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An Improved ABC Algorithm for Energy Management of Microgrid

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Abstract: Microgrids are an ideal way of electricity generation, distribution, and regulation for customers by means of distributed energy resources on the community level. However, due to the randomness of photovoltaic and wind power generation, it is a crucial and difficult problem to achieve optimal economic dispatch in microgrids. In this paper, we present an optimal economic dispatch solution for a microgrid by the improved artificial bee colony (ABC) optimization, with the aim of satisfying load and balance demand while minimizing the cost of power generation and gas emission. Firstly, we construct a mathematical model according to different characteristics of distributed generation units and loads, and improve the performance of global convergence for ABC in order to fit such model. Secondly, we explore how to solve the optimal economic dispatch problem by the improved ABC and give the essential steps. Thirdly, we carry out several simulations and the results illustrate the benefits and effectiveness of the proposed approach for optimal economic dispatch in microgrid.
Keywords: Artificial Bee Colony (ABC), optimization, economic dispatch, microgrid, swarm intelligence.

1 Introduction

The energy crisis and environmental degradation is a global burning issue confronting humanity today, and the microgrid provides an effective way to solve this problem [12]. The microgrid is a micro system consisting of a set of distributed power supply, loads and energy storage systems and control devices, which can supply various forms of power (electricity, heat, etc.) to loads with high reliability. It is able to meet the electricity and heat demand through the output of distributed generation units and energy storage units, as well as improve the energy efficiency and reduce power generation cost and discharge system. At the same time, users in microgrid are free to choose the power supply mode by the optimization demand, and all these factors are the impetus for the development of smart grid [6]. However, there are still many problems on operation control, energy management and scheduling in microgrid. The diversity of distributed generation units and flexibility of their composition makes its energy management become more complex. Thus, it is a challenging issue to achieve optimal economic dispatch in microgrid [11,20].

Significant research has been conducted and reported in the fields of economic dispatch for microgrids, related to the operation costs as well as minimizing emissions. Dynamic programming method was introduced to economic dispatch in microgrid, which obtained the global optimal solution by partitioning the complex problems into smaller stages [3, 18]. But the computation time and memory requirement will increase greatly when the dimension of stage, state and decision-making variable becomes bigger, that is, the dimension disorder. Compared with the traditional optimization algorithms, evolution algorithm is a kind of effective global search technology, which has been successfully applied in the areas of unit combination of electric power system and optimization scheduling, such as Genetic algorithm (GA) [2, 14], Differential Evolution (DE) [5,16], and Bacterial Foraging algorithm (BFA) [4,7]. Although evolution algorithm is a good solution to economic dispatch, it may lead to a long iterative time and poor convergence due to the presence of prematurity and random walk. By evolution algorithm, the searching process starts at a larger random state and ends in a small random state, in which this mechanism of combination search is easy to cause the algorithm converges into local optimal solution. In addition, swarm intelligence was also introduced to microgrid for economic dispatch, such as Particle Swarm Optimization (PSO) [1,19]. Swarm intelligence has the advantages of simple and easy to realize quick convergence and relying on few parameters, which has received more and more attention in the field of microgrid. In addition, some autonomous systems are developed to achieve management automatically, such as Cyber-Physical System [8].

Artificial bee colony optimization, as a specific application of swarm intelligence, has the ability to solve optimization issues by means of local optimization searching behavior of individual artificial bee with a fast convergence speed [15, 17]. The contribution of this paper is as below. 1) A mathematical model of optimal economic dispatch is established in a microgrid based on ABC, by considering time-of-use pricing strategy for both grid-connected and islanded microgrid. 2) The conventional ABC is improved in order to speed up the convergence and avoid local minimum. 3) Simulations are carried out to demonstrate the feasibility and benefits of the proposed approach.

The remainder of the paper is organized as follows. Section 2 improves the conventional ABC algorithm. The mathematical model and economic dispatch strategy in microgrid is presented in section 3. Section 4 describes the optimal economic dispatch solution for a microgrid by the improved ABC. Simulation and results analysis are performed in section 6. A brief conclusion is given as well as the future work.

2 Improvement of ABC

The goal of economic dispatch is to solve the optimal composition problem of distributed generation units in microgrid, in order to reduce the cost and emissions. But the traditional ABC is easy to fall into local optimum and with slow convergence. In this section, we firstly modify ABC by introducing the choice mechanism of the bee's neighborhood individual. Then, we improve the global convergence performance and dynamic regulation of sharing information among individual bees by integrating cross operation, mutation ability and greedy strategy.

2.1 Neighborhood factor

In ABC algorithm, the location update of food source for employed bees and onlookers is defined as:

$$l_{ij} = p_{ij} + r \times (p_{ij} - p_{kj}) \tag{1}$$

where i is the location of food source, $k \in \{1, 2, \ldots, M\}$, $j \in \{1, 2, \ldots, D\}$ and $k \neq j$. r is a random number within $[-1, 1]$. p_{ij} is the current position for the bee and p_{kj} is the food source position by random selection in the neighborhood individuals.

The selection probability for food source is defined as:

$$P_i = Fit_i / \sum_{i=1}^{M} Fit_i \tag{2}$$

where Fit_i means the higher earnings ratio is, the larger probability will be.

When the continuous search for food source by an individual is more than a certain number, a new food source is produced, defined as:

$$x_i^j = r \times (x_{max}^j - x_{min}^j) + x_{min}^j \tag{3}$$

where $j \in \{1, 2, \ldots, D\}$, r is a random number within $[-1, 1]$. x_{max} and x_{min} are the maximum and the minimum value respectively.

In ABC, the optimal solution is calculated by the food source update according to generating new food source from bees' neighborhood. The neighborhood individuals are chosen randomly without considering the relationship between the quality of food source in neighborhood and in current position. Meanwhile, the bee's food source doesn't combine with the search process in food source update. Therefore, the process control is insufficient in ABC algorithm, which causes the relatively slow speed of convergence.

Neighborhood factor can adjust search process dynamically according to the quality of individual food source in the neighborhood. The onlooker compares the quality of the current food source with the food sources in the neighborhood when it choosing the neighborhood individual. If the quality of the food source in the neighborhood is better, the food sharing information should be increased. On the contrary, the food sharing information will be increased.

The location update of food source for onlookers is re-defined as:

$$v_{ij} = \tau \times x_{ij} + \eta \times r \times (x_{ij} - x_{kj}) \tag{4}$$

where τ is forgetting factor, and it means the memory strength of the current food source to search the next food source. η is neighborhood factor that determines the strength of sharing information according to the quality of food sources in neighborhood. The forgetting factor is going down dynamically in the next search in order to make the bees make full use of the search information in neighborhood individuals and get the better global optimization results, defined as:

$$\tau = \lambda \times w_\tau \tag{5}$$

In order to get a better global optimization results in later search period, the neighborhood factor is changing from small to big, defined as:

$$\eta = \lambda \times w_\eta \tag{6}$$

λ is a constant in Eq. 5 and Eq. 6. $\lambda > 1$ when the quality of food source in the neighborhood is better than the current food source. Otherwise, $\lambda < 1$.

w_τ and w_η is changing dynamically along with the search process.

$$w_\tau = w_2 - ((iter_{max} - iter)/iter_{max})^\alpha \times (w_2 - w_1) \tag{7}$$

$$w_\eta = w_3 - ((iter_{max} - iter)/iter_{max})^\beta \times (w_4 - w_3) \tag{8}$$

where w_1, w_2, w_3, w_4 are constants limited within $[0.1, 1.5]$ and $w_2 > w_1$, $w_4 > w_3$. In forgetting factor τ, w_τ decreases from w_2 to w_1 along with the search process, which makes the bees move to the optimal food source area rapidly. To achieve quick convergence, the value of α is less than 1. Since the value is too small to global convergence, the value of α is usually set to $[0.8, 1]$.

In η, w_η increases from w_3 to w_4 along with the search process, which will reach the information sharing degree between the bee and its neighborhood individual. The value of β is bigger than 1 in order to avoid bees missing some optimal food source and limited within $[1, 1.2]$.

2.2 ABC combined with genetic algorithm

(1) Cross operation

Cross operation refers to the mutual exchange of genes between two pairs of chromosomes in certain way, so as to form two new individuals. Cross operator can enhance the global search ability in wide range with global parallelism. In ABC algorithm, role conversion mechanism is realized after bees starting searching the paths and the number of iterations is the same as the one of conversions. In general applications, less iterations can make the algorithm have strong ability in local search but with weak global search ability. By adding cross operator, it can make the ABC algorithm have better ability for global optimization. The detail of the process is as follows.

Step 1: Perform cross operation for all paths by combining any two paths together as P_i and P_j.

Step 2: Select a node position p randomly, and add the area (from P_j to the end) to the left. Delete the node that P_i has done cross operation with P_j.

Step 3: Do the same operation for P_j.

(2) Mutation ability

For ABC algorithm, there may be better solution or even the global optimal solution in the neighborhood of current solution. We add mutation factor to further realize global optimization operation for optimal economic dispatch in microgrid. Mutation operation is conducted for all paths and the procedure is as below.

$j \neq 1$: Select the jth food source and change the position j and $j-1$.

$j = 1$, change the first food source with the last food source.

j is the food source position.

(3) Greedy strategy

During computing process, the worst path will be replaced by the optimal path in each population. There are two optimal paths being preserved for the employed bee in each iteration. For onlookers and scouts, greedy algorithm is adopted for cross operation. If the candidate solution is better than the current solution, then choose the candidate solution as optimal one. The bee doesn't record the path information of the current solution any longer. Otherwise, the path information doesn't need to be changed by the candidate solution. By greedy algorithm and cross operation, the ABC algorithm can be enhanced by sub-operator.

3 Mathematical model and economic dispatch strategy in microgrid

Fig. 1 shows the microgrid architecture studied in this paper, which encompasses wind turbine (WT), micro turbine (MT), photovoltaic (PV), fuel cell (FC), battery (BT), other storage components, general loads and essential loads with diverse features.

In this architecture, the connection point, called point of common coupling (PCC), is the bride between the utility system and the microgrid system. Thus, there are two kinds of modes

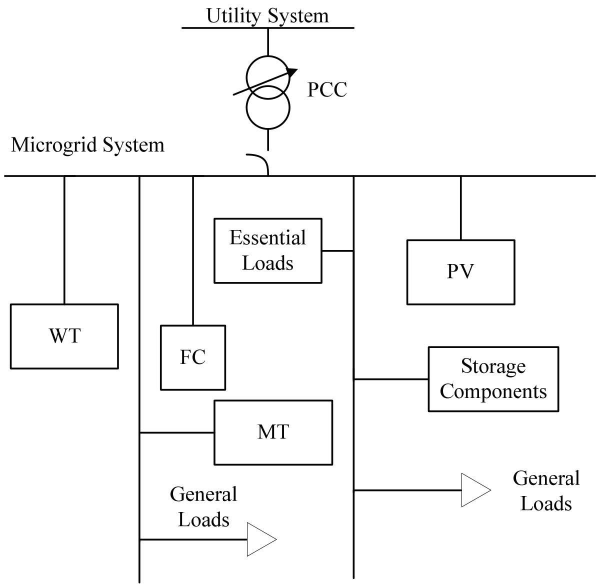

Figure 1: Typical architecture of microgrid system

in microgrid according to the state of PCC, that is, connected state (grid-connected) and disconnected state (islanded mode).

3.1 Mathematical model of economic dispatch

The aim of optimal economic dispatch in MicroGrid is to get the best composition of distributed generation units and reduce the consumption and emission at the same time. We present the mathematical model of economic dispatch by considering both grid-connected mode and islanded mode.

Proposed objective function

a) Grid-connected mode

In grid-connected mode, the microgrid can exchange electricity with the utility system through the PCC, so the selling and the purchasing behaviour are considered in order to get better economic dispatch. The objective function of operating cost is defined as:

$$F = \min \left\{ \sum_{k=1}^{T} \Delta t_k \left[\sum_{i=1}^{N} (CF_i + COM_i + PO_i) + CB_{i,k} - CS_{i,k} \right] \right\} \tag{9}$$

where T is the total operating time of MicroGrid, N is the total number of generating units and Δt_k is the duration of time interval k. CF_i means the fuel cost of the micro generation unit i while COM_i denotes the operation and maintenance cost of the micro generation unit i. PO_i is environmental cost generated by exhaust emissions. $CB_{i,k}$ stands for the purchased electricity of the micro generation unit i in Δt_k if the load demand goes beyond the generated power, and $CS_{i,k}$ implies the income from sold electricity of the micro generation unit i in Δt_k if the generated power is too much for the load demand.

The fuel cost of CF_i is computed by:

$$CF_i = KF_{i,k} \times P_{i,k} \tag{10}$$

where $KF_{i,k}$ is the fuel coefficient (\$/Kwh) of the micro generation unit i in Δt_k and $P_{i,k}$ is the generated power (Kwh) for the micro generation unit i in Δt_k.

The operation and maintenance cost of COM_i is calculated by:

$$COM_i = KOM_{i,k} \times P_{i,k} \tag{11}$$

where $KOM_{i,k}$ is the operation and maintenance coefficient (\$/Kwh) of the micro generation unit i in Δt_k and $P_{i,k}$ is the same meaning as in Eq. 10.

The environmental cost of PO_i is computed by:

$$PO_i = KR_{i,k} \times EP_{i,k} \times P_{i,k} \tag{12}$$

where $KR_{i,k}$ is emission coefficient, $EP_{i,k}$ is emission price and $P_{i,k}$ is the same meaning as in Eq. 10.

The purchased electricity of $CB_{i,k}$ is computed by:

$$CB_{i,k} = KB_{i,k} \times PB_{i,k} \tag{13}$$

where $KB_{i,k}$ is the buying coefficient (\$/Kwh) of the micro generation unit i in Δt_k and $PB_{i,k}$ is the bought power (Kwh) for the micro generation unit i in Δt_k.

The income from sold electricity of $CS_{i,k}$ is computed by:

$$CS_{i,k} = KS_{i,k} \times PS_{i,k} \tag{14}$$

where $KS_{i,k}$ is the buying coefficient (\$/Kwh) of the micro generation unit i in Δt_k and $PS_{i,k}$ is the income (Kwh) for sold by the micro generation unit i in Δt_k.

b) Islanded mode

Under this circumstance, the MicroGrid is disconnected to the utility system and controlled by MicroGrid itself as an islanded entity. No power is exchanged between MicroGrid and utility system through the PCC. Thus, the objective function of operating cost is defined as:

$$F = \min \left\{ \sum_{k=1}^{T} \Delta t_k \left[\sum_{i=1}^{N} (CF_i + COM_i + PO_i) \right] \right\} \tag{15}$$

where all the parameters are the same meanings as in Eq. 9 except removing the cost for purchasing power and the income for selling surplus power.

Equality constraints

a) Grid-connected mode

According to the charge-discharge of battery, there are two kinds of situations for power balance constraints, namely charging balance constraints and discharging balance constraints.

For charging battery, the power balance constraints are defined as:

$$P_{load} = \sum_{i=1}^{N} P_{i,k} - \alpha_{ch} P_{ch,k} + PB_{i,k} - PS_{i,k} \tag{16}$$

where P_{load} is the load power in MicroGrid, $P_{i,k}$ is the generated power (Kwh) for the micro generation unit i in k, $P_{ch,k}$ is the power for charging the battery, α_{ch} is charging efficiency coefficient, $PB_{i,k}$ and $PS_{i,k}$ are the same meanings as in Eq. 13 and Eq. 14.

For discharging battery, the power balance constraints are defined as:

$$P_{load} = \sum_{i=1}^{N} P_{i,k} - \alpha_{dis} P_{dis,k} + PB_{i,k} - PS_{i,k} \tag{17}$$

where all parameters are the same as in Eq. 16 except $P_{dis,k}$ is the power for discharging the battery and α_{dis} is discharging efficiency coefficient.

b) Islanded mode

In islanded mode, MicroGrid cannot exchange any power with utility system, so it doesn't need to consider purchasing power and selling power.

For charging battery, the power balance constraints are redefined as:

$$P_{load} = \sum_{i=1}^{N} P_{i,k} - \alpha_{ch} P_{ch,k} \tag{18}$$

where the parameters are the same meanings as in Eq. 16.

For discharging battery, the power balance constraints are redefined as:

$$P_{load} = \sum_{i=1}^{N} P_{i,k} - \alpha_{dis} P_{dis,k} \tag{19}$$

where the parameters are the same meanings as in Eq. 17.

Inequality constraints

The constraints of micro generation units, buying and selling electricity, and charging and discharging battery constitute the inequality constraints in MicroGrid.

a) Inequality constraints for micro generation units

$$P_{i,k}^{\min} \le P_{i,k} \le P_{i,k}^{\max} \tag{20}$$

where $P_{i,k}^{\min}$ and $P_{i,k}^{\max}$ are the minimum and the maximum operating power of the micro generation unit i.

b) Inequality constraints for buying and selling electricity

$$PB_{i,k}^{\min} \le PB_{i,k} \le PB_{i,k}^{\max} \tag{21}$$

$$PS_{i,k}^{\min} \le PS_{i,k} \le PS_{i,k}^{\max} \tag{22}$$

where $PB_{i,k}^{\min}$ and $PS_{i,k}^{\min}$ are the minimum buying and selling electricity from/to utility system while $PB_{i,k}^{\max}$ and $PS_{i,k}^{\max}$ are the maximum buying and selling electricity from/to utility system.

c) Inequality constraints for charging and discharging battery

$$P_{bt,k}^{\min} \le P_{bt,k} \le P_{bt,k}^{\max} \tag{23}$$

$$E_{bt,k}^{\min} \le \left| E_{bt,0} - \sum_{k=1}^{j} P_{bt,k} T \right| \le E_{bt,k}^{\max} \tag{24}$$

where $P_{bt,k}^{\min}$ and $P_{bt,k}^{\max}$ are the minimum and the maximum charging/discharging efficiency. $E_{bt,k}^{\min}$ and $E_{bt,k}^{\max}$ are the minimum and the maximum battery capacity.

3.2 Economic dispatch strategy

(1) Grid-connected strategy

In grid-connected microgrid, the economic dispatch problem should consider not only the power scheduling strategy of distributed generation units, but also the influence of the system performance of power trading between microgrid and external network.

a) Utilize WT and PV units as output at first, track and control the maximum power.

b) Determine whether to use MT for generating power according to actual load.

c) When the generated power by WT, PV and MT units is beyond the load demand, make battery storage discharge to supply the loads and monitor the state of battery charging and discharging.

d) If the energy from storage battery is enough to meet the load demands, increase the output by storage battery to sell the electricity to the utility system.

e) If the energy from storage battery is insufficient to satisfy the demands in microgrid, purchase the power from the utility system.

f) If the generating cost is higher than the price to purchase electricity from utility system, the microgrid buys the power from outside to meet internal load demand. And if the internal cost is smaller than external price, the microgrid generates the power and sells to utility system.

(2) Islanded mode strategy

In islanded microgrid, it doesn't need to take power trading into account and load demands are completely supplied by the internal micro sources and energy storage devices. The energy control system is responsible for real-time management and maintenance of system reliable operation. The economic dispatch is realized by the optimum combination of power supply.

a) Utilize WT and PV units as output at first.

b) When the generated power by WT, PV and MT units is beyond the load demand, turn off the units with high generating cost to achieve electricity balance.

c) When the generated power by WT, PV and MT units is not enough for the load demands, make battery storage discharge to supply the loads.

d) If the energy from storage battery is enough to meet the load demands, utilize all the distributed generation units and storage batteries together to meet residual load demands according to comprehensive generating cost.

e) Perform load shedding if the generated power is insufficient when all distributed generation units are running and the storage batteries are discharging.

4 Optimal economic dispatch solution for a microgrid by the improved ABC

Optimal economic dispatch in microgrids can be regarded as optimal decisions for multistage decision problems to get different combinations of distributed generation units in different periods [9, 21]. The ABC algorithm is a useful way to deal with multistage decision problems that can compare the performance of combination in each stage. By means of the idea in dynamic programming, we firstly explore the optimal economic dispatch solution based on the improved ABC and then present the key steps of algorithm.

4.1 Implementation of optimal economic dispatch

The ABC algorithm is mainly to solve the non-constraint problem, while the economic dispatch in microgrids is a kind of constraint optimization problem. The key point is to convert the parts of constraint optimization problem to non-constraint problem. The ABC algorithm can solve the equality constraints of distributed generation units directly, and the necessary conversion has to do for the inequality constraints of distributed generation units.

In the proposed approach, the definition of path for optimal composition of distributed generation units is each state of unit combination in a time period constitutes for a decision set from time 1 to time T. So the problem of optimal economic dispatch is a multistage search problem, with the goal of finding a decision path with minimum total cost. The dynamic model is defined as:

$$F_t\left(U_t^l\right) = \min\left\{\varphi_t^l\left(U_{t-1}^k, U_t^l\right)\right\} \qquad t \in T \tag{25}$$

where U_t^l is the state l in the t period, $\varphi_t^l\left(U_{t-1}^k, U_t^l\right)$ is the accumulation of operating cost from the state k in the $t-1$ period to the state l in the t period. $F_t\left(U_t^l\right)$ is the minimum cost in the t period. The constraint conditions are followed the presented mathematical model of economic dispatch.

(1) Conversion of objective function

The objective function of operating cost is redefined as:

$$\min\left(\sum_{i=1}^{n-1} tc\left(s_{\pi(i)}, s_{\pi(i+1)}\right) + tc\left(s_{\pi(n)}, s_{\pi(1)}\right)\right) \tag{26}$$

where $tc(s_i, s_j)$ is the transfer cost from the state i to the state j, and $\pi(i)$ is the optional state set.

(2) Treatment of constraint conditions

We build *tabu* list to restrict the state that cannot meet some constraints. *tabu* is used to record all the states that allow to be transferred in the period t. There is no direct connection between any two periods.

If the state meets the demand, its element in *tabu* is set to 1. Otherwise, its element in *tabu* is set to 0. On one hand, the number of transfer can be restricted by *tabu*. On the other hand, the search behaviour can be run in a feasible solution, which plays certain guidance for bees search behaviours.

In the process of economic dispatch, when the output of a micro source is beyond its upper limit, other micro sources have to adjust their output to keep the system balance.

4.2 Key steps of algorithm

(1) Divide the loads into diverse classes, general loads and essential loads, ordered by the importance.

(2) Create composition states by different distributed generation. Compute the maximum and the minimum output for each state to generate the upper limit and lower limit.

(3) Compare states with loads. If lower limit of one state is bigger than the maximum loads or upper limit is smaller than the minimum loads, remove this state. Otherwise, record this state and its upper limit and lower limit.

(4) Determine the initial state.

(5) Initialize bee number, swarm evolution parameters, random food sources etc.

(6) Search objective food source by scouts and generate employed bees. If the current food source is better than the previous one, store it. Otherwise, ignore this food source.

(7) If the process reaching final time in the iteration, go to step 9. Otherwise, go to step 8.

(8) Compute list of the current period and the earnings rate by the proposed constraint processing methods. Calculate the output and generating cost at this state and update the path information. Go to step 6.

Table 1: Time-of-use pricing (RMB/Kwh)

Time	07:00-10:00	10:00-15:00	15:00-19:00	19:00-21:00	21:00-23:00	23:00-07:00
Usage	Mid peak	On-peak	Mid peak	On-peak	Mid peak	Off-peak
B-price	0.47	0.8	0.47	0.8	0.47	0.16
S-price	0.35	0.64	0.35	0.64	0.35	0.12

Table 2: Emission factor and external cost of NO_X, SO_2, CO_2

Type	EC (RMB/kg)	EF-FC (kg/MWh)	EF-MT (kg/MWh)
CO_2	0.023	489	724
NO_X	8	0.014	0.2
SO_2	6	0.0027	0.0036

(9) Record the shortest path from step 8 and update the path information for global optimization according to the optimization algorithm.
(10) If not reaching the end of iterations and not appearing stagnation phenomenon, go to step 6 for the next iteration. Otherwise, stop the process.

5 Simulations and results analysis

To demonstrate the feasibility and effectiveness of the proposed approach in optimal economic dispatch for microgrids, we carry out several case studies based on the real data, for both grid-connected and islanded microgrid. The basic data are chosen for the typical summer and winter days from the central region of china.

5.1 Testing environment

The collection of the basic data in this experiment includes typical day load curve in winter/summer, local energy data, and technical performance parameters for micro sources. In grid-connected mode, since the battery charging/discharging is only restricted by the performance of itself, we assume the battery charging and discharging have the same situations in winter and summer. The gas price is 2.05 RMB/m^3.

We adopt the time-of-use pricing here, which is classified into three groups: on-peak, mid-peak and off-peak. In different time period, the prices for selling and buying power to/from the utility system are also different, as shown in Table 1.

Because MT and FC power are relying on burning fuel, it is inevitable to produce atmospheric pollutants such as CO_2, NO_X, SO_2, and other solid dust particles. The handling cost of emissions is computed by the estimated external discount cost multiplied by the total generated power and the emission factor (EF). Table 2 gives the emission of FC and MT as well as external cost (EC) [10, 13].

5.2 Case study 1: Typical winter days

According to the proposed algorithm, the output power generated by micro sources is calculated for typical days in winter, also including the best economic dispatch for operation and optimal operation cost. In winter, the micro sources are controlled dynamically followed by the heating requirement.
(1) Grid-connected strategy

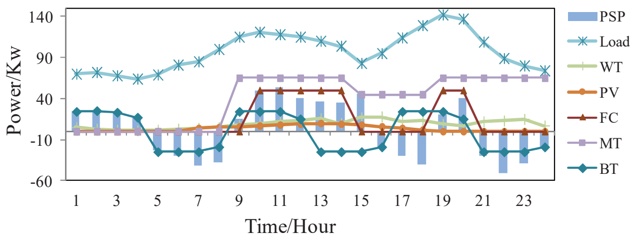

Figure 2: Power balance of grid-connected microgrid in typical winter days

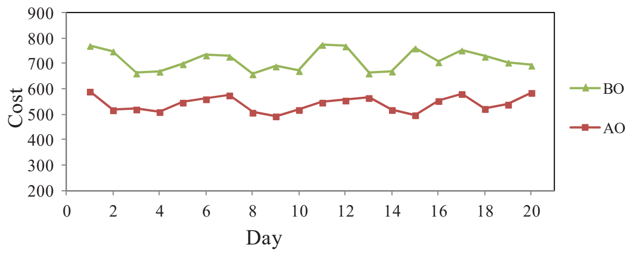

Figure 3: Comparison of total cost of daily power generation in the grid-connected MicroGrid

The power balance of the grid-connected microgrid in typical winter days is shown in Fig. 2, where PSP means the buying power (negative value) and the selling power (positive value) from/to the utility system.

It can be seen from the results that the microgrid bought the power from outside during the off-peak hours and sold the power to utility system during the peak hours, in order to get the best economic dispatch.

We carried out a comparison of total cost of daily power generation for no optimization and after optimization in winter days, in which the number of observed days is 20. The average cost is RMB 712.7 before optimization (BO) while it is RMB 540.95 after optimization (AO), as shown in Fig. 3.

(2) Islanded mode

The power balance of the islanded microgrid in typical winter days is shown in Fig. 4 and the related system cost is given in Fig. 5, including comprehensive cost (C_Cost), fuel cost (F_Cost), operation and maintenance cost (OM_Cost), and environmental cost (E_Cost).

5.3 Case study 2: Typical summer days

In summer, the micro sources are controlled dynamically followed by the cooling requirement.

(1) Grid-connected strategy

The power balance of the grid-connected microgrid in typical summer days is shown in Fig. 6.

It can be seen from the results that the MT and FC run together in peak hours because the power price is higher than it generated by micro sources. The microgrid system purchased the power from outside for supplying loads and battery charging in off-peak time.

The average cost of daily power generation of the grid-connected MicroGrid is RMB 1007.05 before optimization (BO) while it is RMB 810.95 after optimization (AO) in summer, as shown in Fig. 7.

(2) Islanded mode

The power balance of the islanded microgrid in typical summer days is shown in Fig. 8 and the related system cost is given in Fig. 9.

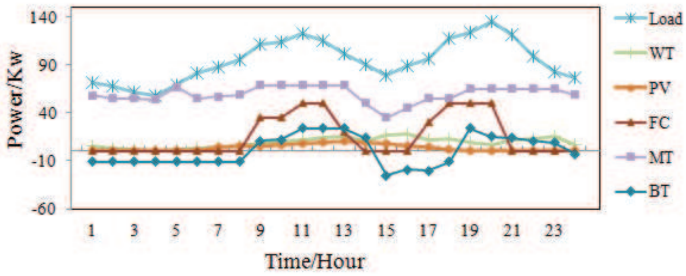

Figure 4: Power balance of islanded microgrid in typical winter days

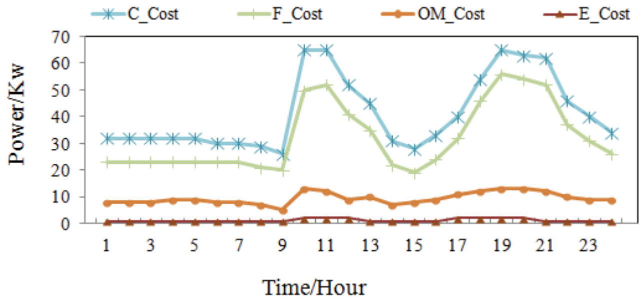

Figure 5: System cost of islanded microgrid in typical winter days

5.4 Results analysis

The simulation results showed that the proposed approach can achieve the optimal economic dispatch for grid-connected and islanded microgrid. In grid-connected mode, the microgrid system used the generated power firstly in peak time in order to reduce purchasing power from the utility system, and it also sold the surplus electricity to the utility system. In mid-peak or off-peak hours, it bought the electricity from the utility system as much as possible so as to reduce the cost of generating power. In winter, the characteristics of charging and discharging storage battery had great impact on electric power trade. In summer, since the full running time of MT is longer than it in winter and the efficiency of PV is better than in winter, the purchasing power from outside system is obviously decreased. The decision factors of buying or selling power in grid-connected microgrid is the generating cost of micro sources, outputs and power price in the utility system.

In islanded mode, it can be seen from the results the load shedding basically happened from 16:00 to 21:00 when the battery needed charging and the power generated by WT was decreasing. We can also learn that the fuel cost occupied most of the total cost. The second expense was operation and maintenance cost, and the environmental cost was minimum. By the influence of battery charging and discharging process, the high cost of the system has occurred in battery charging process. Therefore, to reduce the comprehensive cost in islanded microgrid, the key is to find a better way for flexible and effective scheduling of the storage battery.

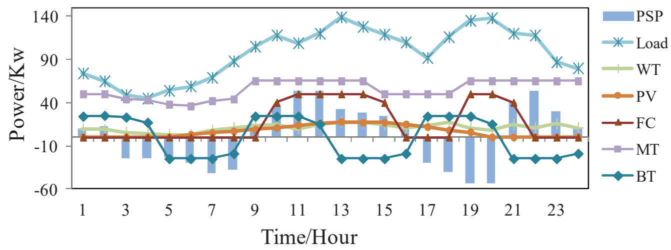

Figure 6: Power balance of grid-connected microgrid in typical summer days

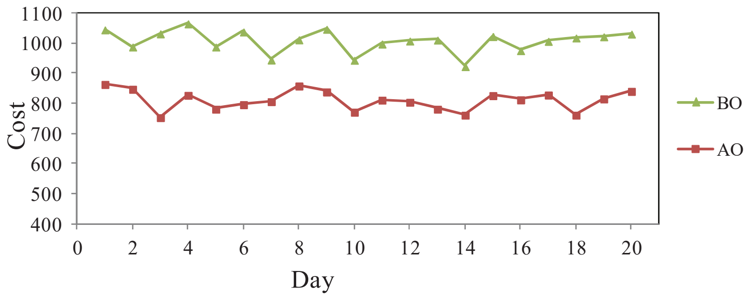

Figure 7: Comparison of total cost of daily power generation in the grid-connected MicroGrid

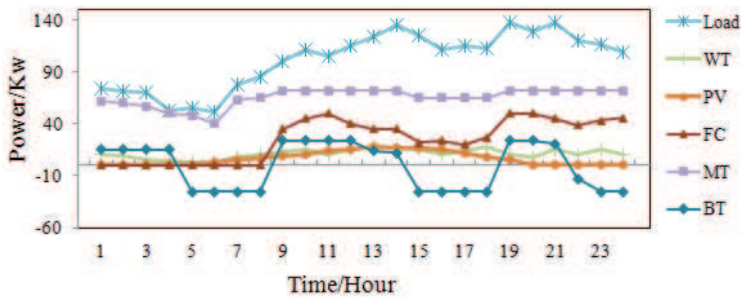

Figure 8: Power balance of islanded microgrid in typical summer days

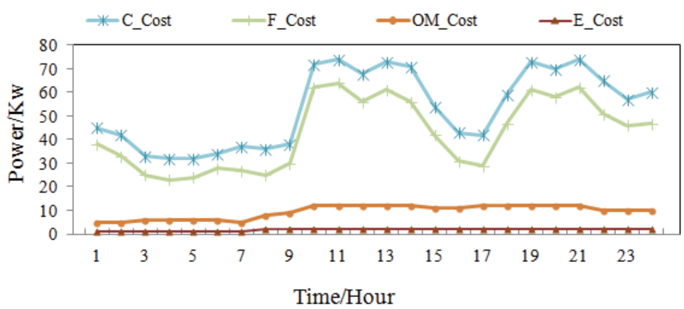

Figure 9: System cost of islanded microgrid in typical summer days

6 Conclusions and future work

Microgrids are the component of the Smart Grid revolution offering a number of important advantages in reducing energy consumption and environmental pollution, and improving power system reliability and flexibility, which changes the way to deal with the increasingly growth of loads. In this paper, we presented a novel approach of optimal economic dispatch in a microgrid with the improved ABC, including grid-connected and islanded mode. In order to overcome the problems of slow convergence and easy to fall into local optimum in traditional ABC, we improved it by introducing neighborhood factor, cross operation, mutation ability and greedy strategy. We constructed the mathematical model of optimal economic dispatch and also gave the economic dispatch rules for a microgrid both in grid-connected and islanded mode. The ABC-based optimal economic dispatch solution was discussed and the detail steps were given. Simulations of typical cases were carried out and the results showed that the improved ABC-based approach is feasible and effective in optimal economic dispatch for microgrids.

Future work will focus on exploring hybrid swarm intelligence algorithms to economic dispatch in microgrid, such as Altruism algorithm and Cuckoo search algorithm. Moreover, flexible switching strategies for real-time scheduling by considering more constraint conditions in microgrid would be a promising direction of future research.

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