Research on Comprehensive Strategy of Microgrid PV Absorption Capability Improvement

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Abstract: As a typical renewable energy, photovoltaic (PV) has developed rapidly due to its permanent, clean and flexible characteristics. However, in the microgrid with a high proportion of PV installed, the difficulty of absorption has always been a hot issue. This paper constructs a photovoltaic microgrid system containing an electric vehicle and introducing a demand response model. Electric vehicles are used as energy storage systems and transferable loads. With the constraints of user satisfaction and the goal of maximizing photovoltaic absorption, the economy of microgrid is also taken into account. The peak, flat and valley time periods of time-sharing tariff are optimized to construct the tariff incentive model, which promotes the movement of the transferable load to the photovoltaic output. Comparing the comprehensive and single effects of energy storage system and demand response and the improved simulated annealing algorithm is used to solve the problem of multivariable nonlinearity. The results show that the combined effect of the two methods can promote the consumption rate and reduce the cost of power generation side and user side, while reducing the emission of polluting gases.

1. Introduction

With the development of society, energy demand is growing. The shortage of fossil resources has led to an increase in the scale of access to renewable energy. Photovoltaic power generation has renewability and good ecological environment affinity. Therefore, the global photovoltaic power generation has increased year by year in recent years, but the difficulty in local absorption has always been the dysentery of the power industry. In 2018, the National Energy Administration of China showed that in the first three quarters, the abandoned light was mainly concentrated in Xinjiang and Gansu. Xinjiang's light rejection rate is 16% and Gansu's light rejection rate is 10%. Therefore, an effective method for improving PV consumption capacity needs to be studied.

At present, many scholars have done a lot of research on the issue of renewable energy absorption from the aspects of power grid planning, demand side management, local control and so on. Starting from the actual load curve and the capacity planning of photovoltaic in a certain place, the maximum photovoltaic absorption capacity of the system feeder is analyzed and the energy storage system is introduced from the perspective of power grid planning. Particle swarm optimization is used to make
the photovoltaic absorption capacity meet the requirements [1]. Taking the electric vehicle as the controllable load, the Monte Carlo algorithm is used to control the charging load of the electric vehicle to absorb the photovoltaic output [2]. By optimizing the management strategy of energy storage and improving the photovoltaic absorption capacity of distribution network, the overvoltage problem caused by excessive photovoltaic output power can be solved [3]. Under the time-sharing electricity price, a multi-time electricity price response model based on electricity price elasticity matrix is constructed, and the charge and discharge strategy of the energy storage system under the time-of-use electricity price and the optimal operation strategy of the photovoltaic micro-grid are proposed [4].

These literatures have achieved certain results in unilateral research on the issue of renewable energy consumption, but they are lacking in terms of the power market and the comprehensive role of electric vehicles. In this paper, in the optimization of microgrid operation with high proportion of photovoltaic and electric vehicles as energy storage systems, the model of demand response is introduced and stratified optimization is carried out. In this paper, we comprehensively consider the role of electric vehicle and demand response model. We use the improved simulated annealing algorithm to solve multi-variable, multi-objective and nonlinear micro-grid optimization operation problems, in order to achieve the goal of increasing photovoltaic absorption rate and improving microgrid economy after satisfying user comfort.

2. Microgrid model and constraints

Microgrid systems are mainly distributed photovoltaics, electric vehicles, and loads. The load is further divided into transferable loads and other loads. The microgrid structure is shown in Figure 1:

![Microgrid structure model](image)

2.1. Distributed photovoltaic output model

As for the PV system, its output power \( P_{PV} \) is strictly influenced by the ambient temperature \( T_{amb} \) and equivalent solar irradiance \( R \), which can be expressed:

\[
P_{PV} = P_{PV,STC} \times \frac{R}{R_{STC}} \times (1 - \gamma \times (T_a - T_r))
\]

\[
T_a = T_{amb} + \frac{R}{R_{STC}} \times (T_{NOC} - 20)
\]

where: \( P_{PV,STC} \) is the maximum power under the standard test condition; \( R_{STC} \) represents the solar irradiance level under the standard test condition; \( \gamma \) is a coefficient and \( T_r, T_a \) and \( T_{NOC} \) are the reference temperature of the PV cells, the actual temperature of PV cells, and the temperature of PV cells under the normal operating condition, respectively.

The PV absorption rate is defined as:

\[
r_{PV} = \frac{\sum [P_{PV}(t) - P_{PV,loss}(t)]}{\sum P_{PV}(t)} \times 100\%
\]
where: \( r_{PV} \) is the PV absorption rate; \( P_{PV}(t) \) is the PV ideal output power; \( P_{PV,loss}(t) \) is the discard power.

2.2. Electric vehicle charging and discharging model

An electric vehicle can be used both as an energy storage device and as a transferable load. When used as an energy storage device, its function is equivalent to a battery. The charge and discharge cannot be performed at the same time.

\[
E(t)^+ = E(t-1) - \Delta T P_{ES}(t) \eta_{in}
\]

\[
E(t)^- = E(t-1) - \Delta T \frac{P_{ES}(t)}{\eta_{out}}
\]

where: \( E(t)^+ \) is the charge during charging; \( E(t)^- \) is the charge during discharge; \( P_{ES}(t) \) is battery power; \( \eta_{in} \) is charging efficiency; \( \eta_{out} \) is discharge efficiency.

2.3. Transferable load model

In order to alleviate the peak-valley gap, this paper adopts the time-sharing tariff incentive policy to encourage users to transfer some flexible loads during peak period to peak period of power consumption or peak period of new energy output. Therefore:

\[
\begin{cases}
L_{in}(t) \geq 0, \text{when } P_{pv} > L \\
L_{out}(t) \geq 0, \text{when } P_{pv} < L
\end{cases}
\]

where: \( L_{in}(t), L_{out}(t) \) are the load transferred in and the load transferred out at the \( t^{th} \) moment.

2.4. Constraints of microgrid

1) Power balance constraints

\[
P_{PV} + P_{N} + E^+ = L_0 - L_{out} + L_{in} + E^-
\]

where: \( P_{PV} \) is the electricity purchased from the grid; \( L_0 \) is the initial load.

2) Safety and reliability constraints

If the microgrid wants to operate safely and reliably, the capacity and branch power flow of the energy storage system should be within a limited value.

\[
\begin{cases}
P_{Z,j}^{min} < P_{Z,j} < P_{Z,j}^{max} \\
S_{min} < S_i < S_{max}
\end{cases}
\]

Where: \( P_{Z,j} \) is the power flow of the \( j^{th} \) branch, \( S_i \) is the stored electrical energy.

3) Energy storage system power constraint

\[
\begin{cases}
0 \leq E^+ \leq E_{max}^+ \\
0 \leq E^- \leq E_{min}^- \\
E^+ \leq P_{PV} - L
\end{cases}
\]

where: \( P_{PV} \) is the photovoltaic output; \( L \) is the load.

3. Demand response model and constraints

3.1. Demand response model

Assuming that the time-of-use electricity price is implemented, the load will only shift and the total amount will not decrease. Define the load transfer rate as the ratio of the load from the high electricity price period to the low tariff period and the high electricity price load after the implementation of the peak and valley tariff. The load under the time-sharing electricity price in each time period is:
where: $\mu_{fg}$, $\mu_{fp}$, $\mu_{pg}$ is peak-valley, peak-flat and flat-valley transfer rates respectively; $L_{f0}$, $L_{p0}$ are the average values of the load during the peak period and the flat period of the time-of-use electricity price; $T_f$, $T_p$, $T_g$ are the peak, flat and valley periods of electricity prices.

**3.2. Restrictions**

The comfort reflects the change of the user's electricity habits. When the time-of-use tariff is not implemented, the user has the greatest comfort when using electricity according to the general habit. After implementing the time-of-use tariff, the tariff incentive changes the user's electricity habits and the comfort is reduced. User comfort ranges from 0 to 1. Its expression is as follows:

$$\beta = 1 - \frac{\sum_{i=1}^{24} |L_{i(f,p,g)} - L_0|}{\sum_{i=1}^{24} L_0} \quad \beta \in [0,1]$$

where: $\beta$ is the user comfort, $\beta=1$ indicates that the load curve has not changed before and after the implementation of the time-of-use tariff. $L_0$, $L_{i(f,p,g)}$ are the loads before and after the implementation of the time-of-use tariff.

**4. Improved simulated annealing algorithm and solution process**

**4.1. Improved simulated annealing algorithm**

The iterative mechanism of the basic simulated annealing algorithm may discard the historical optimal solution. Therefore, the historical optimal solution is recorded simultaneously in the iterative process and the historical optimal solution is output together with the result of the iteration stop after the iteration ends. The electricity price is a discrete value with a minimum unit of 0.01 yuan / (kW * h), so the annealing search may repeatedly calculate the value taken. In this regard, reading the historical results avoids double counting, which can effectively reduce the amount of calculation.

**4.2. Hierarchical optimization solution process**

This paper proposes a two-layer optimization model that takes the user satisfaction as the constraint and takes into account the PV absorption rate and the microgrid economy. The optimization of the upper and lower layers is interrelated. Calculate the initial load curve and pass it to the lower layer. The lower layer is targeted at the lowest power generation cost and is sent back to the upper layer with the corresponding PV absorption rate. After the upper layer obtains the feedback PV absorption rate, the simulated annealing algorithm is used to further search for the optimal tariff setting value. This process is repeated until the annealing order is as shown in Figure 2.
5. Case study

5.1. Case overview
This paper focuses on the combined effects of the two on PV absorption capacity. Scenarios have been established in which only the energy storage system functions, only the demand response functions and both function. The photovoltaic absorption rate and electricity purchase fee under three scenarios are studied and the combined effects and single effects of the two are compared in terms of PV absorption capacity. The maximum, minimum and initial power of all electric vehicles in the micro-grid as energy storage devices are 160, 20, 80 kW*h and the maximum discharge power is 40 kW*h. The PV installed capacity is 150kW. The PV output curve data is based on the forecast data.

5.2. Optimization results and analysis
Before the optimization, the price of the microgrid is a fixed price, which is 0.60 yuan. For the optimization of time-sharing tariff, the simulated annealing algorithm is adopted. The step size parameter \( \eta \) in the simulated annealing algorithm is set to 0.5, the initial temperature \( T_0 \) is taken as 100 and \( \alpha \) is 500; the optimized peak, flat, valley time and tariff are shown in Figure 3. The optimization results of tariff show that the optimal time division of time-of-use tariff is related to the PV predicted power. The larger period of PV is the time of electricity price in the valley, the smaller period of PV is the period of normal electricity price and the zero period of PV is the peak electricity price period.

Figure 4 is a graph of the load curve before and after the PV output and demand response. It can be seen that after adopting the demand response model, the load changes from 135.64 kW to 105.24 kW at night peak. It shows that the response behavior of the demand side to the tariff promotes the movement of the partial load and the transferable load is transferred out during the peak load period. When the photovoltaic output is large, the transferable load is transferred, so that the net power of the photovoltaic output to remove the load becomes smaller, so that the load curve is closer to the photovoltaic output curve in time series.
Figure 5 is a result of charging and discharging when an electric vehicle is used as an energy storage device. It can be seen that when the photovoltaic output during the day is greater than the load, the electric vehicle performs energy storage. When the photovoltaic output drops to zero at night, the electric vehicle is discharged as an energy storage device for the load to use and is insufficient to purchase from the power grid. After the optimization of this paper, the energy storage system is more effective in the peak load, the charge and discharge cycle is more reasonable, and the peak-filling ability is fully exerted.

In this paper, we study the three kinds of optimal scheduling results considering only the demand response, only the energy storage system and the combination of the two, obtaining the comparison results of the electricity purchase cost and the PV absorption rate. As we can be seen from Figure 6, the user's electricity purchase cost in scenario 3 is the lowest, at 46,012 yuan; the photovoltaic absorption rate is the highest at 92%; the power generation cost is also reduced at the most, at 72.46 yuan. It shows that the combined effect of the two has the best PV absorption capacity for the microgrid, which can effectively reduce the amount of discard photovoltaic and achieve the best economical efficiency within the acceptable range of user comfort. Therefore, although the model proposed in this paper aims to improve the PV absorption rate, it is more economical because of the reduction in electricity purchase.

Figure 6. Optimal scheduling results under three scenarios

6. Conclusion
A high proportion of photovoltaics in the microgrid will bring about the problem of photovoltaic absorption. This paper compares the combined role and single role of an electric vehicle as both an energy storage device and a demand response. Taking the user satisfaction as the constraint, taking the
maximum PV consumption rate as the goal and taking the economics of the microgrid into account, a two-layer optimization model is constructed. The improved simulated annealing algorithm is used to solve the model. The optimization results of tariff show that the optimal time division of time-of-use tariff is related to the PV predicted power. The larger period of PV is the time of tariff in the valley, the smaller period of PV is the period of normal tariff and the zero period of PV is the peak tariff period. The comparison between the two examples shows that the combined effect of the two can improve the photovoltaic local absorption rate and reduce the power generation cost of the microgrid. The user's response to the time-of-use tariff policy reduces the user's electricity bill, achieving a win-win situation between the power generation side and the user side, improving the overall economic benefits of the microgrid. At the same time, the increase in the utilization rate of new energy sources has also reduced the emission of polluting gases and has considerable environmental benefits.

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