Capacity Optimal Research of Hybrid Energy Storage Systems for Stand-alone Wind/PV Micro-grid

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Abstract: In order to reduce the cost of the energy storage system in stand-alone Wind/PV power generation system and improve the reliability of power supply, it is necessary to configure the capacity of energy storage system reasonably. An optimization model is constructed, which considers the total cost of the energy storage system in view of the energy storage life within the engineering use fixed number of year as the objective function, the dividing frequency of different types of energy storage’s own compensation frequency band as optimization variables, and considers the LPSP, SPSP, SOC as the constraint, then use the improved PSO algorithm to solve the optimization problem. Finally, the example indicated that the optimization model and algorithm are correct and effective.

1. Introduction

With the growing energy crisis and environmental pollution, the development and use of the wind, light and other cleaner-energy is becoming a hot spot research[1]. Micro grid technology arises at the historic moment. Because the wind, light output has the characteristics of volatility and uncertainty and the load power also has certain volatility. This is a great challenge to the stable operation of the Wind/PV power generation systems, energy storage can be configured to deal with.

A single energy storage technology can’t meet the variety of requirements of the micro grid, so hybrid energy storage systems arise at home and abroad. At present, battery and super capacitor hybrid energy storage systems is relatively mature, it is the most widely used form of HESS [2-4].

On the basis of the above literature research, in this paper, taking stand-alone Wind/PV Micro-grid as the research object, the dividing frequency of battery and super capacitor to compensate own compensation frequency band as optimization variables, and based on the rain flow count method to evaluate energy storage life, finally establishing economic evaluation system.

2. Structure and Principle of Micro-grid

The structure of stand-alone Wind/PV Micro-grid is showed in figure 1[5].

![Figure 1. Structure of independent Wind/PV system.](image)

When the power of Wind/PV is sufficient, the hybrid energy storage system begin to recharge, in order to store excess electricity; When the power of Wind/PV is insufficient, the hybrid energy storage system begin to discharge for supplying load to ensure a smooth continuous power supply, which can improve the power supply reliability of the system.
3. Capacity Optimal Modeling of Hybrid Energy Storage Systems

In order to achieve the goal of configuring the battery and super capacitor-tracking the load curve. In this paper, considering the total cost of the energy storage system in view of the energy storage life within the engineering use fixed number of year as the objective function, the dividing frequency of battery and super capacitor to compensate own compensation frequency band as optimization variables, and considers the LPSP, SPSP, SOC as the constraint, building the optimization model of battery and super capacitor capacity. The overall flow chart of solving the model is showed in figure 2:

![Program flow chart of the optimal configuration.](image)

3.1. The power allocation of hybrid energy storage system

In the process of hybrid energy storage energy exchange, firstly according to the acquisition of wind, light power and power load forecast data, calculating the compensation power \( P_{\text{HESS}} \). So, after a high-pass filter, the compensation power can be divided in two parts, the compensation power of super capacitor is \( P_{\text{uc}} \) and the compensation power of battery is \( P_{\text{bat}} \).

\[
P_{\text{HESS}} = P_{\text{h}} (t) - \left[ P_{\text{b}} (t) + P_{\text{pv}} (t) \right] \tag{1}
\]

\[
P_{\text{uc}} (t) = P_{\text{HESS}} (t) \frac{T_s}{1 + T_s} \tag{2}
\]

\[
P_{\text{bat}} (t) = P_{\text{HESS}} (t) - P_{\text{uc}} (t) \tag{3}
\]

\[
T_h = \frac{1}{2\pi f_p} \tag{4}
\]

\[
0 < f_p < \frac{1}{2T_s} \tag{5}
\]

In order to recycle energy, the power component should be adjusted, ensuring the equal of energy storage charge and discharge quantity.

1. First in the super capacitor capacity calculation time scale for the super capacitor and battery power.

\[
\Delta P = \frac{1}{n} \sum_{n=1}^{\infty} P_{\text{uc}} \tag{6}
\]

\[
P_{\text{uc}}' = P_{\text{uc}} - \Delta P \tag{7}
\]

\[
P_{\text{bat}}' = P_{\text{bat}} + \Delta P \tag{8}
\]
(2) Then in the battery capacity calculation time scale modification again for battery power.

\[ \Delta P = \frac{1}{N} \sum_{i=1}^{N} P_{\text{bat}} \]  

(9)

\[ P_{\text{bat}}' = P_{\text{bat}} - \Delta P \]  

(10)

3.2 The calculation of rated power of hybrid energy storage systems

Through the above power allocation and adjusted, the charge and discharge efficiency of the actual energy storage system must be considered.

\[ P_{\text{ESS}} (t) = \begin{cases} 
\frac{P_{\text{ESS}} (t)}{\eta_{\text{ESS,d}}} \\
\frac{P_{\text{ESS}} (t)}{\eta_{\text{ESS,c}}} 
\end{cases} \]  

(11)

In the whole calculation process, Energy storage maximum absolute value of the actual charge and discharge power is the rated power of the energy storage system.

\[ P_{\text{ESS,N}} = \max \left( \left| P_{\text{ESS}}' \right| \right) \]  

(12)

3.3 The calculation of rated capacity of hybrid energy storage systems

Based on certain actual output data of energy storage, the cumulative charge and discharge of energy of each time can be calculated.

\[ E_{\text{ESS}} (t) = \sum_{r=0}^{N} \left( P_{\text{ESS}} (t) \times T_i / 3600 \right) \]  

(13)

The rest of the energy storage power change can be showed by SOC.

\[ SOC(t) = SOC_0 - E_{\text{ESS}} (t)/E_{\text{ESS,N}} \]  

(14)

The \( SOC_0 \) of energy storage should meet that when the most-positive energy fluctuating, \( SOC \) should not less than lower limit, when the biggest negative energy fluctuating, \( SOC \) should not higher than upper limit.

\[ \begin{cases} 
SOC_0 - SOC_{\min} \geq \max \left\{ \frac{E_{\text{ESS}} (t)}{E_{\text{ESS,N}}} \right\} \\
SOC_{\max} - SOC \leq \min \left\{ \frac{E_{\text{ESS}} (t)}{E_{\text{ESS,N}}} \right\} 
\end{cases} \]  

(15)

Taking the minimum value which meeting all the conditions.

\[ E_{\text{ESS,N}} = \frac{\max \left( E_{\text{ESS}} (t) \right) + \min \left( E_{\text{ESS}} (t) \right)}{SOC_{\max} - SOC_{\min}} \]  

(16)

After the initial charged status of energy storage is obtained, Just set the value as \( SOC_0 \), the entire cycle of charge and discharge requirements can be satisfied.

\[ SOC_0 = \frac{\max \left( E_{\text{ESS}} (t) \right) SOC_{\max} - \min \left( E_{\text{ESS}} (t) \right) SOC_{\max} - \min \left( E_{\text{ESS}} (t) \right)}{\max \left( E_{\text{ESS}} (t) \right) - \min \left( E_{\text{ESS}} (t) \right)} \]  

(17)
3.4 Economic evaluation of hybrid energy storage systems

(1) The economic evaluation model

1) The cost target

The cost of energy storage device including that the initial installation costs, the supporting facility costs of energy storage, the operation and maintenance costs of energy storage.

\[ C = (1 + N_{GH}) k_E ESS_N + (k_p + k_n) L_{GN} + k_p N_{GH} \times P_{ESS,N} \]  

\[ N_{GH} = \text{INT} \left( \frac{L_{GN}}{L_{ESS}} \right) \]  

2) Loss of power supply probability

When the energy storage system is discharging, if after discharge, as a result of the limitation of the energy storage itself, the requirements of the load cannot be meet, this situation will cause the shortage of load power supply.

\[ LPSP = \frac{\sum_{i=1}^{N} (P_i(t) - P_{DG}(t))}{\sum_{i=1}^{N} P_L(t)} \]  

3) Waste of power supply probability

When the energy storage system is charging, if after charge, as a result of the limitation of the energy storage itself, the requirements of the load cannot be matched, this situation will cause the waste of the energy.

\[ SPSP = \frac{\sum_{i=1}^{N} (P_{DG}(t) - P_L(t))}{\sum_{i=1}^{N} P_L(t)} \]  

In conclusion, sometimes the LPSP or SPSP cannot meet the setting, in this paper, \( \lambda_L \), \( \lambda_S \) set as 0.05, and this would increase the cost of system. Therefore, in the process of optimization, if not meet the requirements, should increase the punishment cost of system, eventually get optimal objective function in this paper.

\[ f = C + \left[ C_{LP} \left( LPSP - \lambda_L \right) + C_{SP} \left( SPSP - \lambda_S \right) \right] \sum_{i=1}^{N} P_L(t) \]  

(2) A model for calculating the energy storage life

It is generally believed that the super capacitor does not need to change during the engineering period, so we use the rain flow count method to evaluate the service life of the battery. Battery life is closely related to the way of working, the bigger of the depth of discharge, the shorter of cycle life.

This paper uses the fourth-order function relation to show the relationship between the depth of discharge and cycle life.

\[ N_{C,i} = -a_1DOD_i^4 - a_2DOD_i^3 + a_3DOD_i^2 - a_4DOD_i + a_5 \]  

\[ D = \sum_{i=1}^{N} \frac{1}{N_{C,i}} \]  

\[ L_{bat} = 1/D \times \left( 8760 \times 360 \right) \]
4. The example analysis

4.1 An example and calculation methods

This article takes 25 KW wind power generation system and 15 KW photovoltaic power generation systems as an example [6]. On one typical day, renewable energy output power and load data in 24 h is showed in figure 3:

4.2 Configuration result of energy storage systems

1) Before joining in hybrid energy storage systems

For the stand-alone Wind/PV Micro-grid that not joins in energy storage systems, taking LPSP and SPSP as the objective function, the power balance as the constraint. The result is showed in table 1:

<table>
<thead>
<tr>
<th>Optimize parameters</th>
<th>LPSP</th>
<th>SPSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>The calculation results</td>
<td>0.140832</td>
<td>0.241911</td>
</tr>
</tbody>
</table>

According to the figure 3, the net load power before joining in energy storage systems is showed in figure 4.

According to the above result, before joining in energy storage systems, net load fluctuation is very big, and LPSP and SPSP are also big, it is very bad for the stability of system. Therefore, in order to meet the demand of load joining in energy storage systems to the stand-alone Wind/PV Micro-grid.

2) Joining in hybrid energy storage systems

According to the improved PSO to solve above optimization model, contrasting the result of hybrid energy storage and single battery, the optimization results are showed in table 2:

<table>
<thead>
<tr>
<th>Energy storage type</th>
<th>Battery &amp; Super capacitor</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dividing frequency</td>
<td>0.00079</td>
<td></td>
</tr>
<tr>
<td>Capacity /KW·h</td>
<td>51.6763 &amp; 5.3961</td>
<td>52.5415</td>
</tr>
<tr>
<td>Cost/ ERU&amp;DANA</td>
<td>17.991 &amp; 25.301</td>
<td></td>
</tr>
<tr>
<td>LPSP</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SPSP</td>
<td>0</td>
<td>0.000075933</td>
</tr>
</tbody>
</table>
After analyzing the results in table 2, we find that joining in hybrid energy storage can reduce LPSP and SPSP, improve the reliability of power supply and reduce system costs.

On that typical day, the change of discharge and charge power of hybrid energy storage is showed in figure 5:

![Figure 5. Compensation power of hybrid energy storage systems.](image)

According to the figure 6, because the super capacitor compensates the high frequency power component, so it alleviate the frequent charge and discharge pressure of battery and optimize the working state, this can better extend the working life of battery.

5. Conclusions

For stand-alone Wind/PV Micro-grid, in order to track the load curve and improve the quality of electric energy, we’d better equipped with energy storage system. The example shows that HESS is the most efficient and economic. Not only can better track the load curve, improve power quality, but also can improve the economic benefit of the system, reduce the investment cost.

References


