Micro-grid Capacity Optimisation with a Modified Particle Swarm Optimisation Algorithm

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Abstract— **Particle swarm algorithm the search speed is quick, simple calculation, the efficiency high characteristic, is suitable for the optimization problem of single objective function.But the basic particle swarm optimization (PSO) algorithm is easy to fall into local optimal solution has adverse effect on the correctness of the result.Between the global search and local search, this paper found a suitable inertia weight factor to omega, using linear decreasing inertia weight, make them get the optimal solution space.**

This article includes the fan, photovoltaic power generation, diesel generators and energy storage device independent model of micro grid economy model, think the load constant, in a systematic and objective function is minimum total cost, consider the micro source equipment investment and operation and maintenance costs, the cost of replacement battery and diesel generators of the cost of fuel and pollution costs.According to the discontinuity of wind turbines and photovoltaic cells and consider spare battery and diesel generator operating characteristics, in view of the storage battery charging and discharging characteristics of the analysis of the working process of the storage battery as backup power supply, according to the emission characteristics of diesel generators to consider increase the cost of pollution in the objective function.Based on improved particle swarm algorithm to optimization of system, work out the optimal capacity configuration of system power supply, at last, numerical examples verify its rationality.

Keywords—micro-grid; particle swarm optimisation;

INTRODUCTION

A micro-grid describes a small-scale power generation, supply and utilisation system. Micro-grids have a full suite of power generation, power utilisation and power supply functions, which can optimise the distribution of energy in a grid. Micro-grids can be classified as independent micro-grids and grid-connected micro-grids according to whether or not they are connected with the conventional large grid. In addition, micro-grids can operate in a variety of modes. Micro-grids can be flexibly accessed or connected with the surrounding large grid based on the current situation of load and power supply, making them an important component of next-generation smart power networks.

When operating in connection with the surrounding power grid, a micro-grid and the surrounding distribution network can exchange power back and forth, which can trim peaks and fill valleys in the main grid power supply. If the main grid breaks down, a large micro-grid can be switched into independent operation to supply power continuously for end users. An independent micro-grid does not need to connect with the conventional large grid, because it can consistently supply power over a long time with generation from various distributed power supplies within the micro-grid. Independent micro-grids often used in remote areas like islands and mountainous terrain. Such locales have little access to infrastructure for delivering conventional fuel, and power transmission is inconvenient, but rich renewable energy resources are often available. Thus, micro-grids not only facilitate local residents' lives, but they also use and develop local renewable resources.

In an independent micro-grid system, distributed power supplies can be divided into two categories according to whether or not they can be readily dispatched. Affected by weather conditions and variation in natural resources, the output of renewable energy generators such as wind turbines and photovoltaic (PV) arrays cannot be regulated. Diesel power generation, energy storage devices, fuel cells, and the like can, on the other hand, provide on-demand power. In order to make full use of renewable energy resources, the relatively unreliable renewable power generation units are often used preferentially in the operation of independent micro-grids. Conventional power generation units can supplement renewable generation sources to balance the variability in their power output and allow integrated micro-grids to make full use of renewable energy. In the case that the traditional large grid cannot support a micro-grid, the influences of weather conditions, local availability of resources and load demand are more obvious. Therefore, careful analysis of how to allocate the capacity and quantity of various distributed power supplies within a micro-grid in order to optimise distribution is important for the planning of an independent micro-grid. This optimisation predicts the reliability and quality of power output, in addition to improving economy and rationality in the micro-grid.

Optimisation Model for Micro-grid

In this paper, we propose an optimisation model for an independent micro-grid with diverse distributed generation resources under constant load. The process of optimising the micro-grid system should be divided into the following steps: determining the objective function, determining the constraint, and then performing a further analysis on the specific operation parameters of the micro-grid combined with the work characteristics of each micro-grid component.

A. Operational Description of the Micro-grid Model

The distributed power supply of the micro-grid system modelled in this paper includes wind generators, PV power generation stations, diesel generators and energy storage devices. Wind energy and solar energy are renewable and clean resources with wide distribution, straightforward collection and utilisation, so the wind and PV generation stations are used preferentially during micro-grid operation. When the wind and PV output is sufficient for the load requirement, the spare power will be stored by storage batteries. When wind and PV output cannot supply loads due to factors like wind speed and light conditions the storage battery begins to supply power. At this time, wind and solar power jointly output power with the storage unit, and the energy storage unit is in the discharging state. The active capacity of storage battery exceeds the limitations imposed on the battery by operating either in charging or discharging modes. Therefore, the storage battery can be cut out from the system and connected to a diesel generator to supply power for loads.

B. Objective Function for a Micro-grid System Optimisation Model

Optimisation problems can be divided into single-objective and multiple-objective problems. The selection of an objective function determines the optimal scheme to a considerable extent. We choose to minimise the total cost of the micro-grid system in this paper. The total cost of a micro-grid system includes installation, operation, and maintenance costs. In order to ensure the reliability of the micro-grid system, we introduce a cost for power outages. To ensure a degree of environmental protection around the micro-grid system, an additional cost is introduced to reduce the negative impact of diesel emissions on the environment.

The obtained objective function, i.e. the minimum total cost of system is:

$$\min C = \sum_{i=1}^{3}\left(C_{Pi}x_i + C_{Ami}x_i\right) + C_{rep}x_3 + \left(C_{con} + C_{DE}\right)x_4 + \lambda\max\left[0, \gamma_{set} - \lambda\right] \quad (2\text{-}1)$$

The above objective function includes four kinds of power supply in the system, where $X = [x_1, x_2, x_3, x_4]$ are optimisation variables that represent the number of each micro-resource (wind, light, storage, and diesel, respectively); C_{Pi} and C_{Ami} are the equipment investment cost and the annual operation and maintenance costs, respectively, of the ith micro-source; C_{rep} is the annual resetting cost of the energy storage unit; C_{con} is the cost of pollution control; C_{DE} is the cost of fuel; λ is the coefficient for power shortage punishment; γ_{set} is the presupposed load supply rate, which is 0.98 in this paper; and γ is the actual value of load supply rate in the micro-grid power supply system.

The following functions specify the costs in the micro-grid model, starting with installation cost CP:

$$C_P = C_{ci} Z_{rf}(\alpha, Y) \quad (2\text{-}2)$$

In the above formula, C_i is the unit price of the ith micro-source; and Z_{rf} represents the coefficient of return on investment, whose formula is as follows:

$$Z_{rf}(\alpha, Y) = \frac{\alpha(1+\alpha)^Y}{(1+\alpha)^Y - 1} \quad (2\text{-}3)$$

In the above formula, α represents the discount rate, the current value of which generally is 8%; and Y represents the service life, whose value is 20 a in this paper.

Operation costs are represented with CAm:

$$C_{Am} = K_{OM} P_j \quad (2\text{-}4)$$

K_{OM} is the coefficient of power cost; P_j is the actual power output of micro-source.

Power outages are represented with a cost function Cγ:

$$C_\gamma = \lambda \max[0, \gamma_{set} - \gamma] \quad (2\text{-}5)$$

Power outages are mainly determined by the load power supply rate γ, calculated as follows:

$$\gamma = 1 - \frac{\sum_{t=1}^{T} P_{loss}(t)}{\sum_{t=1}^{T} P_L(t)} \quad (2\text{-}6)$$

$$P_{loss}(t) = \max[0, P_L(t) - P_{PV}(t) - P_B(t) - P_{DE}(t)] \quad (2\text{-}7)$$

In the following formula, $P_{loss}(t)$ is the power vacancy at hour t. We model the micro-grid for one year so the total time period is $T = 8760$.

The following formula determines the pollution cost Ccon:

$$C_{con} = \int_0^T \sum_{m=1}^{k} A_m B_m P_{DE}(t) dt \quad (2\text{-}8)$$

In (2-8), m is an index for the type of pollutant, k is the total number of kinds of pollutants, A_m represents the pollution control cost of each pollutant, and B_m is the emission coefficient for each pollutant.

C. Constraints

Next, we detail the constraints in our optimisation model. In this micro-grid system composed by a variety of distributed power supplies, the power output of each micro-source is affected by not only weather and natural conditions, but also the constraints of load demand and energy storage unit specifications.

Site conditions and the overall scale of the micro-grid power generation system will constrain the available amounts of each micro-source.

$$\begin{cases} 0 \le N_{WT} \le N_{WT\max} \\ 0 \le N_{PV} \le N_{PV\max} \\ 0 \le N_B \le N_{B\max} \\ 0 \le N_{DE} \le N_{DE\max} \end{cases} \quad (2\text{-}11)$$

In the formula, Ni represents the number of each micro-source, and $N_{\max}$ represents the specific maximum number of each micro-source respectively.

The energy storage unit is constrained in how it can provide and store power as follows:

$$\begin{cases} P_{+\min} \le P_+(t) \le P_{+\max} \\ P_{-\min} \le P_-(t) \le P_{-\max} \\ SOC_{\min} \le SOC(t) \le SOC_{\max} \end{cases} \quad (2\text{-}10)$$

$P_{+\min}$, $P_{+\max}$, $P_{-\min}$, and $P_{-\max}$ respectively represent the upper and lower limits of the energy storage unit's charging and discharging input and output. $SOC_{\min}$ and $SOC_{\max}$ respectively represent the minimum and maximum of the charging state of energy storage unit. In this paper, $SOC_{\min}$ and $SOC_{\max}$ respectively is 0.2 and 1.

The coordinated output index for wind and solar power is an important index for micro-grid operation. It reflects whether the wind and PV power generation can meet load demands or not. Coordinating the respective shares of wind and PV output can minimise energy waste and save power generation costs. The formula for the coordination index is as following:

$$U = \frac{\sum_{m=1}^{365}\left[\sum_{t=1}^{24}\delta(t)\right]}{8760} \quad (2\text{-}11)$$

$$\delta(t) = 0\begin{cases}1, P_{PV}(t) + P_{WT}(t) \geq P_L(t) \\ 0, P_{PV}(t) + P_{WT}(t) \leq P_L(t)\end{cases} \quad (2\text{-}12)$$

IMPLEMENTATION OF MICRO-GRID OPTIMISATION MODEL

A. Particle Swarm Optimisation (PSO)

Note that PSO is an optimisation algorithm based on group intelligence. PSO was proposed by Craig Reynolds in 1987 for the simulation and study of the social system of birds. PSO simulates the behaviour of birds foraging in nature. In a given region, a group of birds searches for a randomly placed food resource. Each bird does not know the exact location of the food, but each bird does know the distance between the target food and their own position. The best method for finding this piece of food is for each bird to share its own distance from the food so that all the birds can concentrate their search around the bird closest to the food. Each bird in this model can be considered as a particle, and these particles are given random initial positions. Each particle has its own fitness determined by the optimisation constraints and its movement speed.

Solutions to the PSO problem usually conform to the principles of proximity, quality, stability, adaptability and diversity. PSO is an algorithm of heuristic overall search, theoretically derived from observations of group intelligence. In the behaviour of foraging birds, the distance between each bird and food and flight speed is shared between companions. Similarly, each particle in the model can affect its surrounding particles through information sharing. With constant dynamic adjustments, the search of the overall area can be reduced to the search of the region where particles are closest to the target. In the process of solving an optimisation problem each particle's position is a solution of the optimisation problem, and the positions of the whole particle swarm represents the entire solution set. By comparing the distance between each particle and the optimal solution, i.e., the fitness function, the optimal solution in the space can be determined by emergent dynamic adjustments to the whole particle swarm to realise the optimisation of problem. In PSO, the velocity of the particle swarm can be expressed by $V_i = (V_i \; V_i \quad V_{id})$, and the spatial positions of the particles can be expressed by $x_i = (x_{i1}, x_{i2}, \ldots, x_{in})$, where i is an index for each particle. Equation (4-1) describes the position of particle from time t to time (t + 1).

$$v_{id}^{t+1} = \varpi v_{id}^{t} + c_1 r_1 \left(p_{id}^{t} - x_{id}^{t}\right) + c_2 r_2 \left(p_{gd}^{t} - x_{id}^{t}\right) \quad (3\text{-}1)$$

In the formula, ϖ is the inertial weight coefficient, which can affect the search ability of the i-th particle. Large values of ω enhance the overall search ability of particle, and small ϖ values enhance the partial search ability of particles. When ϖ = 1, we refer to the problem as a basic particle algorithm; if ω ≠ "1", we refer to the problem as the standard particle algorithm. r_1 and r_2 are random numbers between 0 and 1. c_1 and c_2 are learning factors.

Equation (4-2) describes the velocity adjustment of particle i from time t to time (t + 1).

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \quad (3\text{-}2)$$

B. Improvements on PSO

The basic procedure of PSO is charted in Fig. 3-2:

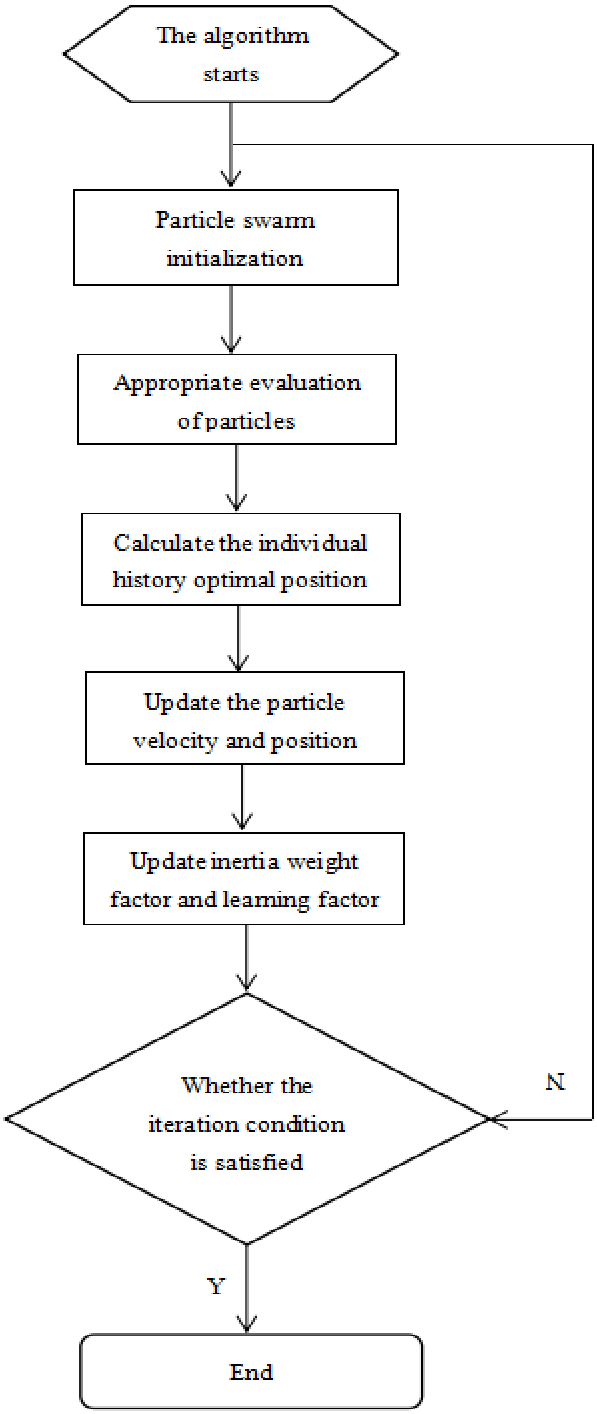

Fig. 3-2. Flow chart of PSO.

PSO has the characteristics of fast search speed, simple calculation and high efficiency, and it is suitable for solving optimisation problems with a single-objective function. However, the basic PSO algorithm is easily trapped by local optimal solutions, which has a negative effect on the overall correctness of the result. The inertia weight factor ϖ has a great influence on the convergence speed of the PSO algorithm. We consider that a suitable inertia weighting factor ϖ should be found between a local search and the overall search, and a linearly decreasing inertia weight is used to obtain the optimal solution within the search space. In this paper, we use a linearly decreasing inertia weight factor to add two parameters $\varpi_{\min}$ and $\varpi_{\max}$. Formula (4-3) represents the linearly decreasing inertia weight:

$$\varpi = \omega_{\max} - \frac{t}{T}(\varpi_{\max} - \varpi_{\min}) \qquad (4\text{-}3)$$

In our model, $\varpi_{\max} = 0.9$, $\varpi_{\min} = 0.4$, which represent the inertia weight of the maximum number of iteration and the initial inertia weight, respectively; t represents the current iteration; and T represents the maximum number of iterations. In this paper, the number of particles is 50, and the maximum number of iterations is 80.

C. Optimisation strategy

we propose the following allocation hierarchy, in view of the cost-effectiveness, reliability and environmental compliance of micro-grid systems:

Wind and PV power generation should be allocated first.

Energy storage systems should provide power in the event that wind and PV power is unavailable.

Diesel generator should provide power as a last resort, only when the combined output of renewable power generation and the storage battery cannot meet demand.

D. Optimisation Process

Due to annual cycles of wind speed, sunshine and other meteorological factors, a year will be used as the scheduling cycle for micro-grid system. Surf the Internet to collect micro-grid location in terms of light and wind speed and other meteorological data, and because of wind speed and illumination change are more slowly, so we set for the unit step of 15 min and we believe that wind turbines, PV output constant within 15 min.

Calculate the unit power output of wind and light; Set the upper and lower limit and the state of charge of the charging and discharging power of the energy storage unit; Set the power output of the diesel generator to 0.

Initialise the particle swarm and calculate the power output of the micro-source of the scenery and wood storage in 8,760 hours.

The target function is calculated, and the optimal capacity allocation of the distributed power supply is obtained by

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using the improved PSO algorithm.

Optimisation flow chart is shown in Fig. 3-3:

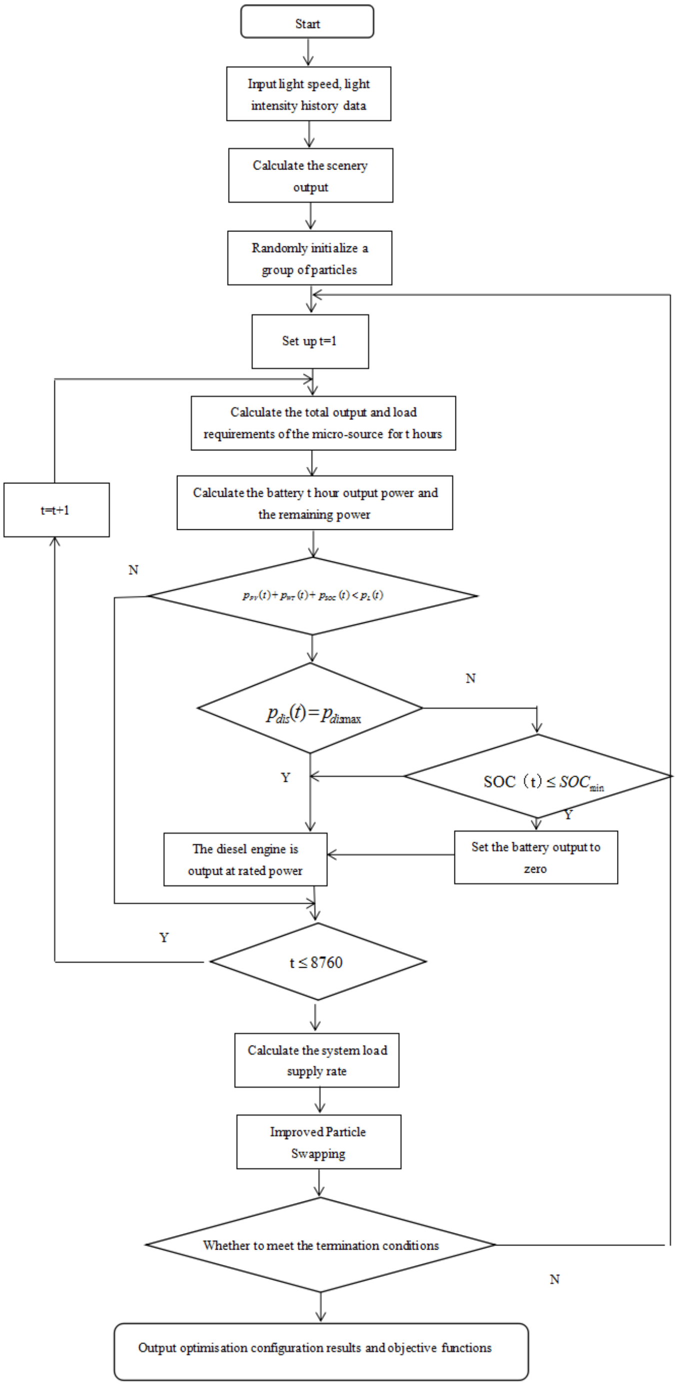

Fig. 3-3. Flow chart of optimisation of PSO algorithm.

RESULTS

This paper models a micro-grid system including wind power units, PV power generation units, diesel power generation units and energy storage units. A year serves as the dispatching cycle. Since meteorological conditions such as wind speed and illumination change slowly, we use 15 min as the time step. In each 15-min time period, the output of the wind turbines and PV arrays remain constant. According to the optimal scheduling strategy, the optimisation target is found with the particle swarm algorithm modified as described above.

A. Micro-grid model and parameters

In this paper, a micro-grid system including wind turbine, PV power generation, diesel generator and energy storage units is simulated. The micro-grid system is isolated from the surrounding distribution grid and the load is considered to be approximately constant. The parameters of our model are displayed in Table 4-1.

TABLE 4-1. PARAMETERS OF INDEPENDENT MICRO-GRID MODEL

Component Type	Rated Power, P, Kw	Installation Cost Cp, Ten Thousand Yuan	Operation And Maintenance Cost Cam, Ten Thousand Yuan/A	Fuel Expense Cde, Ten Thousand Yuan/ Kwh	Replacement Cost Crep, Ten Thousand Yuan/A
Turbine, set	20	50	0.5	0	0
PV conversion cell, set	10	35	0.2	0	0
Diesel engine, set	25	20	0.8	0.0004	0
Storage battery, piece	45	15	0.15	0	7

For the wind turbine modelled in this paper, the cut-in wind speed is 3.5 m/s, the rated wind speed is 11 m/s, and the cut-out wind speed is 22 m/s.

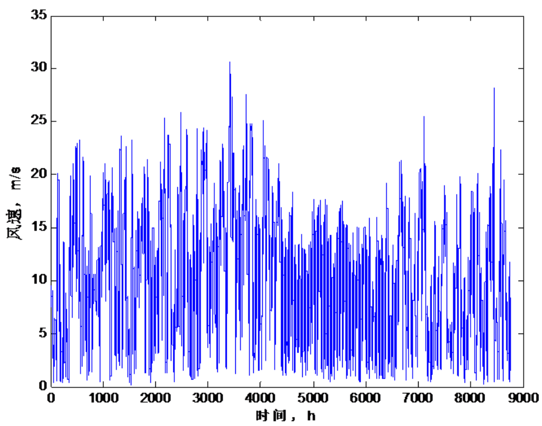

Fig. 4-1. Annual wind speed data.

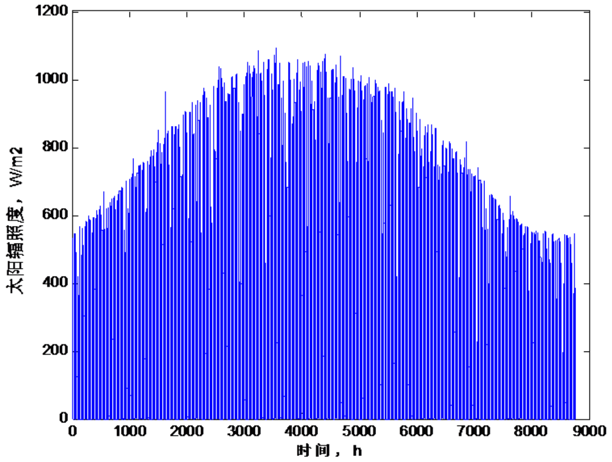

Fig. 4-2. Year of illumination data.

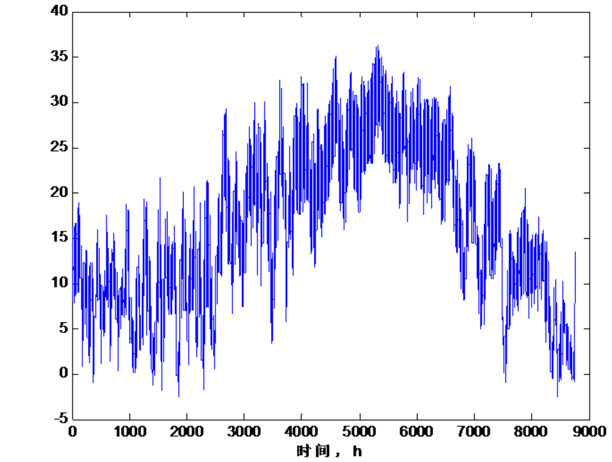

Fig. 4-3. Annual temperature data.

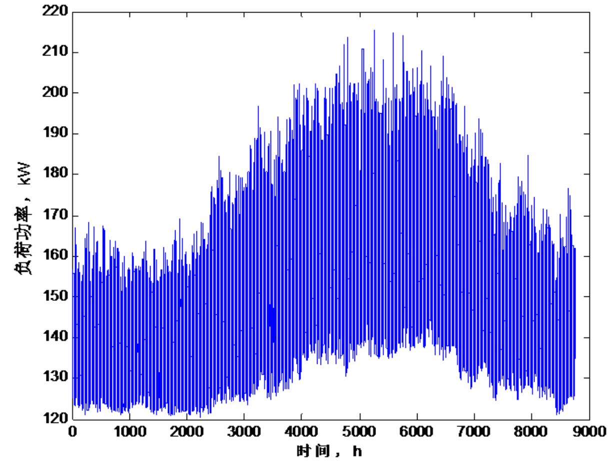

Fig. 4-4. Annual load vs. time.

According to the data we collected, the wind speed changes rapidly and it is generally unpredictable within a year. In general, lighting conditions vary predictably, but they are also affected by local weather patterns. This simulated data confirms our expectation that renewable resources are relatively unreliable.

B. Optimal configuration results and analysis

We chose several independent parameters in the model are set to represent the operation of the micro-grid system. The renewable resource coordination output index is set to 0.8, and the load rate is set 0.97. According to the parameters of each generation unit discussed above and the gathered wind speed and light and temperature data, we calculated the power output of a single wind turbine and a single PV cell.

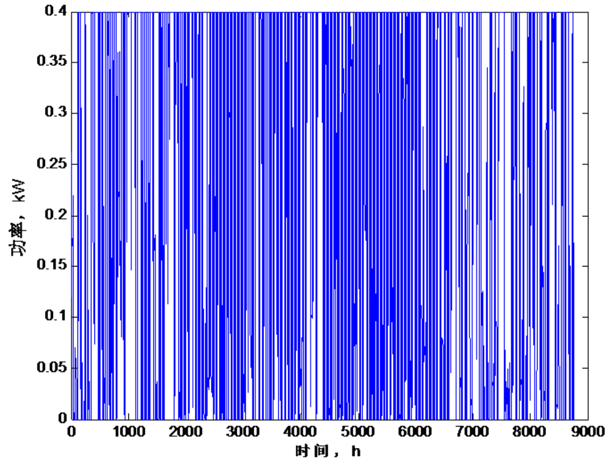

Fig. 4-5. Power output of a single wind turbine.

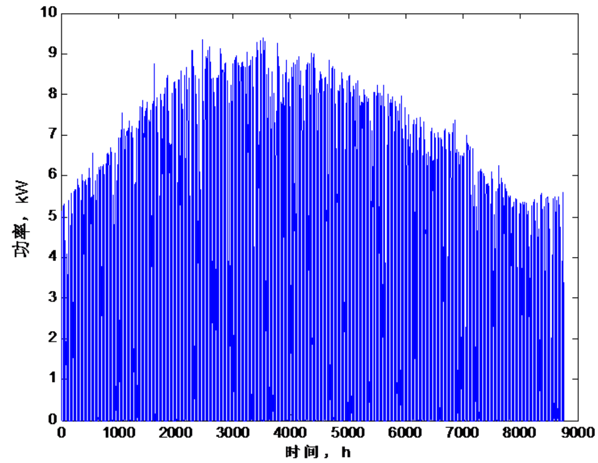

Fig. 4-6. Power output of a single PV cell.

By improving the analysis and calculation of particle swarm algorithm, the optimal configuration results and optimisation indexes of micro-grid were obtained, as shown in the following table:

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TABLE 4-2. Optimised Configuration Results Of The Micro-Grid System Of Renewable And Non-Renewable Resources

Wind Driven Generator, Set	PV Module, Set	Diesel Generator, Set	Storage Battery, Piece	Total System Cost For The Year, Ten Thousand Yuan
19	206	16	2	69.436

TABLE 4-3. Micro-Grid Optimisation Index

Annual Rate Of Load Power Supply	Annual System Total Cost, Ten Thousand Yuan	Renewable Output Index	Electricity Deficiency Rate	Use Ratio Of Renewable Resources
0.9928	69.43	0.8221	0.0009	0.8174

From the results of system optimisation we can see that the micro-grid system allows is a large number of configurations for the PV arrays and energy storage devices. From the historical data of local solar irradiance we can see that residential solar energy is very rich in reserves at the modelled site. The solar irradiance data shows that this particular location is ripe for development of PV generation resources, as days are long and weather is generally clear. From the wind speed historical data we can see that the wind speed in the region is more intermittent, and even much of the time the wind is completely still. Moreover, the power curve of the wind generator unit shows that the turbine operates intermittently and an increase of turbine quantity can only increase the system power output for a brief period of time. If we blindly increase the quantity of the fan, we will greatly increase the equipment costs and need to provide more battery energy storage devices to store surplus energy. With relatively high costs for batteries currently, adding more turbines will therefore be expensive. Therefore, in the configuration of micro-grids, the number of wind turbines should be reduced accordingly.

Analysis of the output of diesel generator

Due to local weather changes reasons or seasonal patterns, the power generation units of the micro-grid system sometimes fail to provide sufficient power to support the load. When that happens, because the battery is incapable of supplying electricity since it is charging, and in order to guarantee the reliability of the system, a diesel engine can operate as a backup generator to reduce the risk of power outages. From the irradiance data comparison in Fig. 4-7 and 4-2 we can see that diesel engines work less frequently in the summer and mainly provide power supply when days are short. The diesel generator mainly supplements the PV arrays in our optimised model.

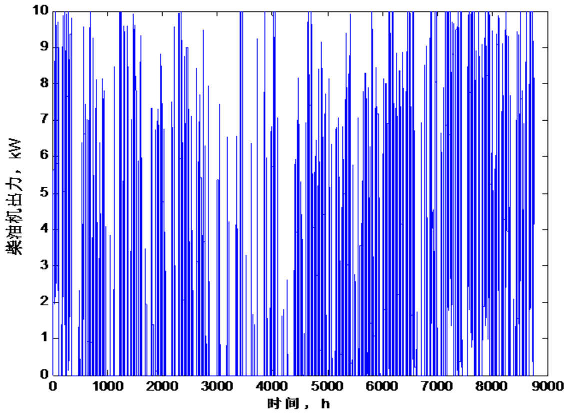

Fig. 4-7. Annual output curve of diesel engine.

2) Improved PSO algorithm compared with traditional PSO

TABLE 4-4. Optimises The Result Of Traditional PSO

Wind Driven Generator, Set	Pv Module, Set	Diesel Generator, Set	Storage Battery, Piece	The Total System Cost Of The Year, Ten Thousand Yuan
19	189	17	0	69.542

TABLE 4-5. Results From The Optimisation Of Traditional PSO

Annual Rate Of Load Power Supply	Annual System Total Cost, Ten Thousand Yuan	Scenery Synergy Output Index	Electricity Deficiency Rate	Use Ratio Of Re-Generable Resources
0.9919	69.542	0.8006	0.0013	0.8023

TABLE 4-6. Computational Cost Comparison Between Improved And Traditional Particle Swarm Algorithms

	Computing Time (S)	Iterations To Convergence
Improved particle swarm optimisation	394100	99
Traditional particle swarm optimisation	133740	51

From improved particle swarm algorithm of the comparison of optimised result of in Table 4-2 we can see that the configuration of distributed power supply results is roughly the same, but total cost when using our improved particle swarm algorithm for the optimisation is slightly less than it is when using the traditional PSO algorithm. At the same time, the load supply rate and renewable energy utilisation are slightly higher with the improved algorithm.

It can be seen from Table 4-6 that the calculation time of particle swarm algorithm is great and the convergence number is relatively high, so this method needs further improvement to achieve computational efficiency.

V. CONCLUSION

Models of independent micro-grids combine distributed power supplies with a variety of renewable resources, which exploits novel energy sources sufficiently while meeting load demands. For the remote mountains or islands which are rich in natural resources but isolated from power-distribution infrastructure, optimisation is of great significance to the research and development of micro-grids. In micro-grid systems, the scheduling model of distributed power supply power output is inherently unpredictable and unstable, which affects the economy and reliable operation of the entire distribution network, increasing the importance of installing rationally designed micro-grids. This paper models wind turbines, PV power generation, diesel generators and energy storage devices in an independent micro-grid. We used a modified implementation of the PSO algorithm to determine optimal allotments of distributed generation in a micro-grid at a particular location. The main results of the study are as follows:

Establish the economic model of distributed generation units in micro-grid, including installation cost and running maintenance cost, and analyses its working characteristics. The objective function of micro-grid optimisation is determined, including the cost and operation maintenance cost of each micro-source, and consider the introduction of power failure penalty and the cost of diesel emission. According to the actual operation condition of the micro-grid and distributed generation unit, the constraint conditions are determined. Finally, the operation strategy of micro-grid optimisation is formulated.

(2) Improve the particle swarm algorithm, use linear decreasing inertia weight PSO algorithm, and consider between the global search and local search to find a suitable inertia weight factor ϖ , and use linear decreasing inertia weight to reach a space to the optimal solution. Combined with the example, the optimisation model of the micro-grid is calculated by improving the particle swarm algorithm, and the optimal configuration results of the micro-grid system are obtained and analysed. Analyse the changing situation of the scenery through the annual output force of the diesel engine; Analyse and compare the difference between PSO and traditional particle swarm algorithm from the perspectives of calculation results, operation time and number of iterations; According to the load power supply rate, scene coordination, annual system total cost and other indicators, the influence of different load power rate on cost is analysed.

The optimisation design of research in the network configuration meets basic expectations. When considering distributed generation capacity, we often make the load power supply rate as large as possible for convenient analysis, but in practice we find that the load demand is not a linear relationship with the system total cost. The choice of power supply rate should be considered with the total cost and landscape indices. Choosing an appropriate scale for micro-grid generation units is more economical, more reliable, and more environmentally friendly than increasing the operational benefits of the micro-grid.

Our study also suffered some disadvantages that we plan to improve upon in future work. We could perform a more robust comparison of the improved particle swarm algorithm advantages and traditional optimisation algorithms. The network structure in our model is simple, and does not take into account the processes of transmission line loss and other factors. We plan to further improve the algorithm detailed above, as well as incorporate line loss in our model to deliver more realistic results.

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