling into the local optimal situation, and require a smaller weight coefficient in the later stage. In this way, the global optimal value can be obtained.

When linear weights balance the global search ability and local search ability of particle swarm optimization algorithm, they appear to be more mechanical and cannot fully reflect the true situation of the search. Some scholars have proposed a nonlinear weighted particle swarm optimization algorithm:

\[
\omega(m) = \omega_{\text{max}} + (\omega_{\text{max}} - \omega_{\text{min}}) \cdot e^{-\left(\frac{m}{\omega_{\text{max}}}\right)^3} \quad (23)
\]

The optimization steps of Zhonghehe participating in peak shaving in office and living parks are as follows:

1) Set the number of particles to 1000; set the number of population, and the number of particles depends on the type of controllable load.
2) Initialize the particle position.
3) Randomly obtain the initial update speed and weight coefficient of particles.
4) Calculate particle fitness. Substitute the generated particles into the objective function to calculate their fitness, and obtain new individual optimal values and overall optimal values.
5) Update the weight coefficient, and update the formula as formula (23).
6) Update the particle position.
7) Determine whether the end condition is met. When the number of iterations reaches the maximum number of iterations, the program terminates and outputs the individual optimal value and the global optimal value, otherwise returns 4).

4.2. Objective function

The purpose of peak shaving is to effectively reduce the load peak-to-valley difference. Therefore, for load characteristics of office and living parks, load fluctuations can be minimized by participating in peak shaving. Minimizing load fluctuations can not only effectively reduce the peak-to-valley difference of the load, but also ensure a smoother load curve. The load fluctuation is equal to the ratio of the standard deviation of the load to the average value of the load. The mathematical expression of the minimum load fluctuation is as follows:

\[ \min f = \min \frac{P_{\text{Lmax}}}{P_{\text{Lavg}}} \quad (24) \]
Where: $PL_s$ is the standard deviation of the load, which reflects the degree of dispersion of the load during this period; $PLav$ is the average of the load, which reflects the concentration of the load during this period of time.

4.3. Case simulation

The rated power of the selected fan is 600Kw, the rated power of the photovoltaic array is 200Kw, and the rated light intensity is 100w/m$^2$, the energy storage capacity on the wind-light side is 300kWh.

Figure 1 is the result of the simulation example. It can be seen from Figure 1 that the load fluctuation is greatly improved, and the peak-valley difference of the load during the peak period is also greatly reduced. Before the source load does not participate in peak shaving, the peak-valley difference in the peak period is 1000kW, and the source load participates in peak shaving After that, the peak-to-valley difference during the peak period was 600kW, which was reduced by 400kW, and the load fluctuation rate was reduced by 4%.

![Figure 1. Equivalent load diagram during peak clipping.](image)

5. Conclusion

In this paper, the output characteristics of wind power and photovoltaic power generation are studied on the micro-power side. On the load side, based on the study of the characteristics of controllable load, the calculation model of peak shaving capacity of electric vehicles, air conditioners, water heaters and refrigerators is analyzed and established. Combined with the research on the source and load side, the minimum load fluctuation rate is established as the objective function, and the improved particle swarm optimization algorithm is used to perform optimization simulation analysis. The results show that source load peaking smoothes load fluctuations and can effectively relieve the peak-shaving pressure of the main power grid.

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7. References

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