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Micro-Hybrid Energy Storage System Capacity Based on Genetic Algorithm Optimization Configuration Research

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Abstract

The energy storage system plays an important role in the utilization of renewable energy. However, traditional battery energy storage is faced with the disadvantages of short life and low power density. The hybrid energy storage system is established by combining the energy storage characteristics of ultra-capacitor and battery. Study two kinds of energy storage element to charge and discharge management strategy, with full life cycle cost of energy storage device as the optimization goal, set up comprehensive indexes such as power, capacity constraints as constraint conditions of constraint model, this paper proposes a hybrid energy storage system capacity based on genetic algorithm optimization configuration method and is verified by an example.

Keywords

Energy storage system, Capacity optimization, Genetic algorithm, Microgrid.

1. Introduction

With the rapid development of industry and the continuous economic growth, the social demand for electricity is also increasingly strong. While the traditional power industry based on fossil energy is facing increasingly serious problems such as resource exhaustion and environmental pollution, building energy Internet with renewable energy such as photovoltaic and wind energy has become a new development direction of the energy industry. However, these renewable energies have disadvantages such as instability, dispersion and low power generation efficiency. Adding energy storage equipment to build micro-grid distributed power generation can effectively solve these problems. Therefore, the breakthrough of the energy storage system is particularly important. In this paper, the hybrid energy storage system with super-capacitor and battery complementary is used to replace the traditional single energy storage system dominated by battery. Under the premise of meeting the requirements of system capacity and power, the integrated cost of the hybrid energy storage system is minimized.

As the optimal configuration of hybrid energy storage system capacity is a typical nonlinear programming problem, this paper chooses the improved genetic algorithm to solve the problem, and the correctness of this convenience is verified by an example

2. Model analysis

2.1 Battery power and energy model

Because the terminal voltage of the single battery is very low, and the capacity of the single battery is very small, usually in the application of the battery needs to combine the single battery to form the battery. If the capacity of the monomer battery for C_{bat}(AH), rated voltage for U_{bat}(V), the cascade

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total number of n_{bat} theory of batteries to store electrical energy $E_{n\ bat}$ (The unit is kW·h, The units of electric energy in this paper are all kW·h, and the power units are all kW, unless otherwise specified)is:

$$E_{n\ bat} = 0.001 n_{bat} C_{bat} U_{bat} \tag{1}$$

Suppose the discharge depth of the battery is λ(0<λ<1), The minimum residual energy Ebat min of the battery is:

$$E_{bat\ min} = 0.001 n_{bat} C_{bat} U_{bat} (1-\lambda) \tag{2}$$

Generally, the battery is regarded as a constant pressure operation, and the working current is controlled within 0.1 C_{bat}. Therefore, the rated output power $P_{n\ bat}$ of the battery group can be obtained as follows:

$$P_{n\ bat} = 0.0001 n_{bat} C_{bat} U_{bat} \tag{3}$$

2.2 Supercapacitor group power energy model.

In the case of ignoring the series and parallel resistance of the super-capacitor, the super-capacitor is equivalent to the ideal capacitor. Remember that the capacitance of the single super-capacitor is C_{uc}(F) and the terminal voltage is U_{uc}(V), The cascade of nuc number of super capacitor's theory of supercapacitor Banks store electricity total energy E_{uc}(J) as follows:

$$E_{n\ uc} = 0.5 n_{uc} C_{uc} U_{uc}^2 \tag{4}$$

In practical application, the terminal voltage of the super-capacitor has a working range, which is denoted as U_{ucmin}~U_{ucmax}, electric energy E_{uc} that the super-capacitor bank can provide for the system in each charge and discharge cycle is:

$$E_{n\ uc} = 0.5 n_{uc} C_{uc} (U_{uc\ max}^2 - U_{uc\ min}^2)/3.6 \times 10^6 \tag{5}$$

If the maximum working current of a single super-capacitor is denoted as $I_{uc\ max}$, the super-capacitor bank with a cascade number of nuc output power $P_{uc\ max}$ is:

$$P_{uc\ max} = 0.001 n_{uc} U_{uc\ max} I_{uc\ max} \tag{6}$$

3. Capacity optimization model of the hybrid energy storage system

3.1 Objective function

In this paper, the initial purchase cost, maintenance cost and replacement cost of the energy storage system during operation are all taken into account, which is called comprehensive cost, to avoid the limitation of only considering the purchase cost. Super-capacitor while the cost is high compared to the battery, but the cycle life of the supercapacitor greater than the battery. Therefore, the objective function considers the life span of the super-capacitor as a life cycle of the hybrid energy storage system, during which the cost of acquisition, operation, maintenance and replacement of the super-capacitor and battery is counted as the total cost. To sum up, the objective function is the integrated minimum cost, so

$$\mathrm{C} = \min(C_0 + C_1 + C_2) \tag{7}$$

In the formula C_0—Initial purchase cost of energy storage equipment;

C_1—Operation and maintenance cost of energy storage equipment;

C_2—The replacement cost of energy storage equipment;

3.2 Energy management strategy of the hybrid energy storage system

Renewable energy, such as photovoltaic or wind power, is intermittent and volatile. When the power generation system is full, the excess energy is stored in storage batteries and super-capacitors. In the power system power shortage, the energy storage system offset load demand deficiency is the release of stored energy. This article will power systems and load-balance of power between become unbalanced power, expressed in Δ P.

Therefore equipped with a hybrid energy storage system should fully consider the characteristics of two kinds of energy storage devices, to identify suitable for micro-network application of energy

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management strategy. Super-capacitors have the advantages of high power density, long cycle life, and fast response, but Low energy density can hardly meet the demand of long-time power supply for load when used alone; The battery has a higher energy density, but the power density is lower than the supercapacitor, and the charging time is long, the cycle life is short, usually can only charge and discharge several hundred times. Based on the characteristics of supercapacitor and battery can be borne by the unbalanced system power Δ P frequent fluctuations in the power, and in case of shock load, make up the lack of battery power, Battery only cover the basic power of the unbalanced power Δ P, so that we can in to ensure that the load demand at the same time avoid the battery charge and discharge frequently, and make the battery work at the rated power, can effectively prolong the service life of battery, improve the applicability and stability of the energy storage system.

3.3 Constraint

When there is a surplus in electricity generation, the excess energy is stored away. The capacity of the energy storage system should be less than the average surplus power (ΔE_{in}), avoid too much capacity. The charging state capacity constraint is:

$$E_{n\,bat} + E_{n\,uc} \leq \Delta E_{in} \tag{8}$$

When power generation is insufficient, the energy storage system makes up for the power gap. The capacity of the energy storage system should be greater than the average power gaps (Δ Eout), to meet the normal operation of the load. The constraint of discharge state capacity is:

$$E_{n\,bat} + E_{n\,uc} \leq \Delta E_{in} \tag{9}$$

When power generation is insufficient, the energy storage system makes up for the power gap. The capacity of the energy storage system should be greater than the average power gaps (ΔE_{out}), to meet the normal operation of the load. The constraint of discharge state capacity is:

$$E_{n\,bat} + E_{n\,uc} \geq \Delta E_{out} \tag{10}$$

In the absence of power supply, the energy storage system should be able to meet the peak power requirements of the impact load. P_{Lmax} is the peak load power. The power constraint is:

$$P_{n\,bat} + P_{n\,uc} \geq P_{Lmax} \tag{11}$$

$$\int_0^t P_{n\,bat}\,dt + \int_0^t P_{nuc}\,dt \geq P_{Lmax} \times t \tag{12}$$

4. Genetic Algorithm

Genetic Algorithm (GA) is a random optimization search method derived from the evolutionary law of the Genetic mechanism of survival of the fittest and survival of the fittest in biology. Its main characteristic is to directly operate on the structure object, there is no derivative and continuity limit; It has inherent implicit parallelism and better global optimization ability; Using probabilistic optimization method, the optimized search space can be automatically obtained and guided and the search direction can be adjusted adaptively without certain rules.

The process of genetic algorithm is shown in figure 1, and the basic steps are as follows:

(1) N initial individuals were randomly generated to form the initial population;

(2) The fitness function value of each individual was calculated;

(3) Based on fitness function value, selection, crossover, variation, generation of a new generation of population;

(4) Judge whether the population meets the stop condition. If not, return to step (2); if so, perform the next step.

(5) Select the optimal individual from the contemporary group as the optimal solution of the optimization problem;

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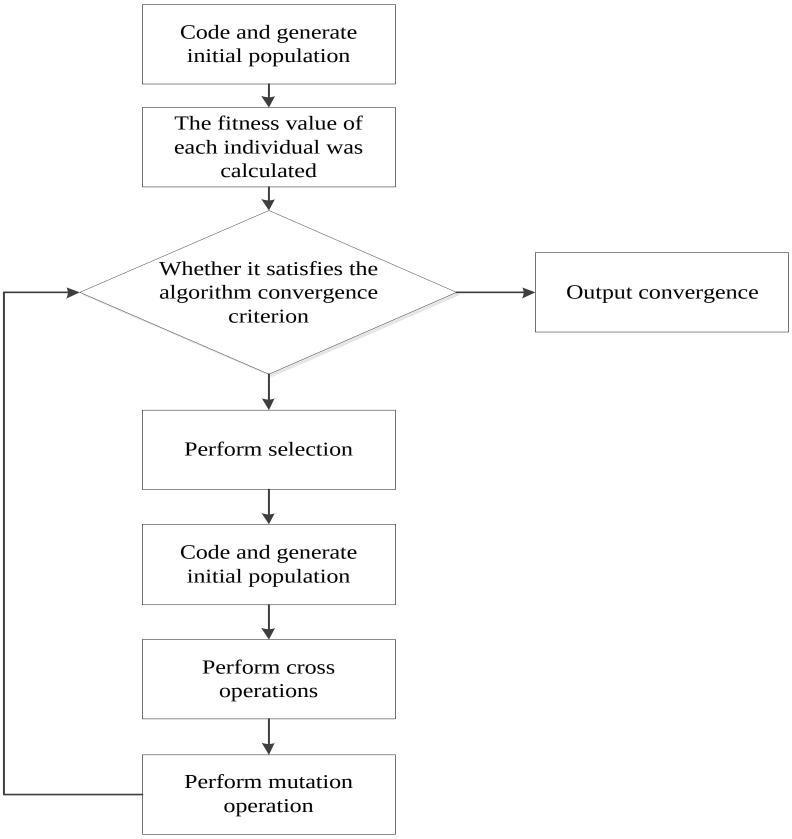

Fig. 1 Basic genetic algorithm flow chart

5. Case analysis

In this paper, the capacity of a hybrid energy storage system is optimized by Matlab with the help of the example of a micro-grid running independently with renewable energy. The specific parameters of the calculation example are as follows:

The rated power of renewable energy generation is 100kW, and the average load power is 35kW. The annual electricity generation of micro-grid is 313381kWh, and the annual electricity consumption of load is 310250kWh, which is slightly higher than the electricity consumption. When generating surplus, the average surplus is 45.55kWh; When the generation gap occurs, the average shortfall is 39.16kWh. The system load peak power is 175kW. The parameters of the adopted energy storage equipment are shown in table 1.

Table 1 Basic parameters of energy storage equipment

Battery		Super-capacitor	
Nominal capacity/(AH)	320	Capacitance/(F)	2400
The rated voltage/(V)	2	The rated voltage/(V)	2.7
The depth of discharge	0.65	Minimum working voltage	0.8
Charge discharge efficiency	0.85	Charge discharge efficiency	0.95
Maximum working current	100	Maximum working current	1500
Comprehensive unit price	320	Comprehensive unit price	1500

According to the power and capacity requirements of the micro-grid system mentioned above, the storage battery and super battery capacity listed in table 1 were substituted into the constraint conditions and the minimum cost function was written.

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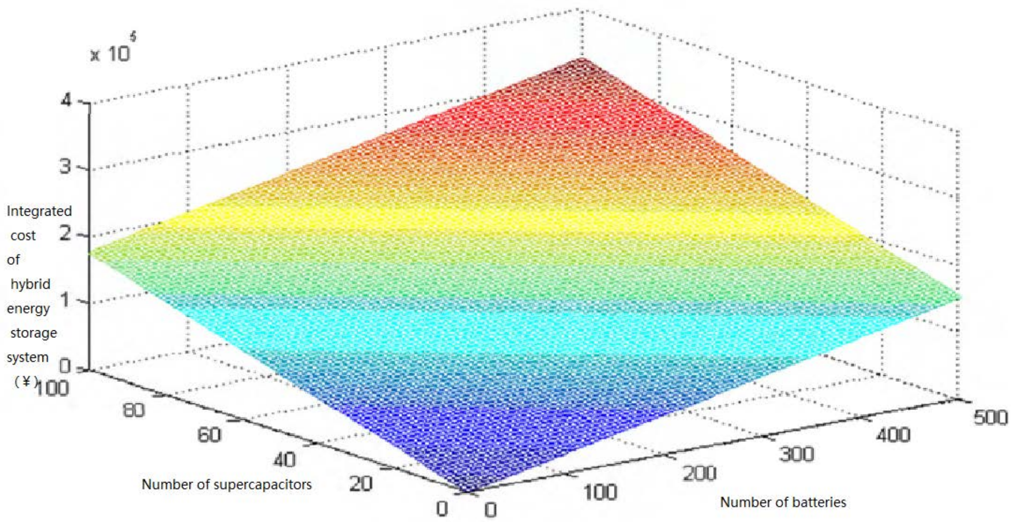

Fig. 2 Schematic diagram of integrated cost of hybrid energy storage

The problem is solved by the genetic algorithm. The iterative process of solving the objective function is shown in figure 3. It can be seen from figure 2 that the genetic algorithm can make the function converge faster and find the approximate best advantage of the load termination condition. The optimized configuration scheme and the single battery energy storage scheme are shown in table 2.

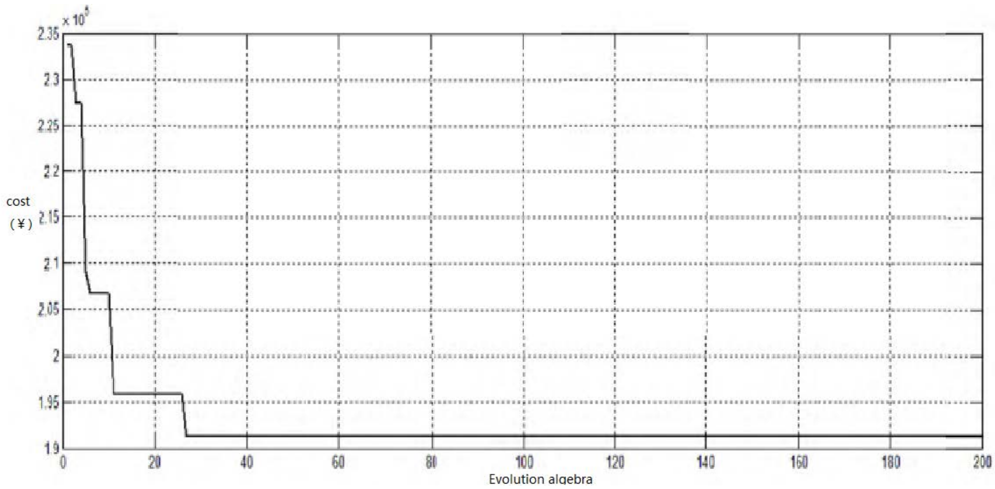

Fig. 3 Optimization process of genetic algorithm

Table 2 Calculation results of capacity optimization configuration

Energy storage way	Number of batteries	Number of ultra-capacitors	All-in cost
Battery	2583	0	826560
Hybrid energy storage	436	35	192020

It can be seen from the optimization results shown in table 2 that when a single battery is used for energy storage, because the power density of the battery is relatively low compared with j, to meet the power supply-demand in case of impact load, a large capacity battery must be equipped, so the cost is high. The hybrid energy storage system is powered by super-capacitors, which can reduce unnecessary battery configuration, reduce the number of charging and discharging of the battery, and extend the battery life, thus effectively reducing the overall cost.

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6. Conclusion

Hybrid energy storage system capacity based on genetic algorithm to optimize the configuration research give full consideration to the battery and supercapacitor their operating characteristics, through the coordination of complementary operation strategy, optimizing the work state of energy storage system, improve the economic efficiency of the energy storage system at the same time, guarantee the stability and feasibility of the microgrid. However, the influence of temperature, converter efficiency and other factors in practical application are not considered in the study, and the life of energy storage equipment is relatively simple to determine. To realize the precise configuration optimization of the capacity of the hybrid energy storage system, it is necessary to study the influencing factors in practical application and make further in-depth research.

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