Simulation of Composite Energy Storage Optimization
Configuration of Micro-grid Based on PSO

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Abstract. The micro-grid studied in this paper contains photovoltaic power generation, wind power generation and energy storage devices composed of super capacitors and storage batteries. Although this method of composite energy storage can effectively utilize new energy sources, the cost is relatively expensive. So, under the condition of normal load and overall normal operation, combined with power balance and other constraints, how to allocate capacity configuration can minimize the overall operating cost of the micro-grid, and improving the economics of micro-grid operation becomes a key issue. In this paper, for the micro-grid with island operation mode, using Matlab to build distributed power model and micro-grid model in micro-grid, aiming at the economical operation of micro-grid, using the basic particle swarm optimization algorithm to obtain the optimal solution, the grid is optimized for configuration and combined with an example for simulation analysis.

1. Main structure simulation of microgrid with wind/light/storage
The micro-grid studied in this paper is a typical small commercial micro-grid structure, in which distributed power sources include wind turbines, photovoltaic generators and energy storage systems, which coordinately supply power to the local load in a coordinated manner.

1.1. Fan model
The wind turbine can rotate the blades through the wind to convert the wind energy into mechanical energy, which is then converted into electrical energy by mechanical energy. As a rich new energy source, wind energy is increasingly used. Wind power generation is a good way to use wind energy. The wind turbine power expression is:

\[ P_{WG}(t) = \begin{cases} 
0, & v(t) \leq v_{ci} \\
(a(v(t))^3 - bP_r) & v_{ci} < v(t) \leq v_r \\
P_r, & v_r < v(t) \leq v_{co} \\
0, & v(t) \geq v_{co} 
\end{cases} \]  

(1.1)

In the above formula, \( v_r \) is the rated wind speed and \( P_r \) is the rated power.
The double-fed wind turbine model can be used to change the number of fans, wind speed and fan parameters. By replacing the doubly-fed wind turbine with a simplified model, a DC power source is used instead of the generator, which is inverted into a three-phase AC voltage by an inverter device. The simplified model is shown in Figure 1.1.

1.2. Photovoltaic power model
The photovoltaic power generation part built by the Simulink module in Matlab is shown in Figure 1.2. The photovoltaic power generation module is filtered, boosted by the boost circuit, and converted into a three-phase AC output through the inverter device.
1.3. Energy storage system Matlab model
The simplified model of the energy storage part built by the Simulink module in Matlab is shown in Figure 1.3. After the battery module is boosted, it is changed from the inverter to the three-phase AC.

![Energy storage system Matlab model](image)

Figure 1.3 Energy storage system Matlab model.

2. Island power micro-grid model
The distributed power models are packaged to build an island-connected micro-grid model. The schematic diagram of the model is shown in Figure 2.1.

![Island operation micro-grid model diagram](image)

Figure 2.1 Island operation micro-grid model diagram.
3. Composite energy storage optimization configuration model

3.1. Objective function

The micro-grid integrated operating cost minimum value of composite energy storage is used as the objective function of the optimization model, and the optimal solution is obtained by the algorithm to achieve the purpose of improving the economic operation of the micro-grid. Its objective function can be expressed as:

$$\min \, C_t = C_i + C_0$$  \hspace{1cm} (3.1)

Among them, \(C_t\) is the total annual cost of the micro-grid; \(C_i\) is the sum of the annual cost of the wind power system, the photovoltaic system, the super-capacitor and the battery system; \(C_0\), for other expenses of the micro-grid, such as construction and installation, purchase of necessary equipment, etc. \(C_0\) according to \(C_t\) in the actual situation, the ratio is small and negligible, so the objective function can be approximated and thus

$$C_t \approx C_1 = C_w + C_p + C_e$$  \hspace{1cm} (3.2)

Among them, \(C_w\), \(C_p\) and \(C_e\) respectively represent the annual cost of wind power system, photovoltaic system, super capacitor and battery composite energy storage system.

3.1.1. Annual cost of wind power structure

$$C_w = N_w \left[ C_{w0} \cdot \frac{r_0 \left(1 + r_0\right)^n}{(1 + r_0)^n - 1} + u(P_w) \right]$$  \hspace{1cm} (3.3)

Among them, \(C_{w0}\) is the price of a wind turbine; \(N_w\) is the number of wind turbines; \(P_w\) is the rated power of the wind turbine; \(u(P_w)\) is the annual operating and maintenance cost for a single wind turbine; \(n\) is the system life; \(r_0\) is the discount rate, which is usually 6.7% based on actual conditions.

3.1.2. Annual cost of photovoltaic power generation structure

$$C_p = N_p \left[ C_{p0} \cdot \frac{r_0 \left(1 + r_0\right)^n}{(1 + r_0)^n - 1} + u(P_p) \right]$$  \hspace{1cm} (3.4)

Among them, \(C_{p0}\) is the price of a group of photovoltaic devices; \(N_p\) is the number of groups of photovoltaic devices; \(P_p\) is the rated power of a single photovoltaic component; \(u(P_p)\) is the cost of operation and maintenance for a single photovoltaic component per year.
3.1.3. **Annual cost of photovoltaic power generation structure**

\[
C_E = N_B \left[ C_{B0} \cdot \frac{r_0 (1 + r_0)^n}{(1 + r_0)^n - 1} + u(W_B) \right] + N_C \left[ C_{C0} \cdot \frac{r_0 (1 + r_0)^n}{(1 + r_0)^n - 1} + u(P_C) \right] \tag{3.5}
\]

Where \( C_{B0} \) is the price of a group of batteries; \( N_B \) is the number of batteries; \( W_B \) is the rated capacity of the battery; \( u(W_B) \) is the annual operation and maintenance cost of a group of batteries; \( C_{C0} \) is the price of a super-capacitor; \( N_C \) is the number of super-capacitors; \( P_C \) is the rated power of a super-capacitor; \( u(P_C) \) is the annual cost of operation and maintenance of a super-capacitor.

3.2. **Restrictions**

In order for the micro-grid to operate normally and meet the actual conditions, the following constraints must be met: First of all, the necessary components of the micro-grid such as wind turbines and photovoltaic power generation systems are subject to the area of the installation and construction site, and there is a certain range in quantity. The upper and lower limits should be reasonably set according to actual conditions or experience.

\[
\begin{align*}
0 \leq N_{WG} & \leq N_{WG,max} \\
0 \leq N_{PV} & \leq N_{PV,max} \\
0 \leq N_B & \leq N_{B,max} \\
0 \leq N_C & \leq N_{C,max}
\end{align*}
\tag{3.6}
\]

Secondly, when the micro-grid system is in normal operation, the system power should be guaranteed in real time

\[
P_W(t) + P_P(t) + P_C(t) = P_I(t) \tag{3.7}
\]

Where \( P_I(t) \) is the current micro-grid system load power.

4. **Case analysis**

There is a micro-grid in this place. The distributed power source in this micro-grid includes wind power, photoelectric and energy storage systems. The wind speed and light intensity data predicted in this year are shown in Figure 4.1 and Figure 4.2 below. Wind and light data in the figure, during the one-year process, a valid data value is selected every half month, and the average value of the half-month stroke and light data is selected as the effective data value. It is known that within the power supply range of this micro-grid, the maximum user load is 250kW, the minimum is 10kW, and the average electricity price of the micro-grid is 0.931 RMB/kW.h⁻¹. Other distributed power parameters are shown in Table 4.1. Based on the above data and conditions, the PSO is used to optimize the capacity configuration of the micro-grid to minimize the annual cost.
Figure 4.1 Annual wind speed data chart.

Figure 4.2 Annual light data map.

Table 4.1 Distributed power parameters in the micro-grid.

| DG             | Index                        | Parameters |
|----------------|------------------------------|------------|
| Fan            | Cut wind speed (m/s)         | 5          |
|                | Cut out wind speed (m/s)     | 37         |
|                | Rated wind speed (m/s)       | 12         |
| Photovoltaic   | Power temperature coefficient| 0.0045     |
| Energy storage | Maximum discharge power (kW)| 150        |
|                | Minimum discharge power (kW) | -100       |

4.1. Case Analysis

Using Matlab 2014a software as the development environment, the particle swarm algorithm itself is a relatively random algorithm. The experimental results of one experiment will have great randomness. This simulation will run the same program 10 times independently, that is the same model, the optimization was performed 10 times, and the lowest total cost of the system was selected as the final simulation result to determine the optimized capacity configuration.
The parameters of the initial particle swarm algorithm are as follows: take $c_1$ as 2.05, $c_2$ as 2.05, the population size is 60, the inertia weight is 0.7, and the maximum number of iterations is 300, that is, the termination condition is 300 iterations.

The capacity configuration of the micro-grid is not only related to the wind speed and illumination conditions caused by the type of distributed power in the micro-grid and the geographic location of the region, but also related to the output distribution strategy of the distributed power sources in the micro-grid. Currently, the common strategy is Cycle Charge (CC), which refers to the use of energy storage systems (batteries, super-capacitors, etc.) in the micro-grid to compensate for the insufficient output of other distributed power sources, playing the role of the energy storage system to reduce pollution and increase the service life of other distributed power sources. However, the disadvantage is that the energy storage system costs more. When the capacity is larger, the cost of the micro-grid will increase. So we need to reduce costs and improve economics as much as possible.

Based on the particle swarm optimization algorithm, input the wind and light data of the micro-grid in the example, optimize the simulation and obtain the annual cost of the micro-grid operation, and obtain the annual cost before and after optimization.

| Table 4.2 Annual cost comparison table before and after optimization. |
|---------------------------------------------------------------|
| Optimized | Before optimization | Cost savings | Saving percentage (%) |
| Operating costs($\times10^7$RMB) | 1.00791981 | 2.13984582 | 1.13192601 | 52.90 |

It can be seen from Table 4.2 that although the micro-grid can be stably operated without optimization, the cost is larger than the optimized result, and the optimization can effectively save the cost of about 52.90%, indicating that the algorithm can effectively reduce the cost and improve economics. In addition, the output of each micro-source in this micro-grid is obtained in one year, as shown in the following Figures 4.3, 4.4, and 4.5:
4.2. Result Analysis

According to Figure 4.3 and Figure 4.4, we can see that, on the whole, the power of wind power generation is greater than that of photovoltaic power generation. That is because the wind energy in this area is sufficient and will not be affected by day and night. But at night, the photovoltaic power generation will stop working because there is no light, so there is no wind power generation. Then observe the maximum output of photovoltaic power generation, which appears in July, so it is in summer, the sunshine is sufficient, and the wind force is relatively small compared with other time periods; the maximum output of wind power generation appears, corresponding to March, at this time, in spring, wind energy is sufficient, so the wind turbine output is high. Looking at Figure 4.5, the energy storage system continuously adjusts the charge and discharge during the one-year process. The maximum discharge power appears. The maximum discharge power is 101.3kW, the maximum charging power appears at x=13, and the maximum charging power is 91.7kW. According to the maximum output power of photovoltaic power generation and wind power generation in one year, the capacity of photovoltaic power generation and fan is obtained as an integer. According to the power of the energy storage system, the capacity of the energy storage system is calculated and taken as an integer. The final determined capacity configuration is shown in Table 4.3.

![Energy storage system operation plan](image)

**Figure 4.5** Energy storage system annual output plan.

| Fan Installed Capacity(kW) | Photovoltaic System Capacity(kW) | Energy Storage System Capacity(kW) |
|---------------------------|---------------------------------|----------------------------------|
| 468                       | 158                             | 1618                             |

**Table 4.3** Capacity configuration table.

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