Capacity allocation of HESS in micro-grid based on ABC algorithm

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Abstract

The hybrid energy storage system (HESS) is a key component for smoothing fluctuation of power in micro-grids. An appropriate configuration of energy storage capacity for micro-grids can effectively improve the system economy. A new method for HESS capacity allocation in micro-grids based on the artificial bee colony (ABC) algorithm is proposed. The method proposed a power allocation strategy based on low pass filter (LPF) and fuzzy control. The strategy coordinates battery and supercapacitor operation and improves the battery operation environment. The fuzzy control takes the state of charge (SOC) of the battery and supercapacitors as the input and the correction coefficient of the time constant of the LPF filter as the output. The filter time constant of the LPF is timely adjusted, and the SOC of the battery and supercapacitor is stable within the limited range so that the overcharge and over-discharge of the battery can be avoided, and the lifetime of the battery is increased. This method also exploits sub-algorithms for supercapacitors and battery capacity optimization. Besides, the Monte Carlo simulation of the statistic model is implemented to eliminate the influence of uncertain factors such as wind speed, light intensity and temperature. The ABC algorithm is used to optimize the capacity allocation of hybrid energy storage, which avoids the problem of low accuracy and being easy to fall into the local optimal solution of the supercapacitors and battery capacity allocation sub-algorithms, and the optimal allocation of the capacity of the HESS is determined. By using this method, the number of supercapacitors required for the HESS is unchanged, and the number of battery is reduced from 75 to 65, which proves the rationality and economy of the proposed method.

Keywords: HESS; capacity allocation; fuzzy control; ABC

INTRODUCTION

The randomness, volatility and uncertainty of renewable energy such as wind and light have always been the main reasons restricting their large-scale grid connected operation [1]. As an important component of the micro network, the energy storage system can significantly improve the power system’s cancellation level of the renewable energy and reduce the impact of the new energy grid on the grid. It has become one of the key technologies to promote the replacement of the main energy from the fossil energy to the clean energy [2].

At present, HESS consisting of battery and supercapacitor is used to stabilize the power fluctuation of the micro-grid. However, the cost of energy storage is high, and choosing the appropriate energy storage capacity is helpful to reduce costs and improve system economy [3]. To ensure the reliability and reduce the cost of the system, a particle swarm optimization algorithm is used to configure the battery capacity in the hybrid system [4]. In reference [5], a configuration method of supercapacitor based on expected power and energy characteristics on an electric train is proposed. In reference [6], it achieves the maximum market revenue from energy arbitrage with the minimal expended life cost by guaranteeing the optimal economic profit by finding the optimal DNC and DOD. In reference [7], the low-pass filtering method is used to suppress the fluctuation of the output power of photovoltaic power generation. At the same time, when the life of energy storage devices is variable, the economy of capacity allocation of a hybrid energy storage system in photovoltaic power generation is studied. In reference [8], considering the state of charge of energy storage and the limitation of charge and...
discharge power, a power allocation strategy based on spectrum analysis is proposed, an economic evaluation model is established and the capacity allocation of diesel generator and energy storage is optimized.

The above methods are based on deterministic analysis, which may lead to inconsistent results. Compared with the traditional hybrid energy storage capacity allocation method, statistical analysis takes into account many uncertainties in the configuration process, which improves the conservatism of the traditional algorithm. In reference [9], a probability method of energy storage capacity allocation based on the uncertainty of wind energy prediction is proposed. In reference [10], a configuration method based on the cutoff normal distribution method for energy storage system capacity is studied to suppress the wind power prediction error and reduce the cost. The capacity allocation of HESS using statistical methods shows that the optimal capacity can be flexibly selected according to operation requirements [11].

In this paper, a micro-grid with photovoltaic generation and wind power generation is selected as the research object, and a method for HESS capacity optimization based on Monte Carlo artificial bee colony (ABC) algorithm is proposed. This method divides the power required by the HESS into high-frequency and low-frequency parts by using the LPF-based power allocation strategy. The high-frequency power is compensated by the supercapacitor, and the low-frequency power is compensated by the battery; the fuzzy control reduces the charge and discharge cycle of the battery and extends its lifetime. This method also explores the capacity optimization sub-algorithms for batteries and supercapacitors, and a statistical model is used to describe the rated power and capacity of energy storage equipment. The ABC algorithm is used to optimize the capacity configuration of HESS, which avoids the problem of low accuracy and being easy to fall into the local optimal solution of the supercapacitor and battery capacity allocation sub-algorithms, and the optimal capacity optimization of HESS in micro-grids is determined. The simulation results verify the rationality and economy of the method.

2 MICRO-GRID SYSTEM MODEL

The micro-grid system studied in this paper is composed of a photovoltaic power generation system, wind power generation system, load and hybrid energy storage system. The structure is shown in Figure 1, in which the hybrid energy storage system is composed of battery energy storage and supercapacitor.

2.1 Photovoltaic generation system model

The output power of photovoltaic array is mainly related to light and temperature and can be expressed as follows: Equation: The output power of photovoltaic array

\[
P_{PV}(t) = n_{PV} P_t \left( \frac{R_c(t)}{R_r} \right) [1 + k (T_c(t) - T_r)]
\]

(1)

where

- \( n_{PV} \) = the number of photovoltaic cells
- \( P_t \) = rated output power of PV array (W)
- \( R_c(t) \) = light intensity of t moment (Lx)
- \( R_r \) = rated light intensity under standard environment (Lx)
- \( T_c(t) \) = temperature of the t moment (°C)
- \( T_r \) = rated temperature under standard environment (°C)
- \( K \) = power temperature coefficient

2.2 Wind power generation system model

The output power of wind power model is generally represented by a piecewise function.

\[
w_t = \begin{cases} 
0 & 0 \leq v(t) < v_1 \text{ or } v(t) > v_0 \\
n \frac{v^3 - v_0^3}{v_1^3 - v_0^3} & v_1 \leq v(t) < v_2 \\
\frac{v_r^3 - v}{v_r^3} & v_r \leq v(t) < v_0 
\end{cases}
\]

(2) Equation: The output power of wind power

where

- \( P_r \) = rated power of fan (W)
- \( v_r \) = rated wind speed of fan (m/s)
- \( v_1 \) and \( v_0 \) = cut-in and cut-out wind speed of the fan (m/s)

2.3 HESS model

It is assumed that the battery terminal voltage will remain unchanged throughout the battery charging and discharging processes. The working state of the battery is divided into charging and discharging states.

\[
SOC_{bat}(t + 1) = SOC_{bat}(t) - \Delta t \frac{P_{dbat}}{\eta_d}
\]

(3) Equation: SOC of battery when discharging

\[
SOC_{bat}(t + 1) = SOC_{bat}(t) + \Delta t P_{cbat} \eta_c
\]

(4) Equation: SOC of battery when charging

where

- \( P_{cbat} \) and \( P_{dbat} \) = the charge and discharge power of the battery in T period (W)
- \( \eta_c \) and \( \eta_d \) = the charge and discharge efficiency of the battery in \( t \) period.

Similarly, when the supercapacitor is charged and discharged, it meets the following:

\[
SOC_{sc}(t + 1) = SOC_{sc}(t) - \Delta t \frac{P_{dsf}}{\eta_d}
\]

(5) Equation: SOC of supercapacitor when discharging
Capacity allocation of HESS in micro-grid based on ABC algorithm

\[ \text{SOC}_{sc}(t+1) = \text{SOC}_{sc}(t) + \Delta t P_{csc} \eta_c' \]

(6) Equation: SOC of supercapacitor when charging

where
- \( P_{csc} \) and \( P_{dsc} \) = the charge and discharge power of the supercapacitor in \( T \) period (W)
- \( \eta_c' \) and \( \eta_d' \) = the charge and discharge efficiency of the supercapacitor in \( t \) period.

\[ P_J(t) = P_L(t) - P_{WT}(t) - P_{pv}(t) \]

(7) Equation: The power that HESS needs to adjust

where
- \( P_L(t) \) = Load power at time \( t \) (W)

The process of power allocation is first to sample the power that HESS needs to adjust, and the sampling period is 10 min. Secondly, the discrete Fourier transform is applied to the sample data \( P_J = [P_J(1), P_J(2), \ldots, P_J(t), \ldots, P_J(N)] \), and the result of spectrum distribution is obtained.

\[ S = \text{DFT} \{ P_J \} = [S_J(1), \ldots, S_J(n)] \]

\[ f_J = [f_J(1), \ldots, f_J(n), \ldots, f_J(N)] \]

(8) Equation: Fourier transform

where
- \( \text{DFT}(P_J) \) = discrete Fourier transform of data \( P_J \)
- \( S_J(n) \) = the amplitude of the corresponding \( n \)th frequency after DFT

Finally, the Fourier inverse transform is used to convert the amplitude frequency results of each compensation band to the time domain, then the power situation of each frequency band can be obtained, and the power instruction of each energy storage device is obtained.

3 HESS POWER ALLOCATION STRATEGY

3.1 Power allocation strategy based on LPF

This paper uses HESS to maintain instantaneous power balance and achieve power distribution. The power distribution is based on the power requirements of the load and the output power of the distributed power supply to calculate the power that the HESS needs to stabilize, as shown in Equation 7. The LPF divides the frequency band into high frequency and low frequency, as shown in Figure 2. The low frequency part is provided with power compensation by battery, and the high frequency part is provided with power compensation by the supercapacitor. The supercapacitor compensates for the short-time high-frequency power fluctuation. The battery only needs to compensate for the long-time low-frequency power fluctuation, which improves the operating environment of the battery and extends its lifetime.

3.2 Time parameter adjustment based on fuzzy control

When the LPF is used, due to the fixed value of the time constant \( T \) of the filter, it is very easy to lead to overcharge and overdischarge without considering the SOC of the energy storage unit. In this paper, the SOC is considered and the filter time constant \( T \) is corrected according to the SOC size of the battery and the supercapacitor, so that the SOC of the units are always stable in a certain range. Therefore, the SOC limit value is set to be as follows:

\[ \text{SOC}_{sc\_min} \leq \text{SOC}_{sc} \leq \text{SOC}_{sc\_max} \]

(9) Equation: SOC of supercapacitor
When $P_J(t) < 0$, HESS needs to absorb energy. If $\text{SOC}_{\text{bat}}$ and $\text{SOC}_{\text{sc}}$ are intermediate values, maintain the default $T$ constant. When $\text{SOC}_{\text{bat}}$ is a minimum and $\text{SOC}_{\text{sc}}$ is a maximum, $T$ is properly reduced to increase the charging power of the supercapacitor. When $\text{SOC}_{\text{bat}}$ is the maximum and $\text{SOC}_{\text{sc}}$ is a minimum, $T$ is properly adjusted to increase the charging power of the supercapacitor.

When $P_J(t) > 0$, HESS needs to release energy. If $\text{SOC}_{\text{bat}}$ and $\text{SOC}_{\text{sc}}$ are intermediate values, maintain the default $T$ constant. When $\text{SOC}_{\text{bat}}$ is a minimum and $\text{SOC}_{\text{sc}}$ is a maximum, $T$ is properly adjusted to reduce the charging power of the supercapacitor. When $\text{SOC}_{\text{bat}}$ is the maximum and $\text{SOC}_{\text{sc}}$ is a minimum, $T$ is properly reduced to increase the charging power of the supercapacitor.

In this paper, a fuzzy controller is added on the basis of the LPF control. According to the SOC of the battery and the supercapacitor and the current charge/discharge status of the system, the filter time constant $T$ is changed in real time so that the SOC of the energy storage unit is stable within the limited range. As shown in Figure 3.

a) Establish input, output fuzzy subsets and membership functions

In this paper, $\text{SOC}_{\text{bat}}$ and $\text{SOC}_{\text{sc}}$ are selected as input, and the correction coefficient $\Delta \varnothing$ of time fixed value is the output. First $\text{SOC}_{\text{bat}}$ and $\text{SOC}_{\text{sc}}$ are normalized, and the membership degree of SOC of the energy storage units are as follows:

\[
\mu_{\text{bat}} = \frac{\text{SOC}_{\text{bat}} - \text{SOC}_{\text{bat\_mid}}}{\text{SOC}_{\text{bat\_mid}} - \text{SOC}_{\text{bat\_mid}}}
\]

(11) Equation: Battery membership degree

\[
\mu_{\text{sc}} = \frac{\text{SOC}_{\text{sc}} - \text{SOC}_{\text{sc\_mid}}}{\text{SOC}_{\text{sc\_mid}} - \text{SOC}_{\text{sc\_mid}}}
\]

(12) Equation: Supercapacitor membership degree

where

- $\text{SOC}_{\text{bat\_mid}}$ and $\text{SOC}_{\text{sc\_mid}}$ = intermediate values of $\text{SOC}_{\text{bat}}$ and $\text{SOC}_{\text{sc}}$

$\mu_{\text{bat}}$ and $\mu_{\text{sc}}$ are used as inputs for fuzzy control, and the fuzzy sets of input are set to $\{\text{NL}, \text{ZE}, \text{PL}\}$, the corresponding domains of $\mu_{\text{bat}}$ are $[-m, m]$, the corresponding domains of $\mu_{\text{sc}}$ are $[-n, n]$, and $m$ and $N$ are both between 0 and 1. In general, the charge/discharge depth of the supercapacitor is greater than that of the battery, so $n > m$. $\Delta \varnothing$ is the output of fuzzy control, and the fuzzy sets are $[-0.98, -0.4, 0, 0, 0.4$ and $0.98]$. Whether $P_J(t)$ is greater or less than zero, its input membership function and output membership function are the same, as shown in Figure 4.

b) Formulate fuzzy rules

From the case where $P_J(t)$ is greater than zero and less than zero respectively; the fuzzy rules are formulated, as shown in Tables 1 and 2.

c) Defuzzification

![Figure 3. Fuzzy control schematic diagram.](image)

![Figure 4. Input/output of membership function.](image)

**Table 1. Fuzzy control rules ($P_J(t) < 0$).**

| $\text{SOC}_{\text{bat}}$ | $\text{SOC}_{\text{sc}}$ | $\Delta \varnothing$ |
|-------------------------|-------------------------|---------------------|
| NL                      | ZE                      | NS                  |
| ZE                      | PS                      | ZE                  |
| PL                      | PL                      | PS                  |

![Equation: SOC of battery](equation)

$\text{SOC}_{\text{bat\_min}} \leq \text{SOC}_{\text{bat}} \leq \text{SOC}_{\text{sc\_max}}$
Table 2. Fuzzy control rules ($P_1(t) > 0$).

| SOCbat | SOCsc | PL | ZE | NS | PS |
|--------|-------|----|----|----|----|
| NL     | ZE    | PS | PL | ZE | ZE |
| ZE     | NS    | ZE | ZE | PL | NE |

The correction coefficient $\Delta \psi$ of reference power is obtained by using the weighted average method for defuzzification calculation, $-1 < \Delta \psi < 1$.

$$\Delta \psi = \frac{\sum_i \sum_j \mu_{1i}(SOC_{bat}) \mu_{2j}(SOC_{sc}) k_{ij}}{\sum_i \sum_j \mu_{1i}(SOC_{bat}) \mu_{2j}(SOC_{sc})}$$

(13) Equation: correction coefficient

$$T' = (1 + \Delta \psi) T$$

(14) Equation: Revised time

where

- $\mu_{1i}(SOC_{bat})$ and $\mu_{2j}(SOC_{sc})$ = $i$th membership value of SOC_{bat} and SOC_{sc}
- $\Delta k_{ij}$ = the corresponding output of two inputs

4 HESS CAPACITY ALLOCATION METHOD

4.1 Battery capacity allocation sub-algorithms

The battery capacity allocation process is based on the energy stored in the battery and the storage capacity of the battery energy storage system $E_A^{bat}$, as shown in Figure 5. First initialize the energy of the battery to the initial SOC $i_{SOC}$. At each calculation step, the exchanged energy $e$ is calculated. When $e \leq 0$, battery needs to release energy $e$, regardless of the state of charge, the new SOC is lower than before. When $e > 0$ and $E_{bat}(i - 1) + e \leq i_{SOC}$, the battery can obtain energy $e$, and the new SOC is higher than before. When $e > 0$ and $E_{bat}(i - 1) + e > i_{SOC}$, the battery cannot obtain energy $e$, and the new SOC is equal to that before. The sub-algorithm takes into account the natural limit of storage capacity of the battery, and the battery cannot be recharged when the maximum SOC is reached. Because deep discharge will reduce the service life of the battery, the range of the SOC of the stored energy is usually set by the discharge depth $D_{bat}$ (75%). During the allocation process, the battery's energy capacity $C_{bat}$ is defined as follows.

$$C_{bat} = \frac{E_A^{bat}}{D_{bat}}$$

(15) Equation: Battery's energy capacity

Battery charge and discharge power constraints are as follows.

$$\begin{align*}
  P_{bat,min} & \leq P_{bat} \leq P_{bat,max} \\
  P_{dbat,min} & \leq P_{bat} \leq P_{dbat,max}
\end{align*}$$

(16) Equation: Battery charge and discharge power constraints

where

- $P_{bat}$ and $P_{dbat}$ = The charging and discharging power of the battery (W)

The number of battery cells is as follows.

$$N_{bat} = \frac{C_{bat}}{C_{bat}}$$

(17) Equation: The number of battery cells

where

- $C_{bat}$ = total capacity of the battery system (W·h)
- $C_{bat}$ = total storage energy of a single battery (W·h)
4.2 Supercapacitor capacity allocation sub-algorithms

The calculation method for energy storage capacity $E_{sc}$ and energy capacity $C_{sc}$ of the supercapacitor is the same as the battery. That is:

$$E_{sc}^A = \max [E_{sc}(t)] - \min [E_{sc}(t)]$$  \hspace{1cm} (18) Equation: The storage capacity of the supercapacitor

$$C_{sc} = \frac{E_{sc}^A}{D_{sc}}$$  \hspace{1cm} (19) Equation: supercapacitor’s energy capacity

$$P_{sc-\text{max}} = \max ([P_{sc}(t)])$$  \hspace{1cm} (20) Equation: supercapacitor charge and discharge power constraints

$$N_{sc} = \max \left( \frac{C_{sc}}{C_{sc}}, \frac{P_{sc-\text{max}}}{P_{sc}} \right)$$  \hspace{1cm} (21) Equation: The number of supercapacitor cells

where

- $D_{sc}$ = discharge depth of supercapacitor
- $C_{sc}$ = storage capacity of a single super capacitor (W·h)
- $P_{sc}$ = the power that a single super capacitor can provide (W)

4.3 Capacity optimization based on ABC algorithm

The battery and supercapacitor capacity allocation sub-algorithm is easy to fall into the local optimal solution. To solve this problem, the ABC algorithm is used to further optimize the capacity allocation and get the optimal configuration of HESS capacity. The ABC algorithm is an algorithm based on honeybee honey collecting behavior. The algorithm seeks the optimal solution by continuously circulating three ways: leading bees search for food in the neighborhood of the food source, following bees search for food by a certain probability and investing bees search for new food sources. The probability of food source $i$ being selected is as follows.

$$p_i = \frac{F(X_i)}{\sum_{i=1}^{N} F(X_i)}$$  \hspace{1cm} (22) Equation: The probability of food source $i$ being selected

where

- $F(X_i)$ = food fitness

Leading bees and following bees will search for new food sources in the neighborhood of the food source. When the new food source returns better, give up the original food source, instead, preserve the original food source. The location of the new food source is defined as $V_i$, the search equation is given by the following.

$$V_j(t + 1) = X_j(t) + r \times \left[ X_j(t) - X_j(t) \right]$$  \hspace{1cm} (23) Equation: The location of the new food source

where

- $j$, $r$ and $k = \text{random number, } k \neq I$, and $r$ is between $-1$ and $1$

If a food source is not improved within the set number of iterations, it is explained that the food source is solved locally and the food source is abandoned. The leading bee corresponding to this food source is transformed into following bee to search for new food sources. The location of its search for a new food source, $Z_i$, is given by the following:

$$Z_i = X_{\text{min}} + r \times (X_{\text{max}} - X_{\text{min}})$$  \hspace{1cm} (24) Equation: The location of its search for the new food source

where

- $X_{\text{max}}$ and $X_{\text{min}}$ = upper and lower borders in each dimension for the original food chain $X_i$

The specific flow of the ABC algorithm is as follows:

Step 1: Initialization. Randomly generate $N$ food sources and calculate the fitness of each food source.

Step 2: Search the neighborhood of $X_i$ of the food source location of each leading bee, and generate a new food source position $V_i$ according to Equation 22. The fitness of $X_i$ and $V_i$ were calculated respectively, and a better food source location was preserved.

Step 3: According to the selection probability of each food source, a food source was selected and searched in the neighborhood of the food source position $X_i$. A new food source $V_i$ was produced according to Equation 23. The fitness of $X_i$ and $V_i$ was calculated, and the better location of food source was retained.

Step 4: Determine whether there is a food source to be abandoned; if so, give up the food source and replace it with the new food source according to Equation 24. Otherwise, take the next step.

Step 5: Determine if the maximum number of iterations has been reached. If not, return to Step 2; otherwise, output the location of the best food source.

The ABC algorithm is used to optimize the HESS capacity of the micro-grid. The specific solution flow is as follows:

Step 1: Initialize the parameters of the ABC algorithm and read the initial capacity allocation and cell number of the battery and ultracapacitor.

Step 2: Stochastic generation of $K$ optimal configuration scheme in the neighborhood of the above initial capacity configuration scheme, and calculate the corresponding number of battery and supercapacitor as the fitness, compared with the fitness above, and retain the optimal allocation scheme.

Step 3: Determine whether the optimization allocation scheme remains unchanged for continuous I times. If so, the corresponding solution is the local optimal solution, and go to the next step. Otherwise, it will continue to solve its local optimal solution iteratively.

Y. Zhang et al.
Step 4: Determine whether to reach the maximum number of iterations \( N_{\text{max}} \); if so, go to the next step. Otherwise, go back to Step 2 and recalculate the best solution in other places.

Step 5: Comparing the local optimal solutions, calculating the global optimal solution, and output the optimal power and capacity of the HESS.

### 4.4 HESS configuration flowchart

Taking full consideration of the influence of uncertainties, this paper uses Weibull distribution and normal distribution to define the wind speed and light intensity respectively. The wind speed and light intensity data are randomly generated by Monte Carlo simulation. The flowchart of the optimal configuration of the capacity of the micro-grid hybrid energy storage system is shown in Figure 6. The algorithm consists of four parts:

1. A set of random distribution parameters \([c, k, \mu, \sigma, \mu_T, \sigma_T, \mu_L, \sigma_L]\) are obtained through Monte Carlo simulation. Moreover, the data of wind speed and light intensity were generated through statistical analysis.
2. Power system time domain simulation and Control strategy. This section describes the LPF-based power allocation strategy and fuzzy control.
3. The calculation methods for rated power and energy capacity include battery and supercapacitor calculation sub-algorithms.
4. Capacity allocation and result analysis of HESS. A large number of random scenarios are generated by Monte Carlo simulation at a certain confidence level, and the capacity allocation results of the hybrid energy storage system are obtained. Then, the ABC algorithm is used to optimize the result, and the solution process ends until the iteration number \( i = N_{\text{max}} \).

### 5 EXAMPLE ANALYSIS

#### 5.1 System power profile

The 48-h environmental data with 98% confidence level of the wind, such as light intensity, wind speed, temperature and load profiles, are shown in Figure 7. The data of wind speed, temperature and light intensity sampled from every 10 min are simulated, and the data of the PV system, fan and load can be obtained. The net load power curve is shown in Figure 8. The result of spectral analysis of net load using the LPF algorithm is shown in Figure 9. According to the above, the spectrum analysis results are divided into two components: low frequency and high frequency.

Furthermore, the curves of charge and discharge power of supercapacitor and battery in 48 h are shown in Figures 10 and 11. The power of the positive half axis of the time axis indicates the power shortage. The energy storage system compensates the missing system power by discharge and absorbs the excess power by charging to keep the power of the system stable. Figure 11 shows that the supercapacitor has a large number of charge and discharge cycles, compensating for short-term high-frequency power fluctuations, and the battery charge and discharge cycle is small, compensating long-term low-frequency power fluctuations. The results show that the LPF allocation strategy based on fuzzy control effectively improves the operating environment of the battery, while the fuzzy control reduces the battery’s small charge-discharge cycle and increases its lifetime.

#### 5.2 HESS configuration and results

Hybrid energy storage system capacity consists of rated power and energy capacity. The rated power is the maximum instantaneous power that the HESS can provide. Energy capacity is defined as the total amount of energy that the HESS can store. The SOC limits for battery and supercapacitor are shown in Table 3. The results show that the LPF allocation strategy based on fuzzy control effectively improves the operating environment of the battery, while the fuzzy control reduces the battery’s small charge-discharge cycle and increases its lifetime.

| Energy storage unit | SOC\(_{\text{min}}\) | SOC\(_{\text{max}}\) |
|---------------------|-----------------|-----------------|
| Battery             | 0.25            | 0.90            |
| Supercapacitor      | 0.20            | 0.95            |

Hybrid energy storage system capacity consists of rated power and energy capacity. The rated power is the maximum instantaneous power that the HESS can provide. Energy capacity is defined as the total amount of energy that the HESS can store. The SOC limits for battery and supercapacitor are shown in Table 3. The results show that the LPF allocation strategy based on fuzzy control effectively improves the operating environment of the battery, while the fuzzy control reduces the battery’s small charge-discharge cycle and increases its lifetime.

In this paper, the HESS capacity allocation using Monte Carlo and ABC algorithms is relatively economical and reliable. In most cases, this capacity allocation can meet the requirements of the micro-grid. When the capacity of battery and supercapacitor is insufficient in rare cases, the demand side controllable load can be used to compensate for additional energy storage capacity requirements.
Figure 6. HESS capacity optimization configuration flowchart.
Table 4. Final result of HESS capacity allocation.

| Capacity allocation                          | $P_{bat}$/W | $P_{sc}$/W | $E_{bat}$/(W·h) | $E_{sc}$/(W·h) | $N_{bat}$ | $N_{sc}$ |
|---------------------------------------------|-------------|------------|-----------------|----------------|-----------|---------|
| Monte Carlo and ABC are not used            | 5255        | 7003       | 39201           | 36599          | 79        | 4       |
| Monte Carlo is used and ABC is not used     | 5133        | 6905       | 38243           | 36100          | 77        | 4       |
| Monte Carlo and ABC are not used            | 4449        | 5588       | 32362           | 32080          | 65        | 4       |
6 CONCLUSION

On the basis of power supply, energy storage type, power and energy characteristics, a hybrid energy storage capacity allocation method based on Monte Carlo and ABC algorithms is proposed in this paper. The hybrid energy storage system aims at stabilizing the power fluctuation of distributed power supply and ensuring that the output power of the micro-grid is within controllable range. Combining the power distribution strategy based on LPF and fuzzy control, the lifetime of the battery is increased by using the complementary characteristics of battery and the supercapacitor, and the stability of the system is improved. The method has also explored the capacity allocation sub-algorithm of battery and supercapacitor, and the optimal capacity allocation of the HESS is finally obtained by using the ABC algorithm. Compared with the traditional capacity configuration method, this method takes into account many uncertain factors in the configuration process, improves the conservative type of the traditional algorithm and makes the system more economical and reliable.

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