Optimal economic dispatch of microgrid based on chaos map adaptive annealing particle swarm optimization algorithm

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Abstract. This paper adds chaos optimization based on adaptive annealing particle swarm optimization algorithm, which improves the global convergence ability and makes up for the shortcomings of traditional PSO algorithm, which is easy to fall into local optimization in addition, this paper adds simulated annealing operator, improving the diversity of better population. In addition, the micro source of microgrid is modeled, and the constraints of the model are set. The fitness of the optimized algorithm is compared with the traditional algorithm, and the objective function involved in microgrid dispatching is taken as the application layer. Finally, through data analysis, the effectiveness of the optimization algorithm for microgrid optimal economic dispatching is confirmed.

1. Introduction
Under the current situation, the microgrid acts as a bridge between the traditional grid and the future smart grid. The development of microgrid originated from the present situation of large power supply and distribution pressure, high loss, and high cost of traditional power grids. More and more distributed power sources are connected to the large power grid to relieve the pressure. The distributed power supply is mainly summarized as 35kV and below power supply and energy storage devices. They have many kinds and different forms. The architecture of the microgrid integrates various types of distributed power sources, energy storage devices, energy conversion devices, including loads, which lack dispatching, to form a coordinated and controllable micro power distribution network, which greatly improves the utilization of energy and power quality. At present, domestic and foreign experts and scholars have analyzed the energy dispatch and economic dispatch of the microgrid and have achieved certain results. Reference [1] uses Adaptive Chaos Particle Swarm Optimization (MACPSO) to study how to deal with the multi-objective optimization problem under the influence of multiple mutually influencing and conflicting objectives. Reference [2] takes particle swarm optimization (PSO) as the idea, optimizes two non-inferior solution sets under the multi-objective function, and applies the optimization method to the economic dispatch of microgrid. Reference [3] uses the random weight balance particle swarm algorithm (SWT-PSO) on the basis of an optimized hybrid particle swarm algorithm to solve the problem of economic dispatch in the microgrid, uses an immune mechanism to distinguish the relationship between particles, and introduces a sub-gradient Speed up particle convergence and optimize particle cognition with nonlinear adjustment methods. Reference [4] which is based on the improved artificial fish school algorithm of annealing algorithm (SA_AFSA) researched the energy dispatching of microgrid, and discussed the problems of low accuracy and slow convergence speed of adaptive artificial fish school algorithm in microgrid applications. Reference [5] applies intelligent single particle algorithm to microgrid dispatching, compares the characteristics of intelligent single
particle algorithm and conventional particle swarm algorithm, and discusses its application to intelligent single particle algorithm with the characteristics of faster convergence speed and less optimization time adaptability in the grid. Reference [6] proposed an adaptive annealing particle swarm optimization algorithm based on chaotic mapping. The results show that the improved algorithm is better than adaptive particle swarm optimization and simulated annealing particle swarm optimization for different types of functions. Based on the above existing research, in this paper, the adaptive annealing particle swarm algorithm based on chaotic mapping is used to optimize the economic dispatch of microgrid. Through simulation and data analysis, the results show that the improved algorithm is better than adaptive PSO and simulated annealing PSO when dealing with the economic dispatch problem of microgrid.

2. Mathematical model analysis

In this paper, the wind turbine (WT), photovoltaic array (PV), fuel cell (FC), micro gas turbine (MT) and load involved in microgrid operation are constructed as a whole model. Because it involves many kinds of different distributed generation, it is necessary to analyze the operation characteristics of each module separately when building the mathematical model. The objective function of generation cost of microgrid is described in detail below, and the overall structure is shown in Figure 1.

![Figure 1. Basic structure model of microgrid.](image)

In the figure, PV represents photovoltaic array, FC represents fuel cell, WT represents wind turbine, Bess represents battery energy storage system, MT represents micro gas turbine, and load represents load set.

2.1 Cost model

2.1.1 Wind turbine. The mathematical model of wind turbine is as follows:

\[
P_w = \begin{cases} 
0 & \text{when } V(t) < V_{wi}, V(t) > V_{wo}, \text{ or } P_w = 0; \\
\frac{P_{R}}{V_{\omega} - V_{\omega}} \frac{V(t)^3}{V_{\omega}^3 - V_{\omega}^3} & \text{when } V_{wi} < V(t) < V_{wo}, \text{ or } P_R \text{ is obtained.} 
\end{cases}
\] (1)

Where, when \( V(t) < V_{wi}, V(t) > V_{wo}, P_w = 0; \) when \( V_{wi} < V(t) < V_{wo}, P_R \) is obtained. In this mathematical model, the cut in wind speed of the wind turbine is expressed by \( V_{wi} \), the maximum cut in wind speed that the wind turbine can bear is \( V_{wo} \), and the blade speed of the wind turbine is \( V_R \) at rated power \( P_R \).
At present, the subsidy calculation of distributed wind turbine is as follows:

$$C_{SUB}(t) = P_{WT}(t) \cdot c_{SUB}$$  \hspace{1cm} (2)

Where: the generating power of wind turbine in t period is $P_{WT}(t)$, the unit is kW, the generating subsidy is recorded as $c_{usb}$, the unit is yuan/kW-h.

2.1.2 Fuel cell. The cost of fuel cell is divided into operation cost and environment cost, which is expressed by $C_{FC}$.

$$C_{FC,1} = C_{FC,om} \sum P_{FC,t} \Delta t + C_{fuel} \cdot V_{FC}$$  \hspace{1cm} (3)

$$C_{FC,2} = \sum_{j=1}^{n} \lambda_{j} \cdot k_{j} (V_{FC})$$  \hspace{1cm} (4)

In the above two equations, (3) describes the operating cost per hour of the fuel cell, and (4) describes the environmental cost per hour of the fuel cell. Among them, the operation cost of the fuel cell also includes the maintenance cost involved in the operation, so the operation and maintenance cost $C_{FC,om}$ is added into the formula; the $P_{FC}$ is calculated by adding the $\Delta t$ output power within the time, and the $P_{FC}$ per unit time $V_{FC}$ is the natural gas consumed by the fuel cell when the output power within the time is $P_{FC, t}$.[2]

$$V_{FC} = \frac{\sum P_{FC,t} \Delta t}{\eta_{FC} \cdot LHV}$$  \hspace{1cm} (5)

Power generation efficiency is $\eta_{FC}$. LHV is the low calorific value of natural gas. It can be seen that the cost needs to add up the environmental cost and the operation cost to get the following formula:[2]

$$C_{FC} = C_{FC,1} + C_{FC,2}$$  \hspace{1cm} (6)

2.1.3 Photovoltaic cell. At present, most of the photovoltaic cell materials in the market are polysilicon. Although the conversion rate of polysilicon to solar energy is relatively low in similar products, its cost is cheap and it is convenient for mass production and replacement. Therefore, the photovoltaic cell model adopted in this paper is polysilicon system, and its mathematical model is as follows:

$$P_p = P_{st} \cdot S_{st} \cdot \left[1 + L(T_e - T_{st})\right]$$  \hspace{1cm} (7)

In the formula, $P_p$ is the active power of photovoltaic power generation, $P_{st}$ is the apparent power, $L$ is the temperature coefficient, $T_e$ represents the temperature value of photovoltaic in t period under the current environment, $T_{st}$ is the set temperature, and this temperature is the standard temperature.

At present, the subsidy calculation of distributed photovoltaic generator is as follows:

$$C_{SUB}(t) = P_{PV}(t) \cdot c_{usb}$$  \hspace{1cm} (8)

Where: the generation power of photovoltaic power generation unit in t period is $P_{PV}(t)$, unit is kW, generation subsidy is recorded as $c_{usb}$, unit is yuan/kW-h.

2.1.4 Micro gas turbine model. Micro gas turbine is popular in recent years, its operation requires low maintenance cost, low noise, excellent energy conversion rate, and can be combined with the current Internet of things technology, with the characteristics of remote control and Internet. Its operation needs to consume natural gas, and this combustion process will produce environmental loss. Therefore, when considering the micro gas turbine model, its cost should be divided into two parts.
\[ C_{MT} = C_{MT,R} \sum P_{MT,t} \Delta t + C_{fuel} V_{MT} \]  
\[ C_{MT,E} = \sum_{j=1}^{n} \lambda_j k_j V_{MT} \]

Where \( C_{MT} \) is the operating cost per hour of the micro gas turbine, \( C_{MT,E} \) is the environmental cost per hour of the micro gas turbine, \( C_{MT,R} \) are maintenance costs required for operation, \( P_{MT,t} \) is the output power of the micro gas turbine in the difference time, \( C_{fuel} \) is the price of natural gas, and the volume consumed in the time is \( V_{MT} \). In formula (9), \( n \) is the type of pollutant discharged after natural gas combustion; \( \lambda_j \) is the pollution cost of the \( j \)-th pollutant to the environment; \( k_j \) is the emission rate of different kinds of pollutants.

2.2 objective function

The objective function of microgrid economic dispatch needs to meet the following three points: the lowest generation cost, the highest economic cost and the lowest environmental cost. Therefore, a multi-objective function can be established

\[ F(S) = \text{min} T \cdot \sum_{t=1}^{q} (F_1(t) + F_2(t) - F_3(t)) \]

Where: \( F_1(t), F_2(t), F_3(t) \) represent the generation cost, environmental cost and economic benefit of microgrid respectively. The \( q \) is the total number of scheduling periods, \( t \) is the length of scheduling periods.

2.3 constraint condition

In the economic dispatch of microgrid, there is equality constraint condition and inequality constraint condition. In this kind of scheduling, the equation constraint condition is considered from the conservation of energy and the balance of electric energy, mainly to satisfy the laws of physics and the balance of supply and demand. However, the constraint condition of the inequality is that considering the upper and lower power limits of the distributed power supply, it is necessary to make it meet the maximum and minimum power. Therefore, generally analysis of microgrid dispatching, it is first necessary to analyse the mathematical model of the above distributed power supply, and then list its various cost formulas, and then find out the constraints after establishing the objective function. In view of the exchange power between the grid and the battery, the capacity analysis of the battery in each period is to analyse the restriction conditions after the model is established, as follows:

\[ \sum_{i=1}^{H} P_{i,t} + P_{g,t} + P_{SB,t} = P_{load,t} \]
\[ E_t = E_{t-1} - P_{SB,t} \Delta t \]
\[ P_{i,\text{min}} \leq P_{i,t} \leq P_{i,\text{max}} \]
\[ P_{g,\text{min}} \leq P_{g,t} \leq P_{g,\text{max}} \]
\[ P_{SB,\text{min}} \leq P_{SB,t} \leq P_{SB,\text{max}} \]
\[ E_{\text{min}} \leq E_t \leq E_{\text{max}} \]

In equation (11): The load power at time \( t \) is expressed as \( P_{load,t} \), and \( E \) is the capacity of battery at time \( t \).

In formula (12): it limits the minimum and maximum active power of distributed generation \( i \), the upper and lower limits of power when exchanging with large power grid, the upper and lower limits of
battery power, and the maximum and minimum values of battery capacity. Where $P_{i,t}$ is the actual active power of the battery, $P_{g,t}$ is the actual active power when exchanging with the large power grid, and $P_{SB}$ is the actual active power of the battery.

3. Algorithm description

3.1. Traditional particle swarm optimization

In the field of algorithm, researchers have summed up a lot of algorithm ideas by analysing the survival behavior of all kinds of biological groups in nature. Among them, the famous particle swarm optimization algorithm is born. As early as 1987, biologist Craig Reynolds put forward the bird aggregation model[7]. In 1990, Frank happenner established the bird flight model[8]. In 1995, American social psychologist James Kennedy and electrical engineer Russell Eberhart proposed particle swarm optimization (PSO) on the basis of previous studies. Particle swarm optimization (PSO) is widely used in the field of computation because of its simplicity and rapidity, but it also has some defects, such as low accuracy, easy divergence, easy to fall into local optimal solution[9]. The basic principles of traditional particle swarm optimization are as follows:

Suppose there are $N$ particles in a $d$-dimensional space, $N$ particles as a group and $D$ as a search space, then

$$u_{id}(t + 1) = \omega u_{id}(t) + c_1 r_1(t) (p_{id}(t) - x_{id}(t)) + c_2 r_2(t) (p_{gd}(t) - x_{id}(t))$$

The expansion of the variable $X_{i'd}$ is as follows:

$$x_{id}(t + 1) = x_{id}(t) + u_{id}(t + 1) \quad i = 1,2,\cdots,N; d = 1,2,\cdots,D$$

Where, $\omega$ is the inertia variable, $r_1$ and $r_2$ are two random variables, which are independent of each other and randomly distributed between $[0,1]$. $c_1$ and $c_2$ are acceleration factors, $c_1$ is self cognitive parameter, $c_2$ is social cognitive parameter; $p_{id}$ is the best position of particle $i$, $p_{gd}$ is the best position of population.

3.2. Chaos phenomenon

Chaos Search can adaptively adjust the flying speed and position of particles in PSO. At present, most researches on Chaotic Phenomena are analysed simultaneously with modern algorithms. Such analysis can often lead to an optimization algorithm. This is because Chaotic Phenomena are Asymptotic self-similar ordering. When used as an optimization mechanism in the algorithm, it can avoid the original algorithm falls into a local extremum. Literature [10] proposes to combine Chaotic Search and adaptive inertia weights with traditional PSO algorithm, which can make the particle swarm jump out of the local optimum when it gathers, thereby improving the ability of global convergence. Literature [11] proposed a Chaotic PSO Algorithm, which optimizes the flight speed and position of particles through Chaotic Search.

3.3. Adaptive annealing particle swarm optimization algorithm based on Chaotic Map

The traditional particle swarm algorithm is easy to fall into the local optimum. When chaos optimization is added, it can make up for the shortcomings of the traditional PSO local optimum. In addition, the simulated annealing algorithm has shown superior jump ability in existing research. When simulated annealing operator is added, Operators can better increase the diversity of the population, so the adaptive annealing particle swarm algorithm based on chaotic mapping is obtained in this paper. Mathematical model reference literature [6], the following Figure 2 is the algorithm flow chart:
4. Case analysis of microgrid

4.1. Economic comparison
Microgrid can be used as the mainstream operation mode of economic and energy saving in the future. Its significant advantage is that it can purchase and sell electricity with large power grid, which can not only regulate the operation of large power grid, but also make superior contribution to economic and energy saving. In addition, in distributed generation, wind power generation and photovoltaic power generation are real-time, unstable and phased, so it is necessary to simulate and predict the efficiency and load demand of wind power and photovoltaic power generation, as shown in Figure 3.
The purchase and sale of electricity in microgrid and large power grid are time-sharing pricing, and the prices are different in different peak and valley periods. The specific prices are listed in Table 1 below. Peak time is 10:00 ~ 14:00, 18:00 ~ 21:00, when the user's power demand is high and the load is large; valley time is from 00:00 to 7:00, 21:00 ~ 00:00, when the user's power demand is low and the load is small.

| Time interval  | Electricity selling price (yuan / kWh) | Power purchase price (yuan / kWh) |
|----------------|----------------------------------------|----------------------------------|
| 0:00~7:00      | 0.22                                   | 0.25                             |
| 7:00~10:00     | 0.45                                   | 0.53                             |
| 10:00~15:00    | 0.65                                   | 0.82                             |
| 15:00~18:00    | 0.42                                   | 0.53                             |
| 18:00~21:00    | 0.65                                   | 0.82                             |
| 21:00~0:00     | 0.42                                   | 0.53                             |

Using the traditional particle swarm optimization algorithm, the operation cost of microgrid is 672,4512 yuan; using the adaptive annealing particle swarm optimization algorithm based on chaotic map, the operation cost of microgrid is 645,6131 yuan, saving about 4%. Therefore, it is feasible to apply the optimization algorithm proposed in this paper to the economic dispatch of microgrid.

4.2. Algorithm comparison
In order to analyse the ability of the algorithm mentioned in this paper for micro grid economic dispatch, the traditional particle swarm optimization algorithm and the algorithm in this paper are optimized by multi-objective optimization, and the fitness curve of the adaptive annealing particle swarm optimization algorithm based on chaotic mapping in the search process is drawn, as shown in Figure 4. It can be found that the particle swarm optimization algorithm falls into the local optimal solution at the initial stage, and reaches the global optimal solution only after 759 times the algorithm has reached the global optimal solution in 200 times, which shows that the algorithm used in this paper has achieved the expected requirements.
5. Conclusion
In this paper, the adaptive annealing particle swarm optimization algorithm based on chaos mapping is successfully applied to the economic optimal dispatch of microgrid. The algorithm adds chaos optimization and simulated annealing operator to the traditional PSO. Compared with the traditional algorithm, it is more suitable for the series problem of microgrid dispatch, more efficient than the traditional method, and it is not easy to fall into the local optimal solution the demand for a degree of freedom. Compared with the application of traditional algorithm in microgrid economic dispatch, the application of this algorithm is more excellent for the optimization of economic dispatch, the economic savings can increase with the increase of the scale and quantity of microgrid, at the same time, it also has the effect of saving energy, and at the same time, it also reduces the environmental pollution economic dispatch of power grid is feasible and effective.

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