Economic and environmental optimal operation of isolated multi-element complementary microgrid based on PSO with adaptive mutation

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Abstract. Standalone multi-element complementary microgrid plays a very important role in solving the electricity problems of many areas, which are rich in renewable energy but have problems in the power supply of traditional power grid. To ensure the reliability of power supply while improving overall economic and environmental operation in micro-grid system, we have to optimize the operation of the system according to actual conditions of the system. This paper considered operating costs of the system and gas pollution emissions, established an optimization model. And the dispatch strategies are designed. Finally, utilized adaptive mutation particle swarm optimization algorithm to solve operational problems. Specific case study results verified the reasonableness and effectiveness of the algorithm.

Introduction

With the emergence of the energy crisis and environmental issues, distributed generation, especially wind and solar photovoltaic, has become a hot research topic worldwide. Microgrid is defined as an autonomous system composed of the distributed power, energy conversion devices, load monitoring and protection devices which can achieve self-control and management [1]. Microgrid can integrate a variety of distributed generation technologies effectively, to meet user requirements for higher power quality and supply reliability, giving full play to economical and environmental benefits that the renewable energy bring [2], [3]. Currently, the research on microgrid optimization operation is still in its infancy. Reference [4] studied the optimization scheduling strategy of different scenarios in the microgrid composed of photovoltaic cells and energy storage systems, improved genetic algorithm is used to verified the effectiveness of the proposed method. Reference [5] uses the improved genetic algorithm to solve economical dispatch in isolated microgrid. Reference [6] studied the best operation strategy of microgrid and uses bacterial foraging algorithm to solve microgrid optimization operation problem. Reference [7] studies microgrid optimal scheduling strategy from the economic, technology and enviromental aspects, a comprehensive scheduling strategy based on the combination of genetic algorithm and analytic hierarchy process is proposed in the condition that there are conflicts among different goals. This paper studies isolated microgrid, containing photovoltaic cells(PV), wind turbine(WT), microturbines (MTG), the diesel generator(DIE) and fuel cell(FC). Due to the fact that the reaction speed of MTG and FC is slow and that of loads may be faster, which will pose threat to normal microgrid operation and even lead to the collapse of the microgrid. Therefore, storage battery is added in this paper to ensure fast power balance. In addition, the operation cost of the system and exhaust gas pollution are considered, the operation cost is composed of fuel costs, system operation and maintenance costs and battery depreciation costs, while the energy penalty fee, the cost of power loss and power subsidies are introduced. Finally, microgrid optimization operation problem

is solved by modified self-adaptive particle swarm algorithm

Independent multivariable microgrid optimization model

A. The establishment of objective function
Based on the local requirements and actual situation, this paper set the corresponding weights to the two objectives above and the multi-objective problem is transformed into a single goal to be addressed by linear weighting.

1) Objective 1:Minimal operating costs.

   a) fuel cost
   The fuel costs of MTG relates to its work efficiency[8].

$$F_{MTG} = C \frac{1}{V_{LHV}} \frac{P_{MTG}}{\eta_{MTG}} \tag{1}$$

   Where the F_{MTG} represents fuel cost per unit time, C represents gas price, which is yuan/m3，V_{LHV} represents low-hot value of natural gas, which is 9.7kWh/m3, η_{MTG} represents the working efficiency of MTG.

   The fuel cost of FC is similar to that of MTG，

$$F_{FC} = C \frac{1}{V_{LHV}} \frac{P_{FC}}{\eta_{FC}} \tag{2}$$

   Where F_{FC} represents fuel cost per unit time, η_{FC} represents the working efficiency, P_{FC} represents output power.

   The fuel cost of DIE is consumption characteristic function and it can expressed，

$$F_{DIE} = a + bP_{DIE} + cP_{DIE}^2 \tag{3}$$

   Where a, b and c are fuel cost coeffients.

   b) operation and maintenance costs
   The microgrid operation and maintenance costs of each unit relate to each power generation unit,

$$E = \sum_{i=1}^{N} k_i P_i \tag{4}$$

   Where N represents the number of microsources, P_i represents the ith microsource output power; k_i represents the ith microsource operation and maintanence cost.

   c) the depreciation costs of battery
   Because the amount of charging and discharging remain constant in the life circle [9], depreciation costs are expressed as follows，

$$C_{old} = \frac{C_{rep}}{Q_{life}} \tag{5}$$

   Where, C_{old} is depreciation cost when the battery charge or discharge 1kW • h; C_{rep} is the battery replacement costs; Q_{life} is the total amount of charging or discharging in the life cycle of the battery.

   d) the penalty fee of energy wasting
   When the battery is fully charged, if surplus electricity still occurs, the extra power has to be wasted. To avoid the waste of energy, so the penalty fee of energy wasting is introduced.

$$C_{waste} = \int_0^T k_{waste} P_{waste}(t) dt \tag{6}$$

   Where k_{waste} is the cofficient of energy wasting penalty (yuan/kWh), $P_{waste}(t)$ is the surplus power(kW).

   e) the cost of power failure
   For independent micro-sources, when the internal power sources and energy storage systems can not meet the loads, part of the non-essential load will be cut off, so the cost of power failure is introduced.

$$C_{loss} = \int_0^T k_{loss} P_{loss}(t) dt \tag{7}$$

Where the k_{loss} represents the coefficient of power failure cost and $P_{loss}(t)$ represents the power vacancy.

f) generation subsidy

Due to the fact that the renewable generation such as wind power and photovoltaic cell is encouraged by governments and the generation subsidy is introduced [10],

$$C_{subsidy} = k_{subsidy} \int_0^T P_{subsidy}(t)dt \tag{8}$$

Where the $k_{subsidy}$ represents the subsidy coefficient (yuan/kW·h), $P_{subsidy}(t)$ is the output power of renewable energy(kW).

Based on the six costs above, the overall operating cost of the system is as follows,

$$C_{total} = F_{MTG} + F_{FC} + F_{DIE} + E + C_{old} + C_{waste} - C_{subsidy} \tag{9}$$

The first objective function is

$$f_1 = \min C_{total} = f(P_1, P_2, ..., P_N) \tag{10}$$

2) Objective 2:Minimal operating costs.

The photovoltaic cells, wind turbine, battery does not produce polluted gases, MTG, FC, DIE are the major sources of polluted gases, mainly emitting CO2, NOx, SOx, their ability of emitting polluted gases is measured by emission factors. In this paper, The damage caused by the various polluting gases to the environment is characterized by conversion cost factor. Thus, the pollution degree of the environment is characterized by,

$$f_1 = \min C_{total} = f(P_1, P_2, ..., P_N) \tag{11}$$

When i equals to 1,2 or 3, $P_i(t)$ corresponds to the output power of MTG、FC and DIE respectively. When j equals to 1,2 and 3, K_i (g/kW·h) corresponds to the coefficients of CO_2, NO_x and SO_x respectively and S_j (yuan/kg) corresponds to the coefficients of CO_2, NO_x and SO_x respectively.

The second objective function is:

$$f_2 = \min E_{harm} = f(P_1, P_2, ..., P_N) \tag{12}$$

According to local requirements and the actual situation, economical and environmental objectives are given corresponding weights, and the third objective function can be obtained by the linear weight:

$$f_3 = \min(\lambda_1 C_{total} + \lambda_2 E_{harm}) = f(P_1, P_2, ..., P_N) \tag{13}$$

Where $\lambda_1 + \lambda_2 = 1$, $0 \le \lambda_1 \le 1$ and $0 \le \lambda_2 \le 1$.

B Constraints

1) power balance constraint

$$\sum_{i=1}^{N} P_{dgi}(t) = P_{load}(t) + P_{BAT}(t) \tag{14}$$

Where N represents the number of microsources; $P_{dgi}(t)$ represents ith micrsource output power; $P_{BAT}(t)$ represents charging or discharging rate of energy storage unit and its sign is a plus in charging and a minus in discharging; $P_{load}(t)$ is the total load.

2) Power limit constraints

$$P_i^{min} \le P_i \le P_i^{max}, \forall i = 1, ..., N \tag{15}$$

Where P_i^{max} and P_i^{min} are the maximum and minimum output power of the ith microsource, N is the number of microsources.

3) Constraints on Batteries

$$SOC_{min} \le SOC \le SOC_{max} \tag{16}$$

Where SOC_{min} and SOC_{max} are the minimum and maximum of residual capacity for battery, generally $SOC_{min} = 0.1 \sim 0.2$, $SOC_{max} = 0.8 \sim 0.9$. In order to make battery firstly coming into use be able to charge or discharge, the value of $SOC(0)$ is set at $0.5 \sim 0.6$.

In order to prevent over charge and over discharge, the limit of maximum charge/discharge current and rate are taken into account, so the constraints on charging and discharging rate are as follows:

$$P_{c\,max} \le P_{BAT}(t) \le P_{d\,max} \tag{17}$$

Where the P_{cmax} is the lower limit of the battery output power representing charging power, whose sign is a minus and the P_{cmax} is the upper limit of the battery output power, representing discharging power, whose sign is a plus.

The solutions

The difference between the adaptive particle swarm algorithm and standard particle swarm algorithm is as follows.

A Inertia weight changes with the search process self-adaptively

In the standard particle swarm algorithm, inertia weight ω commonly remain constant or a decreasing trend, the adjustment for search capacity is limited, which cannot be well adapted to non-linear and high-dimensional complex practical problems. In this paper, ω is adjusted according to the difference of optimal fitness.

$$\overline{f} = \frac{1}{6} \sum_{t=i-6}^{i-1} fitness(t) \tag{18}$$

$$k = \frac{1}{6} \sum_{t=i-6}^{i-1} (fitness(t) - \overline{f})^2 \tag{19}$$

$$w = \begin{cases} 0.9, & i<7 \\ 0.6 + rand/2, & i>6 \text{ and } k \geq 0.01 \\ 0.2 + rand/4, & i>6 \text{ and } k<0.01 \end{cases} \tag{20}$$

Where, *fitness*(t) is the optimal fitness value of the t-th iteration, $\overline{f}$ is the mean value of optimal fitness value in 6 iterations; rand is uniformly distributed random number between 0 and 1. When $k \geq 0.01$, the differences of the optimal fitness value among 6 iterations are large, representing the population is at the exploratory stage, w take a larger value is in favor of speeding up the algorithm convergence. When $k<0.01$, the differences of the optimal fitness value among 6 iterations are little, w take a smaller value is in favor of fine search to get accurate solution.

B Use mutation in particle swarm algorithm for reference

In this paper, the advantages of genetic algorithm are used for reference, the mutation is introduced and the diversity of the population is increased to allow the algorithm to escape from local optimal solution and ultimately obtain global optimal solution.

When the population is seriously lack of diversity or optimal fitness value remain constant for a long time, then perform mutation. The average distance D in each iteration characterizes the degree of population diversity. Whether the fitness value remain constant can be judged by the optimal fitness differences k, the formula to calculate k is similar to (19).

$$D = \frac{1}{N \cdot L} \sum_{i=1}^{N} \sqrt{\sum_{d=1}^{n} (x_{id}^t - \overline{x_d})^2} \tag{21}$$

Where N represents the population size, L is a diagonal length of the search space, t_{xid} represents the tth iteration, the ith particle and dth dimensional coordinate values, x_d is the mean value of the dth dimensional coordinates of all the particles.

When $D<0.001$ or $k<0.01$, mutation is performed. the process is that each particle is sorted in accordance with the quality of the fitness values [11] and take the corresponding number of particles with best fitness value to mutate.

$$x_{id}^t = x_{id}^t [1 + 0.25(rand_1 - rand_2)] \tag{22}$$

Where $rand_1$ and $rand_2$ are random numbers between 0 and 1.

Test results

A Case introduction and parameter setting

The rated capacity of PV, WT, DIE, FC, MTG and BAT are 15kW, 15kW, 8kW, 6kW, 10kW and 6kW respectively in this case. The hourly data of load is shown in Fig.1 in a day, The predicted output power of PV and WT is shown in Fig.2, the coefficients of operation and maintenance cost , the polluted gases emission and conversion cost is shown in in Table I, Table II and Table III respectively, the operation and scheduling period is 1h.
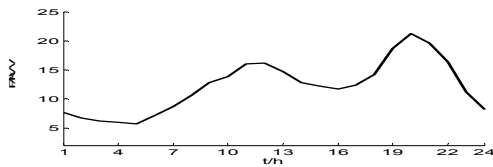

Fig.1 Forecast data of hourly load power in a day
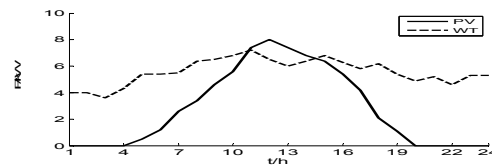
Fig.2 Forecast data of PV and WT output power in a day

Table 1. maintenance costs of each power source

Microsources	WT	PV	MTG	DIE	FC	BAT
k_i	0.0296	0.0096	0.0385	0.0825	0.04	0.0275

Table 3. Discounted cost coefficients of polluting gases

Gas type	CO_2	NO_x	SO_x
conversion cost	0.11	27.54	6.49

Table 2. emission coefficients of polluting gases

Emission type	MTG emission Factor(g/kW·h）	FC emission Factor(g/kW·h）	DIE emission factor(g/ kW·h）
CO_2	1.6	1.625	1.432
NO_x	0.44	0.023	21.890
SO_x	0.008	0.006	0.406

Gas is 2 yuan/m³, the low-hot value is 9.7kW•h / m3,the generation efficiency of full cell is 50%, the consumption parameters a, b and c of DIE are 6, 0.012 and 0.00085 respectively, the replacement costs of battery is 90 yuan, the total amount of battery charging or discharging in the life cycle is 100kW•h, the coefficient of energy wasting penalty is 0.2, the subsidy coefficient is 0.4, power failure cost factor is 0.3, the value of $SOC(0)$ is 0.5, the range of SOC is from 0.1 to 0.8, and the limit of battery charging or discharging is 1kW.

The population size is 20, the maximum number of iterations is 200, learning factor c1 and c2 are both 1.49445 and the mutation rate is 0.2.

B Optimization Results and Analysis

Microgrid operates to achieve object 1, the output power each hour of DIE, FC and MTGs are shown in Fig.3, the operating cost each hour is shown in Fig.4, the total cost of a day is 118.3237 yuan, and the charge or discharge power of the battery is shown in Fig.5.
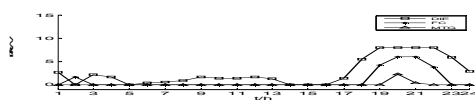

Fig.3 Hourly output of DIE, FC and MTG based on objective 1
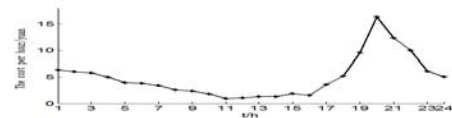
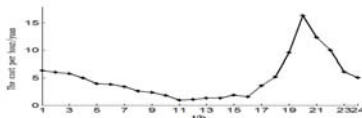

Fig.4 Hourly operating cost based on objective 1

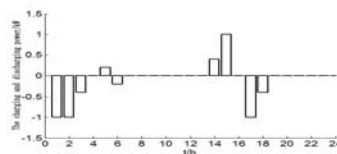Fig.4 Hourly operating cost based on objective 1

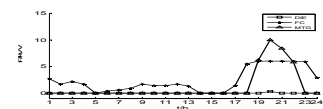Fig.5 Battery charge and discharge power of each hour

Fig.6 Hourly output of DIE,FC and MTG based on objective 2

Microgrid operates to achieve object 2, the output power each hour of DIE,FC and MTGs are shown in Fig.6 and the charge or discharge power of the battery is shown in Fig.5.

Microgrid operates to achieve object 3, assume $\lambda_1 = \lambda_2 = 0.5$ and then the output power of DIE,

FC and MTG each hour are shown in Fig.7, the operating cost each hour is shown in Fig.8, the total cost of a day is 74.7315 yuan, and the charge or discharge power of the battery is shown in Fig.6.
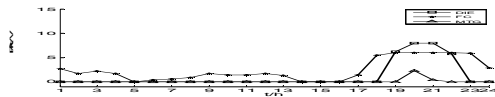

Fig.7 Hourly output of DIE、FC and MTG based on objective 3
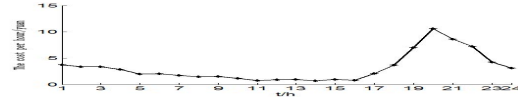
Fig.8 Hourly cost based on objective 3

Fig.3 to Fig.8 shows that when the microgrid operates mainly for economical objective, PV, WT, DIE are the main power generation unit, FC and MTG are the back up power, when the system operates mainly for enviromental objective, PV, WT, FC are the main power generation units, DIE and MTG are the back-up power. the utilization of renewable energy greatly reduces the emissions of polluted gases. When power generation is greater than the load, the extra power is substantially absorbed by the battery. When power shortage occurs, battery is the first to discharge. In addition, the value of λ_1 and λ_2 can be modified to focus on different optimization objectives.

Conclusion

Multiple independent complementary microgrid play a very important role in supplying power to places where the renewable resources are abundant but it is difficult for traditional power grids to supply power. From the perspective of economic and environmental operation, considering the system's operating costs, environmental pollution, the effective optimization model is established and reasonable scheduling strategy is designed. By combining specific case, self-adaptive particle swarm algorithm with mutation is used to solve the microgrid optimization problem, which provide a theoretical basis for studying microgrid effective reasonable operation further.

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