Active and Reactive Power Joint Optimization Dispatch of islanded Microgrid Based on SCCSA Algorithm

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Abstract. Based on the requirements of the economic reliability of the operation of islanded micro grid, a joint optimal dispatch model of the active power and reactive power of the islanded micro grid is proposed in this paper, which considers the constraints of upper and lower limits of output force and power balance of each micro source. In order to minimize the cost of operation and the penalty cost of voltage deviation of each node, an improvement is made on the basis of the original crow search algorithm, and combined with the advantages of the sine cosine algorithm, the improved sine cosine crow search algorithm is used to solve the model and the results of the active reactive power output of the island are obtained. The simulation results show that the proposed method can effectively control the voltage of each node in the micro grid within the allowable range, and is more beneficial to the economic operation of micro grid.

1. Introduction

China is a great marine country with many islands [1]. The island is rich in renewable resources such as wind and solar energy which provides a quality resource environment for the development of the island and the life of its residents. As an independent controllable energy supply system composed of distributed generation, energy storage and loads, island micro grid is the most effective form to give play to renewable energy efficiency.

As is known to all, the output of wind turbines and photovoltaic on the island has volatility. When these distributed power sources are connected to the island micro grid, the fluctuation of supply and demand in the system may lead to a large change of power flow, which will result in a large deviation of point voltage. Therefore, how to properly manage the operation of the internal distributed power supply of the islanded micro grid to realize the optimization of the economic, technological and environmental benefits of the micro grid becomes a vital research topic.

In [2], the economic dispatching optimization model is established for the micro grid system in the isolated grid mode, and the simplified gradient force method is used to solve the model. In [3], active power output characteristics of distributed generating sets and charge-discharge characteristics of energy storage units are comprehensively considered in the modeling of micro grid economic dispatch problem, and the original optimization problem is transformed into a mixed integer linear programming problem for solving by using the linearization method. However, most existing researches only consider the active power optimization scheduling problem of island micro grid, ignore the characteristics of active-reactive power strong coupling in micro grid, and seldom consider the active- reactive power combined optimal dispatch. Nevertheless, in the actual island micro-grid engineering, the voltage level is relatively low, and the impedance ratio of transmission line is generally large, so that the bus voltage is also greatly affected by active power then active- reactive power flows will affect the line loss and voltage quality [4]. As the use of renewable energy becomes more and more extensive, power generation keeps increasing, which poses a new challenge to solving the intelligent algorithm used in multi-objective optimization scheduling. Improving the traditional optimization method to deal with the impact of renewable energy access on the economic operation of island micro grid has always been the focus of academic research. Common algorithms for multi-objective economic optimal scheduling include particle swarm optimization and genetic algorithm, etc. In [5], an economic scheduling model for power system is established, and the crow search algorithm is adopted to solve the problem. But, the constraint condition is too simplified and the effect of active power on voltage is not considered. In [6], on the basis of the improvement of traditional optimization algorithms, such as particle swarm algorithm, the relevant models of micro grid are solved, which all indicate that the improved algorithm has better convergence and the fitness value is better. In [7,8,9], an improvement was proposed on the traditional raven search algorithm, and the classical test function was used to verify that the improved algorithm has better convergence and better performance in searching for the global optimal solution.

In this paper, an independent islanded micro grid including photovoltaic (PV), wind turbine (WT), gas turbine, storage battery (SB) and Diesel Engine (DG) is proposed to model the distributed generation respectively, considering the balance of active-reactive power and the constraints of each micro source. Based on the objective function of the operating cost of each micro source and the minimum voltage deviation of each node, a joint optimal dispatch model of the active reactive power and reactive power of the islanded micro grid is established. Finally, sine cosine crow search algorithm (SCCSA) was used to solve the problem. The simulation results showed the effectiveness of the proposed model and algorithm.

2. Unit models of islanded micro grid

2.1. Model of micro gas turbine

The fuel cost of a micro gas turbine is related to its own efficiency

$$F(P_{mt}(t)) = C_{gas} \frac{1}{LHV} \frac{P_{mt}(t)}{\eta_{mt}} \tag{1}$$

Where $F(P_{mt}(t))$ is the combustion cost of micro gas turbine; C_{gas} is the price of natural gas; LHV is low calorific value of natural gas; $P_{mt}(t)$ is the output power of micro gas turbine at the moment t.

2.2. Model of storage battery

Energy storage systems play an important role in maintaining system stability. In this system, the storage capacity of the battery should be kept within the appropriate range, as it does not want to run out or overcharge. The remaining electric quantity of the storage battery at time t is related to the remaining electric quantity of the battery at time t-1, the charging and discharging quantity of the storage battery from time t-1 to time t and the electric quantity attenuation per hour [10].

Battery discharge time: $P_{soc}(t) \geq 0$, the remaining capacity at time t is:

$$S_{soc}(t) = S_{soc}(t-1) - P_{soc}(t) / \eta_{dis} - D_b^s Q_b^s \tag{2}$$

Battery charge time: $P_{soc}(t) \leq 0$, The remaining capacity at time t is:

$$S_{soc}(t) = S_{soc}(t-1) - P_{soc}(t) / \eta_{cha} - D_b^s Q_b^s \tag{3}$$

Where $S_{soc}(t)$ is the remaining capacity of the storage battery at the time t; $P_{soc}(t)$ is the charging and discharging power of the storage battery at the time t; η_{cha}、η_{dis} respectively are charging and discharging efficiency; D_b^s is the self-discharge ratio per hour of the storage battery; Q_b^s is the total capacity of the storage battery.

The operating cost of the energy storage unit is

$$F(P_{soc}(t)) = \frac{\alpha_{soc} I^p_{soc}}{8760} P_{soc}(t) + G_{soc} P_{soc}(t) \tag{4}$$

$$\alpha_{soc} = r_{soc} / \left[1 - \left(1 + r_{soc}\right)^{-N_{soc}}\right] \tag{5}$$

Where r_{soc} is annual utilization, N_{soc} is the working life, I^p_{soc} is the cost of investment and installation. G_{soc} is the cost of operation and maintenance.

2.3. Model of DG

Diesel generator, as the main power source in the conventional power system, has the characteristics of high reliability and mature operation and maintenance technology. Therefore, it can be used in microgrid to make up the shortage of micro generation and improve the reliability and flexibility of islanded microgrid operation. The power generation efficiency of diesel engine is reduced under light load condition and fuel consumption is high. Usually, the minimum output power of DEG is set between 30%-50% of the rated power. Figure 2 shows the fuel consumption rate (l/h) for a 100Kw diesel engine. The relation between fuel burning cost and active power output is generally expressed by quadratic polynomial, as shown in the formula:

$$F(P_{de}(t)) = \alpha + \beta P_{de}(t) + \gamma P_{de}(t)^2 \tag{6}$$

Where $F(P_{de}(t))$ refers to the combustion cost; α、β、γ is the combustion cost coefficient; $P_{de}(t)$ is the output power of diesel generator at the moment.

The output model of photovoltaic cells is shown in literature [11,12], and the output model of fans is shown in literature [13].

3. Objective function

In order to make the node voltage deviation of islanded micro grid as small as possible and to give full play to its economic benefits, a real-time optimal dispatch model of the active reactive power and reactive power of the island micro-grid is established in this paper, with the aim of minimizing the operating cost of each micro source. At the same time, a penalty term related to the maximum deviation of node voltage is added to the objective function.

3.1. Generating cost

Due to the uncertainty of the power output of distributed generation, the generation cost of wind turbine and photoelectric is less than that of fuel unit, so it can be ignored.

$$\min \sum_{t=1}^{24} (F(P_{mt}(t)) + F(P_{de}(t)) + F(P_{soc}(t)) \tag{7}$$

Where $F(P_{mt}(t)), F(P_{de}(t)), F(P_{soc}(t))$ respectively are gas generator, diesel engine and energy storage unit per hour operation costs.

3.2. Voltage deviation penalty function

The deviation between the actual voltage and the reference voltage is taken as the objective function to keep the voltage at a good level so as to minimize the total voltage deviation of the node as far as possible.

$$\min \lambda V_{d,\max} \tag{8}$$

$$V_{d,\max} = \max\left\{V_{d},(t_1)\right\}, V_{d,i}(t_1) = \left|V_i(t_1) - V_N\right| \tag{9}$$

λ is the penalty coefficient of voltage deviation. V_N indicates the rated voltage level. $V_i(t_1)$ is the voltage amplitude of the node i. $V_{d,\max}$ represents the maximum deviation of the node voltage from the rated level (the maximum deviation of the node voltage).

4. Constraint condition

4.1. Power flow constraint

Considering the coupling of active and reactive power, the active power and reactive power of adjustable resources are jointly optimized. Here, it is assumed that diesel and gas units and energy storage units are involved in both active and reactive power regulation. In this way, power flow constraints can be expressed as:

$$\begin{aligned} &P_{mt}\left(t\right) + P_{de}\left(t\right) + P_{soc}\left(t\right) + P_{w}(t) + P_{pv1}\left(t\right) + P_{pv2}\left(t\right) \\ &-P_l(t) - \sum_{g=1}^{h} V_f(t)V_g(t)(G_{fg}\cos\theta_{fg} + B_{fg}\sin\theta_{fg}) = 0 \end{aligned} \tag{10}$$

$$Q_{soc}(t) + Q_{mt}(t) - Q_l(t) - \sum_{g=1}^{h} V_f(t)V_g(t)(G_{fg}\sin\theta_{fg} - B_{fg}\cos\theta_{fg}) = 0 \tag{11}$$

Where h is the number of nodes in the system. $f = 1,2\cdots,h_{fg}, B_{fg}, \theta_{fg}$ are the conductance, susceptance and the phase angle difference between the node f and the node g.

4.2. Other constraints

$$V_f^{\min} \leq V_f(t) \leq V_f^{\max} \tag{12}$$

$$P_i^{\min} \leq P_i(t) \leq P_i^{\max} \tag{13}$$

$$R_{mt}^{l}\Delta t \leq P_{mt}(t) - P_{mt}(t-1) \leq R_{mt}^{h}\Delta t \tag{14}$$

$$R_{de}^{l}\Delta t \leq P_{de}(t) - P_{de}(t-1) \leq R_{de}^{h}\Delta t \tag{15}$$

$$-S_{soc}^{inv} \leq P_{soc}(t) \leq S_{soc}^{inv} \tag{16}$$

$$-\sqrt{(S_{soc}^{inv})^2-(P_{soc}(t))^2}\le Q_{soc}(t)\le\sqrt{(S_{soc}^{inv})^2-(P_{soc}(t))^2} \tag{17}$$

$$E_{soc}^{\min}\le E_0+\sum_{t=1}^{N}(P_{soc}(t)\times dt)\le E_{soc}^{\max} \tag{18}$$

$$E_{soc}(0)=E_{soc}(T) \tag{19}$$

$$P_{mt}(t)\le S_{inv,mt} \tag{20}$$

$$0\le Q_{mt}(t)\le\sqrt{S_{inv,mt}^2-P_{mt}^2(t)} \tag{21}$$

Where $V_f^{\max}$ and $V_f^{\min}$ are the upper and lower voltage of node f respectively; $P_i^{\min}$、$P_i^{\max}$ are the minimum and maximum active power of the ith micro generation. $Q_{soc}(t)$ is the charge-discharge reactive power of the ac side of the energy storage unit at the time t; $E_{soc}^{\min}$ $E_{soc}^{\max}$ are the maximum and minimum residual capacity of the storage battery respectively; S_{soc}^{inv} is the capacity of energy storage unit inverter; $S_{inv,mt}$ is the capacity of gas turbine unit inverter. T is the scheduling cycle 24.

Based on the above-mentioned optimization objective functions and constraint conditions, the optimal scheduling model of islanded micro grid system with active and reactive power can be obtained. It should be noted here that in the optimal operation of large power networks, the start-stop problem of generating sets (namely the unit combination problem) is usually considered to make the start-stop plan of generating sets more economical on the premise of meeting the load demand. However, the islanded micro grid considered in this paper has a small capacity and a small number of micro source units. In order to meet the load demand in real time and stabilize the fluctuations of wind power and photovoltaic output, most micro sources are in operation state. In view of this, the unit start and stop problem is not considered in this paper for the moment [14].

5. Solving algorithm

5.1. Crow search algorithm (CSA)

Crows are widely distributed birds and are now considered one of the smartest animals in the world. The crow search algorithm [15] is a simulation of the crow's behavior of hiding food. The crow hides the excess food in a hidden place and retrieves it when it needs it. It is not easy to find the hidden food of the crow, when the crow finds another crow following it. It will fool the follower to the location of another environment. From the point of view of optimization, the crow is the searcher and the environment is the search space. The location of each environment corresponds to a feasible solution. The quality of the food source is the value of the target (fitness) function. The best source of food in the environment is the problem global solution.

Suppose there is a d dimensional environment and a flock of crows. The number of crows (population size) is N . $x^{i,iter}$ $(i=1,2,\cdots,N;\ iter=1,2,\cdots,iter_{\max})$, $x^{i,iter}=[x_1^{i,iter},x_2^{i,iter},\cdots,x_N^{i,iter}]$ is the $iter$ generation of crow i in search space. $iter_{\max}$ is the maximum number of iterations. Every crow has a memory of where the food is hidden. In the $iter$ iteration, m_i^{iter} is where the crow i hides the food. This is the crow i best position to date so far. In fact, each crow remembers the best place in his experience. Crows search the environment to find better food sources (hidden places).

Now in the $iter$ generation, the crow j wants to see its hiding place m_i^{iter}. The crow i decides to follow the crow j to its hiding place. Then there will be two situations.

Case 1: the crow j does not know that the crow i follows it. Thus, the crow i will approach the crow j hiding place, and in this case, the crow i new location is as follows:

$$X_i^{iter+1} = X_i^{iter} + r_i \times fl_i^{iter} \times (m_j^{iter} - X_i^{iter}) \tag{22}$$

r_i is a random number uniformly distributed between 0 and 1; fl_i^{iter} represents the flight length of the $iter$ generation of crow i.

Case 2: the crow j knows that the crow i follows it. So, to protect its food from theft, crow j will search for another spot in space to deceive the crow i

Cases 1 and 2 can be expressed as follows:

$$\begin{cases} X_i^{iter+1} = X_i^{iter} + r_i \times fl_i^{iter} \times (m_j^{iter} - X_i^{iter}) & r_j \geq AP^{j,iter} \\ Random\ \ selection\ \ of\ \ values & r_j < AP^{j,iter} \end{cases} \tag{23}$$

r_i is a random number uniformly distributed between 0 and 1; $AP^{j,iter}$ represents the perception probability of a crow j in the $iter$ generation.

5.2. Sine cosine algorithm (SCA)

Swarm optimization algorithm is to initialize a series of random solutions, and then substitute these random solutions into fitness function calculation. These random solutions will be updated according to some rules, and then the value of the objective function will be calculated to find the global optimal solution. This is the core of the swarm optimization algorithm, but in the swarm optimization algorithm, when the number of iterations is less, it is not guaranteed to find the global optimal solution.

The swarm optimization algorithm is divided into two stages. In the first stage, the random solution in the random set is combined with the random high random rate to find the possible region of the search space. In the latter stage, the random solution is constantly updated and the random changes are obviously smaller than the random changes in the previous stage. Based on this, the following two positions updating equations are proposed [16].

$$x_i^{t+1} = \begin{cases} x_i^t + r_1 \times \sin(r_2) \times \left| r_3 p_i^t - x_i^t \right|, & r_4 < 0.5 \\ x_i^t + r_1 \times \cos(r_2) \times \left| r_3 p_i^t - x_i^t \right|, & r_4 \geq 0.5 \end{cases} \tag{24}$$

X_i^t represents the position of the i dimension update to the t generation; $r_1 / r_2 / r_3$ is a random number; r_4 is a random number between 0 and 1. P_i is the optimal position of the dimension i.

5.3. Sine cosine crow search algorithm (SCCSA)

Using the advantages of different algorithms, a new algorithm can be developed, and the hybrid algorithm is inspired by it. Although the above two algorithms perform well in optimization, some improvements can be considered to better solve the optimization problem. In this paper, two algorithms are mixed, and a new algorithm called Sine Cosine Crow Search algorithm (SCCSA) is proposed [17].

The first drawback of the CSA algorithm is that the search agent does not necessarily follow the best location obtained so far. Second, when $r_j < AP^{j,iter}$, the search agent updates its location to a random location in the solution space, this obviously degrades the performance of CSA. In order to improve the search efficiency of CSA, the location model derived from the advantages of the two algorithms is as follows:

$$X_i^{N+1} = \begin{cases} X_i^N + r_1 \times \sin(r_2) \times \left| r_3 \times P_i^N - X_i^N \right|, & r_4 < 0.3 \\ X_i^N + r_1 \times \cos(r_2) \times \left| r_3 \times P_i^N - X_i^N \right|, & 0.3 \le r_4 \le 0.6 \\ X_i^{N+1} = X_i^N + r_i \times fl_i^N \times (m_j^N - X_i^N) & r_4 \ge 0.6 \end{cases} \tag{25}$$

Where r_1、r_2、r_3、r_4 are random numbers. The calculation flow of active and reactive power joint optimal control in islanded micro grid based on SCCSA algorithm is shown in figure 1.

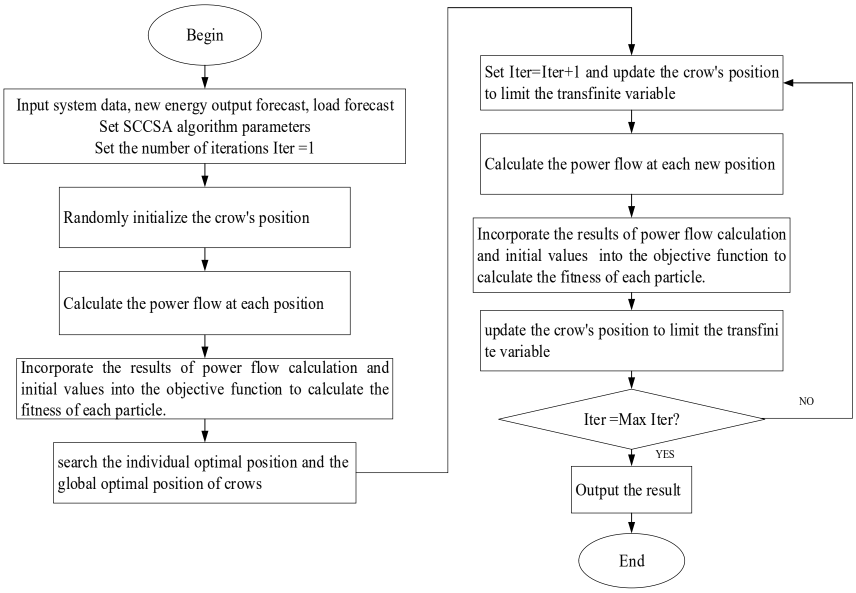

Figure 1. Active and reactive power joint optimization dispatching process in microgrid

The specific steps are as follows:

1)Input the topological parameters of islanded micro grid and current prediction data of wind power, photovoltaic and load; Set parameters such as population N and r1, r2, r3, r4 and maximum number of iterations $iter_{\max}$.

2)Population initialization: randomly initialize the position of crow in the population within a restricted range.

3)Calculate the power flow according to the position data of each initialization and get the node voltage in the current state. The fitness function was calculated.

4)Make $iter = iter + 1$ and calculate x_i^{iter+1} according to the position updating formula of the SCCSA algorithm, then the fitness value of each crow was calculated.

5)When $iter = iter_{\max}$, the real-time scheduling was completed in one day, it ends; otherwise, perform a real-time schedule for the next period.

6. Case study

6.1. Parameters setting

In this paper, the structure of islanded microgrid shown in reference [18] is used to analyze the optimal dispatching of active and reactive power. Two groups of photovoltaic power supply are connected to node 5,12 and wind power unit to node 10 respectively. The controllable power supply in the microgrid includes WT and DG. At the same time, the (Static Capacitor, SC) capacity of the static capacitor is 50kvar. by adding reactive power equipment on the busbar of the microgrid. The maximum allowable deviation from the node voltage is $\pm 7\%$.

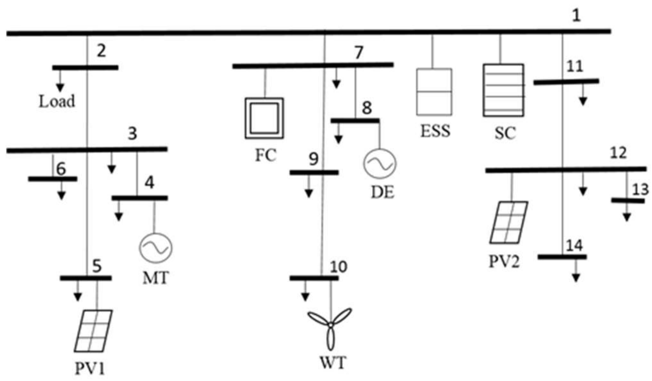

Figure 2. Topology structure of an example of microgrid

See the literature [18] for the parameters of each power supply and circuit. The 14-bus system adopts master-slave control strategy, and the traditional Newton-Raphson method is a common method for power flow calculation in distribution network. The power flow calculation of islanded microgrid under master-slave control strategy is similar to that of traditional distribution network, so the traditional Newton Raphson method is suitable for its calculation. Participating in reactive power regulation are energy storage units and diesel engines, micro gas turbines. Set No.1 node as the balance node of the system, set $V_1 = 1.06p.u.$, $\delta_1 = 0°$ .The rest are PQ nodes.

6.2. An example analysis

In this paper, the wind turbine and photovoltaic output force are used first, under the condition of satisfying the load power demand and the operating constraints of each micro-source, the proposed scheduling model is solved by using SCCSA algorithm, and the active and reactive power output of each micro-source is reasonably allocated. The economical operation cost and node voltage deviation of microgrid are minimized. The optimization result curves are shown in the figures:

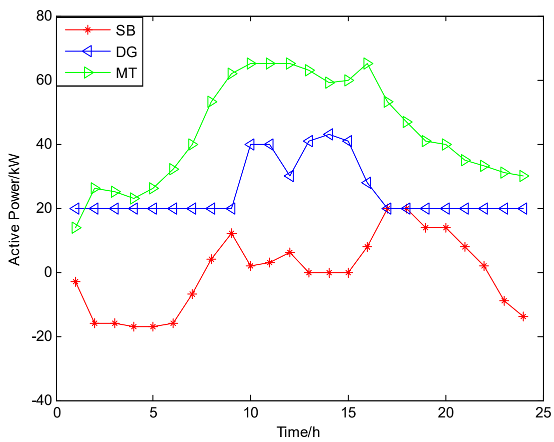

Figure 3. Results of active dispatch of microgrid

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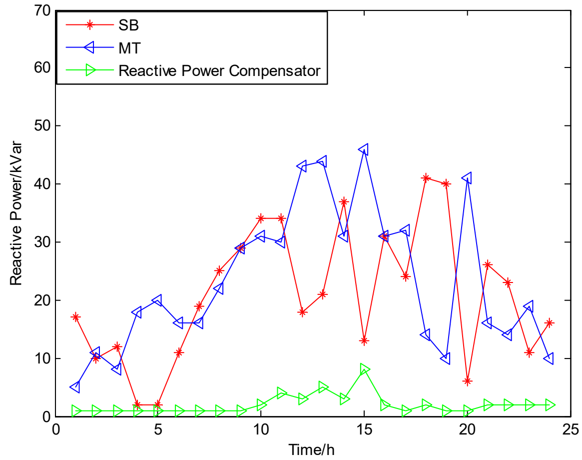

Figure 4. Reactive power dispatching results of microgrid

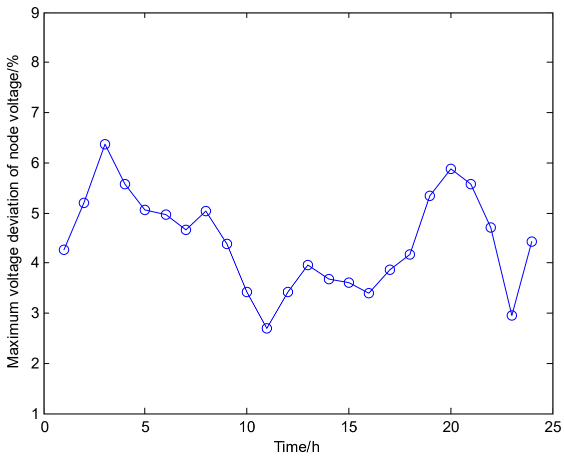

Figure 5. Maximum voltage deviation of node voltage at each time period

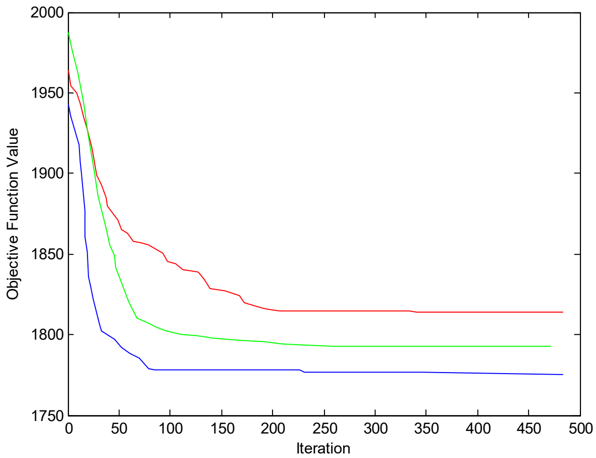

Figure 6. Algorithm comparison chart

Figure 3 shows each part of the active power scheduling results from 1 to 7 periods, the load is relatively small, the wind turbine and photovoltaic priority to transfer the output. For diesel engine and gas turbine, the residual charge produced by each unit is the peak period of system load in the period of 8-17, and the output force of each micro-source increases continuously and reaches the upper limit of active power output. When the energy storage system is in the discharge state of 17, the load begins to decrease and the output force of the micro source decreases gradually. After a period of time, the energy storage equipment starts to charge again.

Figure 4 shows the reactive power dispatch results of the reactive power generating equipment (micro gas turbine, energy storage unit, reactive power compensation equipment) involved in reactive power regulation. It can be seen from the diagram that the reactive power demand of the system is mainly provided by the reactive power compensation equipment. The energy storage unit and the micro gas turbine provide a small amount of reactive power while providing active power, maintain the reactive power balance and play the role of voltage control.

Figure 5 is the maximum deviation of voltage amplitude for each node. The daily average value for 24 periods is 4.35%. From the voltage amplitude curve in the diagram, it can be seen that the node voltage operates within the range of $\pm 7\%$ of the reference voltage.

7. Conclusion

In this paper, a multi-objective economic dispatching model of island micro grid system considering both active and reactive power supply by distributed generation is established. A specific islanded micro grid including wind, light, storage, firewood and micro gas turbine is taken as an example. The SCCSA algorithm and Newton-Raphson method are used to obtain the output results of the active and reactive power of each micro source in the islanded micro grid. A simulation example is given to verify the validity of the proposed model and algorithm.

This paper considers that the reactive output provided by the micro source itself meets the system's reactive demand, reduces the additional investment in installing the reactive compensation device, and is more in line with the actual operation requirements of the islanded micro grid.

As a very effective method to solve multi-objective optimization problems in engineering, crow search algorithm has the advantages of simple algorithm, less parameters and fast convergence speed. In order to overcome the defects of the crow search algorithm, the improved algorithm of sine-cosine crow search is applied to the active and reactive power joint optimal scheduling problem of the islanded micro grid.

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