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Optimal Dispatching of Microgrid for Island Operation Based on Improved Particle Swarm Algorithm

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Abstract

With the development of the national economy, people's demand for electricity continues to increase, but in some remote areas such as islands and mountain areas, it is usually far away from the conventional large power grid, and it is difficult to get a good power supply. These areas generally contain abundant renewable energy, such as wind and solar energy. Therefore, in these areas, priority can be given to the development of micro-grids for clean energy power generation, making full use of renewable energy sources such as wind energy and solar energy to achieve self-sufficiency. However, wind energy and solar energy depend on natural conditions and have obvious randomness and volatility. Therefore, it is necessary to determine the control strategy of this island-operated microgrid and ensure its economic efficiency. This paper takes wind / solar /diesel engine/ storage island operation microgrid as an example to study the optimal control strategy of this microgrid in island mode, and uses an improved particle swarm optimization algorithm to optimize. The results show that the operation results can meet the needs of users. Both economical.

Keywords

Manuscripts; Microgrid; Improved particle swarm optimization algorithm; Optimal dispatch.

1. INTRODUCTION

The island-operated microgrid can effectively solve the power supply problem in remote areas, such as islands and remote mountain areas, which plays an important role in improving the quality of life in such areas. In recent years, domestic and foreign scholars have carried out a series of researches on independent microgrids. Among them, island microgrid optimization scheduling is an important problem to be solved for design of independent microgrids, and it is one of particularly important factor to maximize the benefits of the entire microgrid system. In this paper, the island operation microgrid model is used as a prototype, and the improved PSO is adopted. With the lowest comprehensive operating cost as the objective function, the upper and lower limits of the state of charge of the battery during operation, the scale limitation of the island operation microgrid, and the output of various micropower sources are employed to limit and the power balance limit in the system are used as constraints, we formulate an operation scheduling strategy for operating the microgrid in the island mode. The improved particle swarm optimization algorithm is used to solve the optimal operation scheduling strategy, and by comparing the operation results of the basic particle swarm optimization algorithm and the improved particle swarm optimization algorithm, it is proved that the improved particle swarm optimization algorithm has faster convergence speed and more excellent convergence accuracy, which provides the necessary theoretical basis for the optimal design of island-operated microgrids.

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2. PROPERTIES

2.1. Main Structure Modeling of A Microgrid With Wind, Solar, Diesel and Storage.

The microgrid in this paper is a typical small commercial microgrid structure. The distributed power sources coordinately provide stable power to local loads, including wind turbines, photovoltaic generators, diesel generators, and energy storage systems First of all, the modeling and simulation of the distributed power supply structure mainly contains the following modules:

2.1.1 Wind turbine model

As a rich new energy, wind is getting more widely used. The wind power source is one of good ways to utilize the wind energy. The wind generator can drive the fan to rotate the blades by the wind, and then convert the wind energy into mechanical energy, after which the mechanical energy can be converted into the electrical energy. The wind turbine power expression can be expressed as:

$$P_{WG}(t)=\begin{cases}0, v(t)\le v_{ci}\\ a(v(t))^3-bP_r, v_{ci}\le v(t)\le v_r\\ P_r, v_r\le v(t)\le v_{co}\\ 0, v(t)\ge v_{co}\end{cases} \tag{1}$$

Where, Vr is the rated wind speed, Pr is the rated power, Vci is the cut-in wind speed, Vco is the cut-out wind speed, and the fan will only output power when the wind speed is between the cut-in wind speed and the cut-out wind speed.

2.1.2 Photovoltaic power generation model

The output power of the photovoltaic array is related to light intensity, temperature and other factors. The mathematical expression of its nonlinear output power is:

$$P_{PV}(\mathrm{t})=f_{PV}P_{STC}\frac{G_C(t)}{G_{STC}}[1+k(T_c(t)-T_{c,STC})] \tag{2}$$

Where, GSTC = 1000KW / m2 under standard test conditions (STC), and the surface temperature of the photovoltaic cell TSTC = 25°C; fPV is the derating factor of the photovoltaic array, which means that in actual situations, there is a certain amount of loss of the photovoltaic panel in the calculation due to some reasons, and fPV is usually taken as 0.9; GC(t) represents the light intensity. TC(t) represents temperature; k is the power temperature coefficient. Generally, the value of k is very small and can be ignored, so the above formula can be simplified as:

$$P_{pv}(t)=0.9\cdot P_{STC}\frac{G_c(t)}{G_{STC}} \tag{3}$$

2.1.3 Diesel engine controlling

The diesel generator uses diesel as the main raw material, and uses the diesel engine as the prime mover to drive the generator to generate electricity, which is a common small-scale power generation equipment and plays a very important role as a supplement to the entire system in the microgrid.

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2.1.4 Energy storage system model

Effectively regulating the load fluctuations of the power grid, achieving smooth operation of the power grid, and stable power supply are the main features of the microgrid. The charging and discharging of the energy storage system in the microgrid is an effective way to achieve the above functions. Therefore, the role of energy storage systems in the microgrid is crucial. The energy storage system in the microgrid studied in this paper consists of a battery and a supercapacitor. Generally, the supercapacitor is responsible for the high-frequency part of the load fluctuation, and the battery is responsible for the low-frequency part, which is often larger. The actual capacity is not the same as the rated capacity during the operation of the battery. The mathematical expression of the relationship between the actual capacity and the use of temperature can be obtained by:

$$E(t) = E_{STC}[1+\delta_B(T(t)-T_{STC})] \tag{4}$$

Where, ESTC is the rated capacity under standard test conditions; δB is the capacity temperature coefficient, which represents the temperature effect on the actual capacity of the battery, which is generally setted to 0.006, T(t) is the battery operating temperature, and TSTC is 25 ° C.

2.2. Improved Particle Swarm Optimization

Particle swarm optimization (PSO) was proposed in 1995, by exploring bird species clusters for food, it is founded that although a bird in the bird group does not know the exact location of the food, because the bird itself has some experience, and each bird in the bird group has certain interaction, they will update the direction until finding foods.

The main idea of the basic PSO algorithm is that members of the group can learn from their own experience during the activity, or learn from the social experience of others, and then they can achieve information sharing and collaboration through individual information exchange in the interactive environment of the group. Eventually the speed of particles will be dynamically changed to achieve the optimization of group behavior.

$$\frac{dw(\mathrm{k})}{dt} = \frac{2\left(w_{\max}-w_{\min}\right)}{\mathrm{k}_{\max}{}^{2}} \times \mathrm{k} \tag{5}$$

After simplification we can get:

$$w(\mathrm{k}) = w_{\max} - \frac{\left(w_{\max}-w_{\min}\right)}{\mathrm{k}_{\max}{}^{2}} \times \mathrm{k}^2 \tag{6}$$

Where w is the inertia weight, wmax is the maximum inertia weight, wmin is the minimum inertia weight, k is the current number of iterations, and kmax is the total number of iterations. In the initial iteration, the inertial weight w is relatively large, and it has a good global search ability; as the number of iterations accumulates, the value of w and the speed of the particles becomes smaller and smaller. At this time, the particles have good local search capabilities.

The classic test function is emplied to test the particle swarm algorithm before and after the improvement.

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Test function: find the maximum value of the Rastrigin function and get the position of the maximum value, where the expression of the Rastrigin function is shown as:

$$f(x)=\sum_{i=1}^{n}\left[x_i^2-10\cos(2\Pi x_i)+10\right] \tag{7}$$

The Rastrigin function is a multi-peak function. Figure 1 shows that the improved particle swarm algorithm can quickly find the maximum value after a relatively small number of iterations, while the basic particle swarm algorithm before improvement has a slower convergence rate. Figure 2 represents the change of the value of the optimal solution on the three-dimensional image. The results of data shown in Table 1 can be obtained by comparing the average results of multiple tests. By analyzing the results, we can get that the average number of iterations of the PSO before convergence is 127 and the improved number is 45, indicating that the improved PSO can increase the convergence speed of the particle swarm. The success rate of the PSO optimization before improvement is 54% and the improved one is 94%. It shows that the improved PSO can also raise the success rate of the particle swarm algorithm, which proves that the improved PSO can search for the optimal solution better and faster.

Table 1. Rastrigin function performance analysis of different algorithms

Type of algorithms	Number of experiments	Convergence times	Number of iterations	Number of iterations at convergence	Success rate
Basic PSO	100	54	300	127	54%
Improved PSO	100	94	300	45	94%

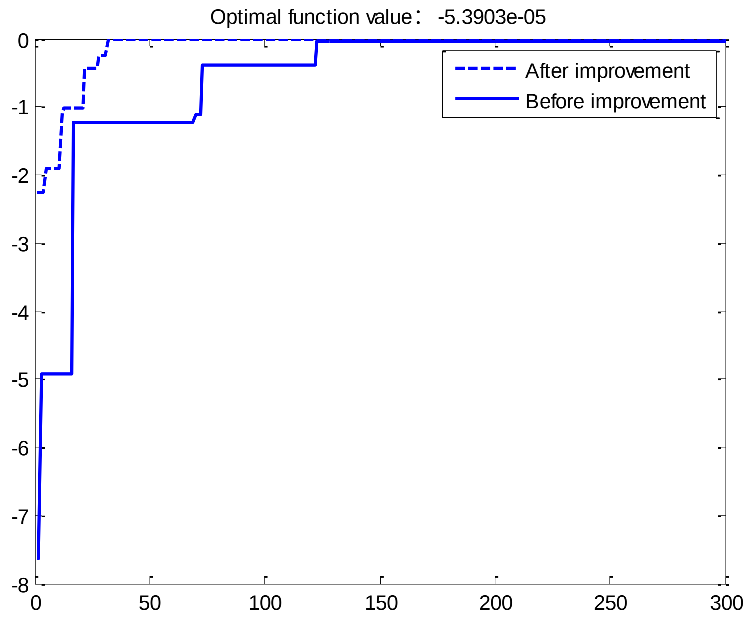

Figure 1. Change curve of fitness function value

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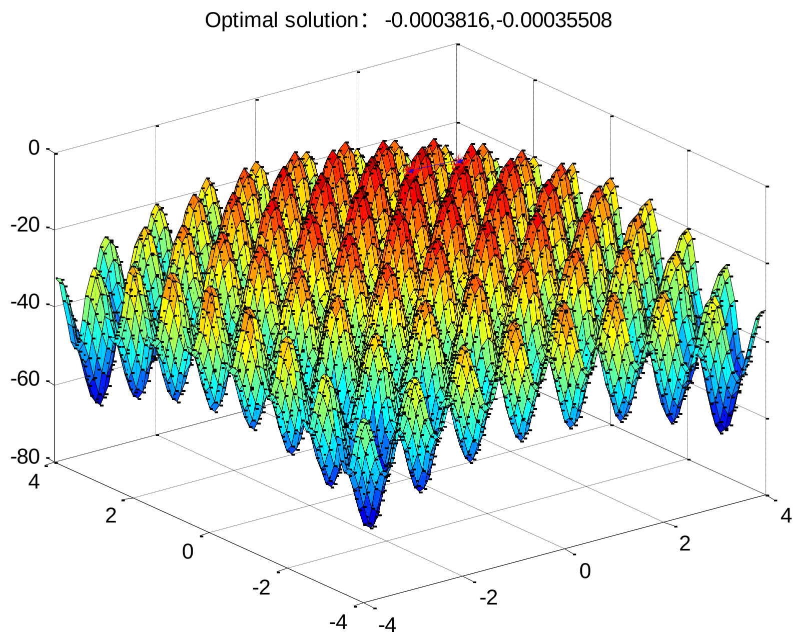

Figure 2. Rastrigin function image

2.3. Objective Function

Taking the minimum value of the integrated operation cost of the microgrid as the objective function of the optimization model, the optimal solution is obtained through the algorithm to achieve the purpose of improving the economic operation of the microgrid. The objective function can be expressed as:

$$C_1(P)=\min\sum_{t=1}^{T}\Big(F_1\big(P(t)\big)+F_2\big(P(t)\big)+F_3\big(P(t)\big)\Big) \tag{8}$$

Where, $C_1(P)$ represents the operating cost of the microgrid; $F_1(P(t))$ represents the fuel cost of the diesel generator in the microgrid at time t, and $F_2(P(t))$ represents the operation and maintenance cost of each micro-power source in the microgrid at time t, $F_3(P(t))$ represents the environmental punishment cost for each micro-power source in the micro-grid to emit polluting gas at time t for pollution control.

2.3.1. Fuel cost of diesel generator

The island-operated micro-grid studied in this paper is only composed of wind power, photovoltaic power, diesel power and energy storage units. The fuel cost is mainly generated by diesel generators. The following formula is the fuel cost of diesel generators during operation. function.

$$F_1\big(P(t)\big)=\sum_{i=1}^{n}C_i\big(P_i(t)\big) \tag{9}$$

Where, $C_i(P_i(t))$ represents the fuel cost of the micro power supply i at time t.

2.3.2 Operation and maintenance cost of micro power supply

Since each micro-power source in the micro-grid requires operation and maintenance, the cost sources mainly include periodic inspection and maintenance of equipment, fault repair and replacement, and human operation and maintenance. The operation and maintenance cost is

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generally proportional to the electric power of the micro power supply. The following formula is the calculation formula of the operation and maintenance cost of the micro power supply:

$$F_2\left(P(t)\right)=\sum_{i=1}^{n}\xi_i\left(P_i\left(t\right)\right) \tag{10}$$

Where, ξ_i represents the coefficient of maintenance cost of micro power supply i, and $P_i(t)$ represents the power output of micro power supply i at time t

2.3.3. Environmental governance costs

Wind power generation and photovoltaic cells in the micro-grid do not generate polluting gases due to the use of clean green energy such as wind and light. The diesel generator type micro-power source uses fuel diesel to generate electricity, so it will produce a series of polluting gases and cause certain harm to the environment. The pollutant gas produced by diesel generators mainly includes sulfur dioxide, carbon dioxide, nitrogen oxides, etc. The amount of pollutant gas generated by the micro power supply can be estimated based on the amount of electricity generated by the micro power supply. For different polluting gases, there will be different gas penalty coefficients and penalty fees. The environmental governance penalty cost of the microgrid can be obtained by:

$$F_3\left(P(t)\right)=\sum_{i=1}^{n}\sum_{j=1}^{n}\left(\xi_{ij}\times P_i\left(t\right)+\zeta_{ij}\times P_i\left(t\right)^2\right)\times f_j \tag{11}$$

Where, ξ_{ij} and ζ_{ij} represent the penalty cost calculation coefficient of the jth gas emission of the micro power supply, f_j represents the environmental penalty cost rate of the jth polluting gas, and n represents the corresponding types of polluting gases number.

3. TESTS

3.1. Planning

Taking a typical microgrid in a certain place as an example. The distributed power supply in this microgrid mainly includes wind power units, photovoltaic power generation units, diesel engine power generation and energy storage systems. It is known that the wind speed, light intensity and temperature data on a typical day here are as shown in Fig. 3, Fig. 4 and Fig. 5. The load on this typical day is shown in Fig. 6. The maximum output of wind and light can be obtained by wind speed, temperature and light intensity

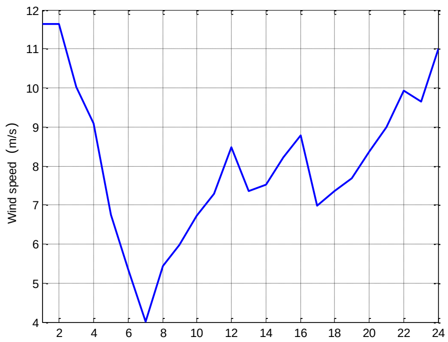

Figure 3. Typical daily wind speed curve

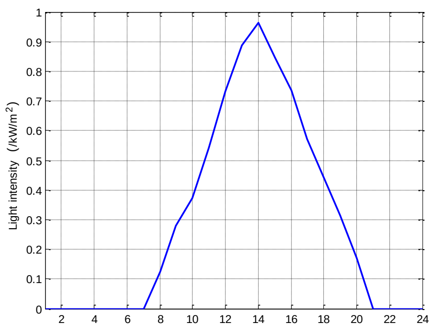

Figure 4. Typical daylight intensity curve

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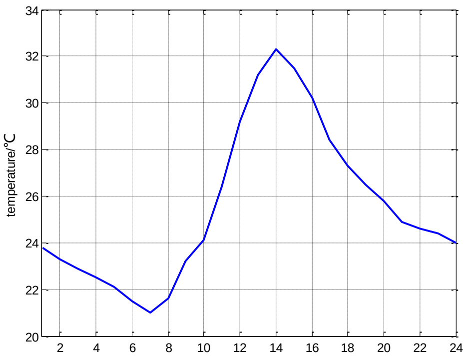

Figure 5. Typical daily temperature curve

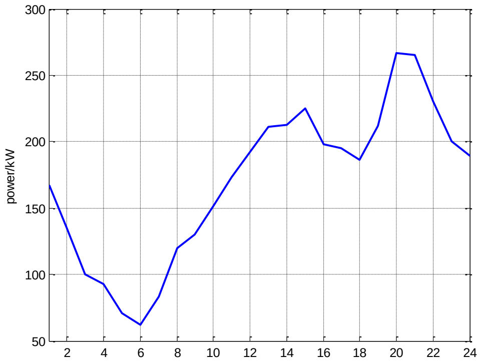

Figure 6. Typical daily load curve

The main parameters of the improved particle swarm algorithm are set as follows: population size M = 40, inertia weight factors w_{max} = 0.9, w_{min} = 0.4, learning factors $c1$ and $c2$ are set to $C1$e = $C2s$ = 0.5, $C1s$ = $C2e$ = 0.5, maximum speed V_{max} is 2 and the maximum number of iterations K_{max} is 300.

When calculating the operating cost of the microgrid, the operation and maintenance cost of the micro power supply equipment is an important operating cost. Therefore, the operating cost coefficient of each micro power supply equipment must be known, and the operation and maintenance can be calculated through the data given in Table 2 The fuel will emit a large amount of polluting gases during power generation. In order to correctly estimate the adverse effects of these polluting gases on the environment, this article considers the environmental treatment costs caused by polluting emissions, corresponding to different pollution The management fees for different types of objects are shown in Table 3.

Table 2. Parameters of distributed power

project name	specification	Quantity	capacity	cost/Ten thousand yuan	Service life/year	Operation and maintenance costs coefficient(yuan/kW)
Wind Turbine	30kW	3	90kW	180.0	20	0.00460
Photovoltaic power generation system	180W	556	110kW	110.0	25	0.00252
Diesel generators	200kW	1	200kW	15.0	15	0.02703
Lead-acid batteries	2V/1000Ah	25	50kW·h	4.5	10	0.02648

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Table 3. Pollutant discharge environmental treatment costs

Type of pollutant	NO_x	CO2	CO	SO2
Pollutant emission coefficient (g/kW • h)	0.023	635	0.054	0.464
Penalty factor ξ_{ij}	1	0.002875	0.125	0.75
Penalty factor ζ_{ij}	0.25	0.00125	0.02	0.125
Penalty rate f_j	1.633975	0.008169	0.130718	0.816987

In the island mode, the load demand of the microgrid is supplied by distributed power. When the electrical energy generated by renewable resources such as wind / light cannot meet the system load demand, the diesel generator and energy storage system can be used to discharge. When the electrical energy generated in the system is excessive, the battery can be charged to ensure the load demand during the peak period.

Control strategies are mainly divided into two categories: load following strategy and cyclic charge and discharge strategy: load following refers to using diesel engine as the main power reserve to follow the fluctuation of load, using battery as auxiliary reserve to supplement the missing part of diesel engine, and coordinated operation to ensure the island power balance of the microgrid. Control strategies are mainly divided into two categories: load following strategy and cyclic charge and discharge strategy: load following refers to using diesel engine as the main power reserve to follow the fluctuation of load, using battery as auxiliary reserve to supplement the losing part of diesel engine, and coordinately operating to ensure the island power balance of the microgrid. The cyclic charge and discharge strategy refers to the priority to use the battery to supplement the shortfall after the wind power reaches the maximum output power. After the diesel engine compensates the wind power storage power, it still cannot meet the load requirements. The cyclic charge and discharge strategy can maximize the use of the battery and can reduce pollution, but frequent charging and discharging will affect the service life of the battery. This paper makes corresponding improvements to the cycle charging strategy. When the battery compensation still cannot meet the load demand, the diesel engine is used to compensate together, and the supplementary role of the battery and the diesel engine is fully exerted. Discharge. Figure 7 shows the overall operation of the microgrid after optimization.

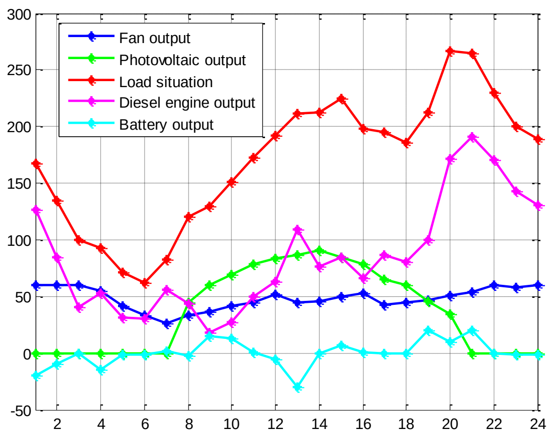

Figure 7. Overall operation of microgrid

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Table 4 is a table of average costs obtained after running 10 times optimized control strategy. It can be seen that the optimized island microgrid can significantly save operating costs. At the same time, the operation optimization strategy under the micro-grid island operation mode can also realize the optimal comprehensive income of the micro-grid under the safe operation condition. From the data results in Table 3.3, it can also be obtained that the use of clean energy for power generation can effectively reduce environmental costs and can make full use of natural resources. This micro-grid model can be widely promoted in regions with rich natural resources such as isolated islands and remote mountain areas.

Table 4. Comparison of comprehensive costs before and after optimization

	Before optimization	After optimization	save costs
Operating costs($\times 10^6$yuan)	7.65450	3.79838	3.85612

In order to prove the advantages of the improved particle swarm optimization algorithm, a standard particle swarm optimization algorithm was used to perform optimization experiments. Each algorithm was run 100 times, and the average result was finally obtained. The experimental results are shown in Table 5 below. By comparing the convergence results, we can see that the basic particle swarm algorithm tends to stabilize the results on average 159 iterations and the improved particle swarm algorithm tends to stabilize on average 48 iterations. The basic particle swarm optimization algorithm achieved convergence results only 68 times out of 100 experiments, proving that the success rate was 68%, while the improved particle swarm optimization algorithm converged 94 times out of 100 experiments, with a success rate of 94% It can be proved that the improved particle swarm optimization algorithm has better optimization accuracy and faster convergence speed, and can achieve the optimization goal of this paper.

Table 5. Performance analysis of different algorithms

Algorithm type	Number of experiments	Convergence times	Number of iterations	Number of iterations at convergence	save costs ($\times 10^6$yuan)
Basic PSO	100	68	300	159	3.04318
Improved PSO	100	94	300	48	3.319284

4. CONCLUSION

This paper takes wind / solar / diesel / storage island operation microgrid as an example to study the optimal control strategy of this microgrid in island mode to make it economical while satisfying user needs. Research on the optimization strategy of distributed power supply in island microgrid is an important research content to promote the development of distributed power supply and make up for the shortcomings of traditional large power grid. Since the objective function of the optimal operation model of the microgrid is a multi-objective function with many constraints, it is easy to fall into the local optimal value when solving its optimal solution. In this paper, an improved particle swarm algorithm is used. The algorithm can prevent it from falling into the local optimal value and get the optimal solution faster and more accurately. The research in this paper can provide a certain model basis for power system

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operation optimization, and make a certain contribution to the application of microgrid optimization theory to practice.

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