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Research on hybrid energy storage and demand response strategy of high proportion solar energy microgrid

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Abstract: *In response to the impact of the increasing proportion of new energy generation in the current microgrid, the application of hybrid energy storage devices to optimize and adjust such microgrids has become a trend. Based on this, the article conducts research on microgrid systems containing a high proportion of wind and photovoltaic power generation, introduces energy storage systems to optimize the microgrid on the existing basis, and determines peak shaving and valley filling, reducing operation and maintenance costs, and reducing electricity costs as the main optimization objectives. Using multi-objective analysis methods for modeling and analysis, targeted optimization of demand response strategies is carried out. From the simulation analysis results, it can be seen that the optimization strategy has basically achieved the expected goals, indicating that this study has potential application value.It is expected to be gradually promoted and applied in the subsequent construction of microgrids.*

Keywords: *microgrid; hybrid energy storage; response strategy*

1. Introduction

The characteristics of intermittence, randomness and volatility of photovoltaic power generation wind power generation system are more prominent, and the impact on the existing distribution network more significant.So we need to adjust the demand response strategy of such microgrid to ensure that microgrid is always in an efficient and stable operation state.

2. Analysis of the basic architecture of the microgrid

It is mainly for the microgrid with a high proportion of photovoltaic power generation and wind power generation. The microgrid is equipped with hybrid energy storage device and power supply for load units. The overall architecture is shown in Figure 1

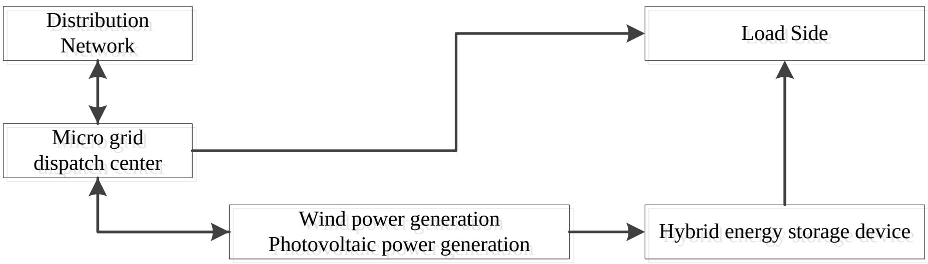

Figure 1 Schematic diagram of the basic architecture of the microgrid

In the operation process of the microgrid, the following requirements are set: (1) the lithium battery pack in the hybrid energy storage device shall have the relative minimum daily operation cost; (2) the peak-valley difference of the daily load curve of the microgrid shall be reduced as far as possible; and the load end of the microgrid shall have the relative minimum daily electricity cost. Based on the above objectives, the demand response strategy of hybrid energy storage of this high proportion of solar microgrid is studied[1-2].

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3. Demand response strategy design

3.1 Power analysis of microgrid

Due to the outstanding intermittent, randomness and volatility characteristics of photovoltaic power generation and wind power generation system, the output power of the microgrid is not constant and cannot be fitted through conventional functions. For this purpose, a three-layer BP neural network is applied to predict the power value, and the model of this network is shown in the Figure 2.

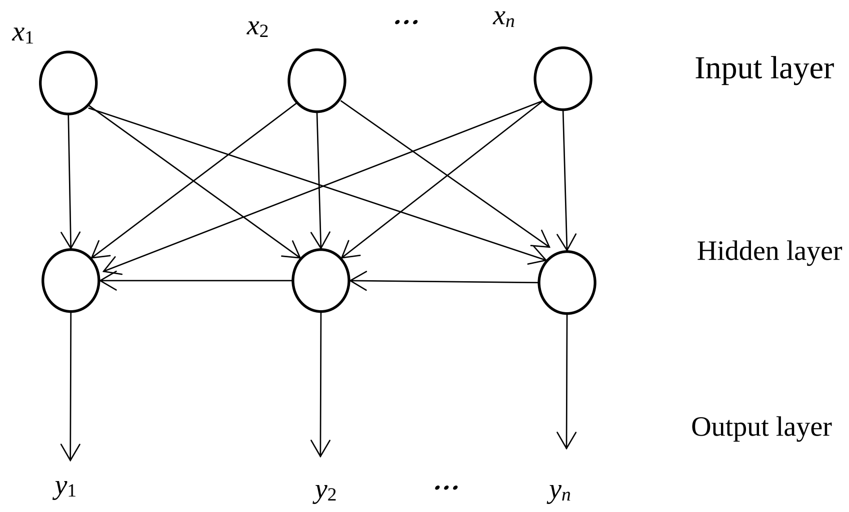

Figure 2. Schematic diagram of the three-layer BP neural network

According to the three-layer BP neural network architecture, the microgrid power analysis is conducted as follows: (1) capture the historical data of the microgrid to obtain the wind power, photoelectric power and total load power data of recent three years; (2) set the training sample to 1344 groups and test sample to 96 groups and normalize the training sample and test sample data; (4) refer to figure 2 and set the parameters for training; (5) apply BP neural network for prediction, and normalize the prediction results; (6) compare the true value with the predicted value of the test set, Output result after the error value meets the requirements[3-4].

3.2 Objective function design of the microgrid model

Based on the operation objectives of the microgrid set in Chapter 1, the objective functions are designed as follows:

First, the daily operation and maintenance cost is minimized by the objective function. Combined with the operation characteristics of the lithium battery, the U-shaped average cost curve is applied for analysis, and the expression of the objective function is obtained as follows:

$$min\ f_1 = \rho_{om2} \times \sum_{j=1}^{Nba} C_{ba}(j) \tag{1}$$

$$\rho_{om2} = \rho_{om1} \times \left(\frac{k}{exp(V_a)} + \frac{exp(V_a)}{k} \right) \tag{2}$$

$$\rho_{om1} = \rho_{inv} \times E_{ba} \times k_{om} \times \frac{r(1+r)^{Y_e}}{(1+r)^{Y_e} - 1} / \left(\frac{n}{Y_e} \right) \tag{3}$$

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$$V_a = \frac{1}{N_{ba}-1}\sum_{j=1}^{N_{ba}}\left(C_{ba}(j) - \frac{1}{N_{ba}}\sum_{j=1}^{N_{ba}}C_{ba}(j)\right)^2 \tag{4}$$

$$\rho_{ela}(t) = \rho_{rig} \times exp\left(k \times \frac{P_{buy1}^{ela}(t)}{P_{ela1}(t)}\right) \tag{5}$$

In the above expressions, ρ om1 and ρ om2 represent the operation and maintenance cost of the fixed unit cycles of the lithium battery pack respectively; k represents the proportional parameter in the demand side price response function; Va represents the variance of the daily cycle number of each lithium battery unit; Cba (j) represents the daily cycle number of the j lithium battery unit; and Nba represents the number of units included in the lithium battery pack. In addition, ρ inv, Eba, kom, r, Ye and N respectively represent the investment cost, rated capacity, operation and maintenance cost coefficient, interest rate, theoretical service life, and theoretical cycle times of lithium battery unit. In addition, Prig, ρela (t), ρelabuy1 (t) and ρela1 (t) respectively represent the rigid price, real-time price, the grid power purchased when the real-time price reaches the upper limit, and the additional power of renewable energy generation at time t.

Second, the objective function minimized the peak and valley difference of the daily load curve of the grid, whose expression is as follows.

$$min\ f_2 = \max_{t=1\sim T}\left(P_{load}^{aft}(t)\right) - \min_{t=1\sim T}\left(P_{load}^{aft}(t)\right) \tag{6}$$

$$P_{load}^{aft}(t) = P_{load}(t) + P_{ela}^{up}(t) - P_{ela}^{down}(t) - P_{sc}^{cha}(t) - P_{ba}^{cha}(t) \tag{7}$$

$$P_{ela}^{up}(q) = 0, q \in S_{et,2}; S_{et,2} = \{t \mid P_{gap}(t) \geq 0\} \tag{8}$$

$$0 \leq P_{ela}^{up}(q) = \sum_{s \in S_{et,2}} P_{ela}^{tran}(s,q) \leq -P_{gap}(q) \tag{9}$$

$$0 \leq P_{ela}^{down}(q) = \sum_{s \in S_{et,1}} P_{ela}^{tran}(s,q) \leq P_{gap}(s); S_{et,1} = \{t \mid P_{gap}(t) < 0\} \tag{10}$$

$$P_{ela}^{down}(s) = 0; s \in S_{et,1} \tag{11}$$

$$P_{sc}^{cha}(t) = \sum_{i=1}^{Nsc} P_{sc,j}^{cha}(t), P_{ba}^{cha}(t) = \sum_{i=1}^{Nba} P_{ba,j}^{cha}(t) \tag{12}$$

In the above expression, Equation (6) represents the process of transferring partial load during "peak shifting"; the value of T is 96, which is 96 equal to the time of the day. Paftload (t) represents the total load after the load load; Plot (t) represents the initial value of the total load; Pupela (t) represents the load transferred from the peak period; Pdownela (t) represents the load transferred to the trough period; Pchasc (t) and Pchaba (t) represent the supercapacitors and lithium batteries in the hybrid energy storage module Charging power of the group; Ptranela (s, t) represents the load power transferred from time s to time t. Pchasci (t) represents the charging power of the i-th supercapacitor unit; Pchabaj (t) represents the charging power of the j-th lithium battery unit; Nsc represents the number of units contained in the supercapacitor bank.

Third, the daily power consumption cost of the load end users is compressed to the lowest level, and the expression is as follows:

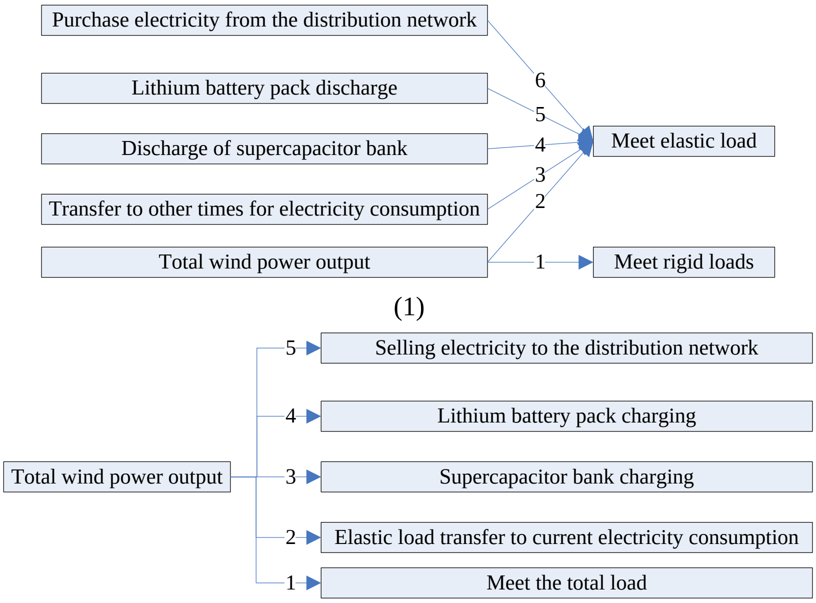
$$min\ f_3 = \sum_{t=1}^{T}\begin{pmatrix} \rho_{rig} \times \left(P_{wt}(t) + P_{pv}(t)\right) + \\ \rho_{rig} \times \left(P_{ela}^{down}(t) + P_{sc}^{dis}(t) + P_{ba}^{dis}(t)\right) + \\ \rho_{ela}(t) \times P_{buy1}^{ela}(t) + \rho_{pel}(t) \times P_{buy2}^{ela}(t) \end{pmatrix} \times \Delta t \tag{13}$$

$$P_{sc}^{dis}(t)=\sum_{i=1}^{N_{sc}}P_{sci}^{dis}(t),P_{ba}^{dis}(t)=\sum_{i=1}^{N_{ba}}P_{baj}^{dis}(t) \quad (14)$$

In the above expression, the expression (13), the four from before to after respectively by new energy (this refers to the photovoltaic and wind power two parts, similarly hereinafter) to meet the load power cost, load transfer after the total cost, distribution network purchase power cost, and excess punitive costs. Meanwhile, Pelabuy2 (t) indicates the additional power purchased from the external distribution network under the maximum limit; ρ pel indicates the punitive electricity price after exceeding the maximum limit; △ t represents the time interval of 15min.In addition, in expression (14), the two indicators to the left of the equal sign represent the discharge power of the i-th capacitor and the jth lithium battery unit, respectively.

3.3 Constraint condition setting

After the target optimization function is determined, combined with the actual operation characteristics of the microgrid system, the following constraints are set for this study, as shown in Figure 3.



(2)

Figure 3 Order diagram of power output and load satisfaction with lower than load (1) and higher than load (2)

The number in Figure 3 represents the sequence number, and the smaller the number, the higher the priority of the sequence.

3.4 Solution method design

Due to the design of the three optimization goals of the importance must have certain differences, so first determine the weight of each optimization target, the process and results are shown in Table 1 and Table 2 respectively.

Table 1 Shows the process of determining the weight coefficient by using the judgment matrix

Goal	F1	F2	F3
F1	1	37/76	37/45
F2	76/37	1	76/45
F3	45/37	45/76	1
	4.2703	2.0789	3.5111

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Table 2 Determines the results of the weight coefficient by using the judgment matrix

Parameter	π1	π2	π3
Value	0.4003	0.7370	0.2342
	3.4691	1.5138	0.4810
	0.7201	0.8963	0.2848
		3.1471	3.000027

After the consistency test based on the results in Table 2, it is determined that the consistency test result is less than 0.1 and meets the analysis requirements. Therefore, the last column in Table 2 is the weight values of the three indicators, which are 0.2342,0.4810 and 0.2848 respectively. On this basis, the multi-objective linear weighting method is applied for the linear weighting treatment of the above three indexes to establish a new single objective F as the final objective of this analysis.Based on the above conditions, the natural selection-based particle swarm algorithm (Particle Swarm Optimization, PSO) is used to solve the demand response strategy model[5].

4. Simulation analysis results and discussion

In the process of simulation analysis, combined with the actual operation of the micro grid, the simulation analysis parameters are set as follows: the maximum output power of the wind turbine is 2000kW, and the maximum output power of the photovoltaic generator is 1000kW. The hybrid energy storage device is composed of 5 supercapacitor packs and 5 lithium battery packs. The specific parameters are shown in the table.

Table 3 Parameters table of the hybrid energy storage device

parameter	Supercapacitors	Supercapacitors
power rating /kW	30	250
rated capacity/kWh	120	350
SOC superior limit	0.9	0.8
SOC lower limit	0.1	0.2
Initial SOC values	(0.27,0.13,0.64,0.64,0.84,)	(0.33,0.22,0.60,0.60,0.76)

After the above conditions are set, the load power of the microgrid is first predicted based on the BP neural network model in Section 3.1, and the prediction results are shown in Figure 4.

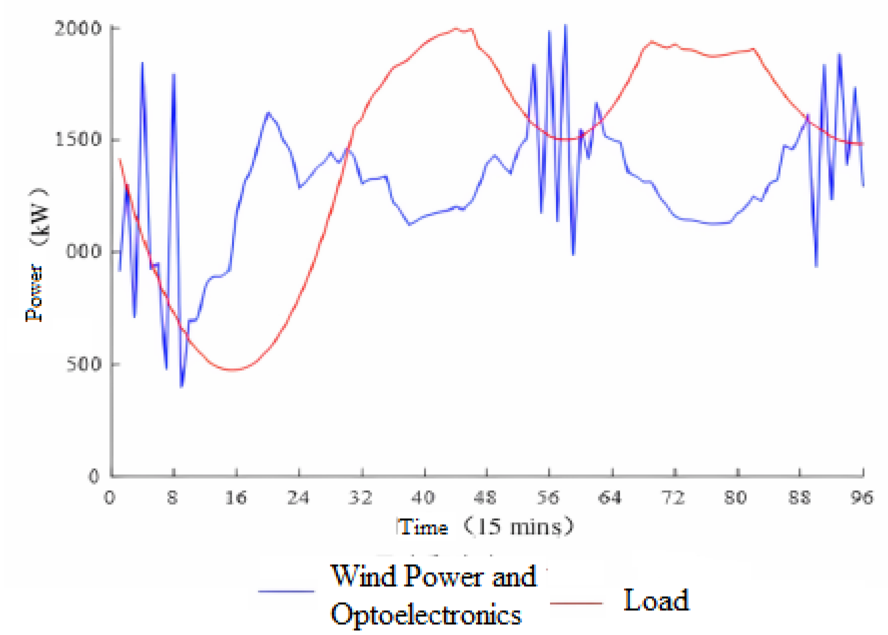

Figure 4 Forecast results of wind power, photoelectric power and total load power

Based on the prediction results, the operation of wind power, photovoltaic and energy storage units is scheduled according to the above optimized scheduling scheme to meet the demand response, and thus the changes of the total load and the generating power of renewable energy are shown in Figure 5

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and Figure 6 respectively.

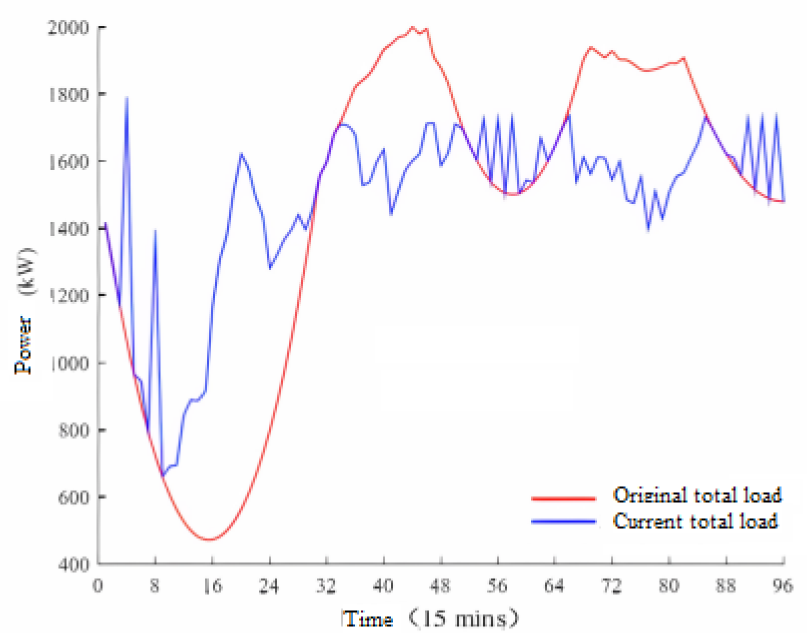

Figure 5 Change diagram of total load

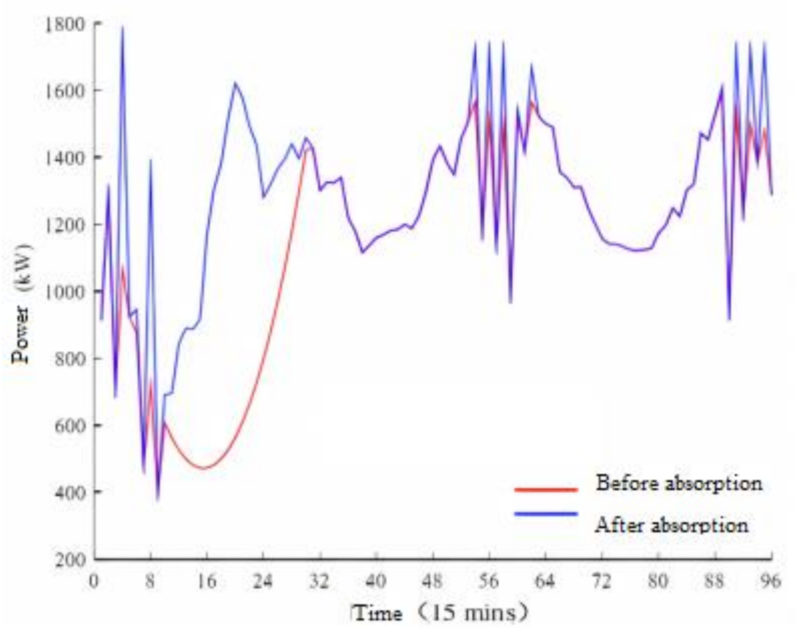

Figure 6 Power generation change diagram of renewable energy sources

According to figure 5, after the application of the demand response strategy, daily load curve peak valley rate from the initial value of 76.39% to 62.28%, the gap between the two data is significant, shows that the demand response strategy played a certain peak filling effect, make the peak part of the load transfer to other moments, it also shows that the new energy power generation module played a role. At the same time, according to Figure 6, the daily new energy generation absorbed in the microgrid increased by about 12.7%. Therefore, the load curve and the renewable energy output curve are better matched in the time dimension.

5. Conclusion

In general, in this research work, the cost reduction and peak load shifting and valley filling are determined as the main goals, and the optimal scheduling strategy is obtained through multi-objective

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modeling and solution. From the simulation analysis results, this optimized dispatching strategy has basically achieved the expected goal, which is helpful to improve the actual operation quality of the microgrid.

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