Optimal Operation of Hybrid AC/DC Microgrid Including PV/WT/ES Considering Battery Charging and Discharging Times Constraint

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Abstract. Distributed generations have obvious features, including flexibility, randomness, intermittence and uncertainty. Energy storage can be equipped with such power supply, which can improve the new energy consumptive rate and ensure the reliability of power supply. The service life of the battery is mainly affected by its discharge depth, charge and discharge times and other factors. In this paper, the battery state of charge constraints, charge and discharge times constraint are taken into account, so as to decrease the battery charging and discharging frequency. Through an actual example, artificial bee colony is used to solve the objective function of the minimum operation cost of hybrid AC/DC microgrid including PV/WT/ES.

Introduction

With the development of society, energy demand is increasing day by day and fossil energy is facing the crisis of exhaustion. It is urgent to develop and use new green energy. Distributed generation (DG) has attracted worldwide attention due to its advantages of friendly environmental effect, high energy use efficiency and flexible installation site. DG mainly includes micro turbine (MT), fuel cell (FC), wind turbine (WT), photovoltaics (PV), and diesel generator (DEG), which have become an important part of the national energy strategy and develop rapidly in recent years. But because of wind power and photovoltaic power generation has obvious volatility and intermittent, so the output of these kinds of DG cannot be completely used. Microgrid (MG) came into being [1].

MG contains various micro sources (MS), load, energy storage (ES) and power electronic devices, which can achieve efficient use of renewable energy and ease the crisis of coal resources decreasing [2]. Plenty of renewable energy is uncontrollable, which needs microgrid to coordinate and manage. At present, the research on microgrid is mostly carried out around AC power grid. With the application of DC loads more and more widely, hybrid AC/DC microgrid has become the research focus and difficulty recently [3]. Research shows that the fluctuation and intermittence of wind turbine and photovoltaics in hybrid AC/DC microgrid have great influence on the stable operation of microgrid, and the output power fluctuation of such DG need to be suppressed [4].

Some scholars apply energy storage device to store up the extra output power of PV and WT and use it while the power supply output is deficient to improve the utilization ratio of renewable energy. In order to achieve effective suppression of the DGs’ power fluctuation, microgrid needs to be equipped with a long cycle life and high power density energy storage device. Reference [5] chose Na/S battery as distributed energy storage unit and introduced its characteristics. Containing battery energy storage, reference [6] proposed a microgrid real-time energy optimization scheduling method.

Currently, the price of energy storage equipment on the market is expensive, so how to length the service life of the battery in hybrid AC/DC microgrid is the focus of this study. Research shows that high frequency of the battery charge and discharge cycle influences the battery service life [7].
Considering the battery charge and discharge times constraint, the operation optimization object function of hybrid AC/DC microgrid including PV/WT/ES is established. In this paper, the artificial bee colony is used to solve the multi-objective, multi constraint and nonlinear optimization objective function of hybrid AC/DC microgrid, and the feasibility and correctness of the algorithm are verified through a practical example.

**Mathematical Model of Hybrid AC/DC Microgrid**

In this paper, the cost of purchasing electricity from power system, fuel cost of MSs, environmental cost, network loss and operation and maintenance cost are considered in the economic optimization objective function of hybrid AC/DC microgrid.

\[
F = F_{\text{Grid}} + F_{\text{Fuel}} + F_{\text{en}} + F_{\text{loss}} + F_{\text{om}}.
\]

Where \( F_{\text{Grid}} \) is the cost of purchasing electricity; \( F_{\text{Fuel}} \) is fuel cost; \( F_{\text{en}} \) is environmental benefit cost; \( F_{\text{loss}} \) is network loss; \( F_{\text{om}} \) is equipment operation and maintenance cost.

For the mathematical model of hybrid AC/DC microgrid, the following constraints should be satisfied:

1) Internal power balance constraints in microgrid.

\[
\sum_{i=1}^{N} P_{\text{MS}}^t + P_{G}^t = P_{\text{ACL}}^t + P_{\text{ES}}^t + P_{\text{DCL}}^t.
\]

2) Constraint of public link transmission capacity.

\[
|P_{G}^t| \leq P_{G,\text{max}}.
\]

3) Controllable micro source climbing rate constraint.

\[
P_{t}^t - P_{t-1}^t \leq r_{i}\Delta t.
\]

4) Battery charge and discharge upper and lower limits.

\[
|P_{\text{ES}}^t| \leq P_{\text{ES,\max}}.
\]

5) The upper and lower bound of battery charge state.

\[
S_{\text{oc,\min}} \leq \text{Soc}^t \leq S_{\text{oc,\max}}.
\]

6) Battery power balance constraints before and after the battery.

\[
\text{Soc}^{t+1} = \text{Soc}^t + \frac{uu \times \eta \times P_{\text{ES}}^t \Delta T}{Q_{\text{ES}}},
\]

7) The state of charge remains unchanged at the whole time of the battery.

\[
\text{Soc}_{\text{init}} = \text{Soc}_{\text{end}}.
\]

8) Battery charge and discharge times constraints.

\[
\sum_{t=1}^{T} |x_{t+1} - x_{t}| = n.
\]

Where \( N \) is the number of micro sources; \( P_{\text{MS}}^t \) is the output of each micro source during each period; \( P_{G}^t \) is the purchasing power from the grid; \( P_{\text{ACL}}^t, P_{\text{DCL}}^t \) are AC and DC loads; \( P_{G,\text{max}} \) is the transmission capacity through common connection point; \( r_{i} \) is the ramp rate of micro source \( I \); \( \text{Soc}^t \) is the state of charge; \( S_{\text{oc,\min}}, S_{\text{oc,\max}} \) respectively represents the upper and lower limits of the state of
charge; η is battery charge discharge efficiency; \( uu \) is the charge/discharge coefficient, Charge time is 1, discharge time is -1; \( Q_{ES} \) is battery capacity; \( x \) is the battery state of charge and discharge, which is 1 when discharge or charge .and is 0 in the last periods; \( T \) is a number of scheduling periods; \( n \) is the limited number of charge/discharge.

**Artificial Bee Colony**

Professor Karaboga of the Erciyes University in Turkey proposed artificial bee colony (ABC) firstly in 2005 which is simple and intuitive and has global convergence, and has attracted the attention of many researchers [8]. The bee is a social animal, which has clear division of labor in the honey process between the individual workers. They find nectar through the exchange of information and cooperate with each other. Biologists have found that bees through a dance which looks like '8' to exchange news and nectar quality is positively related to dancing time and nectar [9]. Based on this principle, ABC mainly includes employed bee, onlooker bee, and scout bee [10]. ABC is a swarm intelligence algorithm with the feature of a role conversion between three kinds of bees, so as to improve the success rate and accuracy rate to find the nectar. Artificial bee colony takes nectar position as the solution of the optimization problem and the quality of the nectar is reflected through the fitness value. The algorithm generally has the following 3 steps:

1) The employed bee finds the source of honey and share information through "8 dance".

Suppose the problem dimension is \( D \), the initial population size is \( SN \), total number of iterations is \( M \), the current iteration number is \( m \), the initial test times, counter is 0, The position of nectar \( i \) \((i=1,...,NP)\) can be represented as \( X^m_i = \{x_{i1}^m, x_{i2}^m, ..., x_{iD}^m\} \), the range of \( x_i \) is \([L_d, U_d]\), \( d=1,2,...,D \). The initial position of nectar is calculated through formula (10):

\[
x_{id} = L_d + \text{rand}(0,1) \cdot (U_d - L_d).
\] (10)

After the initialization, employed bee find new nectar in the vicinity, iterative formula is as follows:

\[
v_{id} = x_{id} + \varphi(x_{id} - x_{jd}).
\] (11)

Where \( j=1,2,...,NP \), and \( j \) is not equal to \( i \). After operations, the location of new nectar is as follows:

\[
V_i = \{v_{i1}, v_{i2}, ..., v_{id}\).
\] (12)

According to the method of greedy selection, if the fitness of new source \( V_i \) is better than the original fitness of \( X_i \), the latter will be replaced by the former, otherwise \( X_i \) is reserved.

2) According to the information provided by the employed bee, the onlooker bee will select a employed bee and follow it base on the probability calculated as follows:

\[
p_i = \frac{f_{it_i}}{\sum_{i=1}^{NP} f_{it_i}}.
\] (13)

Where \( f_{it_i} \) is determined by the objective function value \( f(x_i) \) of the optimization problem.

\[
f_{it_i} = \left\{ \begin{array}{ll} 
\frac{1}{1+f(x_i)} & f(x_i) \geq 0 \\
\frac{1}{1+|f(x_i)|} & f(x_i) < 0 
\end{array} \right.
\] (14)

According to the roulette method, the onlooker bee choose the employed bee \( i \) if \( p_i \) is greater than random number \( r \) which obeys the uniform distribution of \([0, 1]\). Then the onlooker bee produces a new nectar nearby through the formula (11) and choose a better on between the old nectar and the new nectar in accordance with the greedy criteria,

3) The onlooker bee will abandon the nectar of \( X_i \) if it did not find a better nectar after limit time search and set counter to 0. Then the onlooker bee will become a scout bee which randomly generates a new nectar nearby the hive near according to formula (10).
\[ X_{i}^{\text{new}} = \begin{cases} \text{counter} \geq \text{limit} & \left[U_{i} + \text{rand}(0,1)(U_{i} - L_{i}), L_{i}\right) \text{counter} < \text{limit} \end{cases} \]

(15)

It can be concluded that the employed bee is to improve the position of the bee and conduct greedy selection. The onlooker bee is the role of calculating probability, selecting nectar, and changing the position. The scout bee is the role of randomly generating new nectar and preventing the algorithm taking a local optimal answer. When the iterative algorithm iterates to the maximum number of iterations, the position of nectar is the optimal solution vector.

**Cases and Results Analysis**

As shown in Fig.1, the practical structure of hybrid AC/DC microgrid demonstration project in Zhejiang, China is used in this paper. The case includes DEG and WT in AC area, FC, PV and ES in DC area. AC area is connected with DC area by bidirectional converters. The charge state of the battery in the table is varied from 0.3-0.9, the charge and discharge times are limited within 6 times.

**Figure 1.** The typical structure of hybrid AC/DC Microgrid.

After running the ABC program, the optimal results are obtained as Fig.2-Fig.6.

**Figure 2.** Power output curves of each microsource of AC area.

**Figure 3.** Cost curves of AC area.

Fig.2 is power output curves of AC area where the GRID represents the purchasing electricity from power system. Fig.3 is operating cost curves of AC area. Because of the pollution mainly caused by DEG, so the environment cost curve varies with the power output curve of DEG.

**Figure 4.** Power output curves of each microsource of DC area.

**Figure 5.** Changing curve of SOC.
Fig.4 is power output curves of AC area. Fig.5 is the changing curve of battery SOC which indicates that the optimal results obey each battery constraint condition. It can be seen from the Fig.5 that the whole charging and discharging times of the battery is 5, meeting the charging and discharging times constraint.

![Environment cost Fuel cost Grid cost DC area total cost](image)

**Figure 6. Cost curves of DC area.**

Fig.6 is operating cost curves of AC area. In Fig.6, due to the MSs in DC area which include PV, FC and ES have good environmental benefits, so the environment cost is close to 0.

In this paper, in order to verify the performance of ABC, particle swarm optimization (PSO) is used to solve the optimal objective function of hybrid AC/DC microgrid including PV/WT/ES. After several operations, the average cost is shown as follows.

| Algorithm | Operation costs[ ¥ ] | Operation time[s] |
|-----------|----------------------|------------------|
| PSO       | 2487.5               | 16.2             |
| ABC       | 2382.4               | 9.4              |

From the above table, it can be seen that ABC can effectively solve the optimization problem of hybrid AC/DC microgrid economic operation. Compared with particle swarm optimization, the artificial bee colony has obvious advantages in running results and running time.

**Conclusion**

In the view of the optimal operation problem of hybrid AC/DC microgrid including PV/WT/ES, the nonlinear multi-objective function is established under considering multiple constraints including charging and discharging times constraint to length the battery's using life and artificial bee colony is used to solve the problem. The following conclusions can be drawn:

1) Considering charging and discharging times constraint, the nonlinear multi-objective multiple constraints function of hybrid AC/DC microgrid is correct and feasible which can be applied to practical engineering.

2) It is verified that the artificial bee colony is suitable to solve the hybrid AC/DC microgrid economic optimization problem which has better convergence properties than PSO.

3) In the future, more effective methods should be discovered to reduce the battery loss so as to prolong the service life of the battery.

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