

Micro-Grid Day-Ahead Dispatch Based on Two Stage Search Algorithm

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Abstract. This paper established a Micro-grid model with wind turbine, photovoltaic cell, storage batteries and conventional loads. Under the conditions of wind and light load, the average power can be predicted formulated the optimal dispatch strategy with the optimal load price as the goal considering the use of wind, light and the battery in the model. The problem can be simplified as a mixed integer programming problem using two stage search algorithm to solve. For the first stage, the simulated annealing (SA) algorithm to search wind, light use factor and battery charge and discharge strategy. In the case of battery charge and discharge, in the second stage pattern-search algorithm is used to solve the optimal charging and discharging power to find the global optimal solution. Comparing the results of the optimization model with the single scheduling model, it has better economic performance.

1. Introduction

Recently, the development of renewable energy source represented by wind power and photovoltaic has been paid more attention on by the whole world due to the global depletion of fossil fuel based energy resources and environmental pollution problem. Consequently, Micro-grid attracts much attention as one of the effective ways to consume renewable energy [1-2]. Micro-grid is a new type of network structure, constructed by distributed power, load, energy storage systems, energy conversion devices and control devices constitute. It can convert decentralized energy to electricity in-situ and then supply local loads nearby. In addition, it can operate both with the external grid and in isolation. Research on Micro-grid mainly focus on energy storage technologies, operation control, system planning and design, and safety protection [3-4]. In this paper, the economic dispatch of Micro-grid is studied on the condition that micro-grid has access to external grids and renewable energy generating capacity has been predicted. We set the overall planning model for Micro-grid by aiming at minimizing the average load power supply cost per day.

However, the economic dispatch of Micro-grid belongs to dynamic, multidimensional and non-linear function optimization problem. It requires two aspects: one is reaching the global optimum; the other is high convergence speed. To solve it, many scholars have done a lot of research and proposed many methods. These methods mainly include Mathematical analysis, genetic algorithm, evolutionary algorithm, particle swarm optimization and so on [5]. Mathematical analysis includes Lagrangian relaxation (LR) [6] and dynamic programming [7]. Regrettably, they have some specific requirements



for models, restricting their applications. In contrast, intelligent algorithms are well suited for nonlinear optimization problems and are widely used in the optimal dispatch of Micro-grid. A multiperiod artificial bee colony optimization algorithm is implemented in [8] for economic dispatch considering generation, storage, and responsive load offers. In [9], an improved particle swarm optimization (PSO) algorithm with adaptive weight and acceleration coefficients (AWCPSO) was proposed for solving the economic, environmental and health dispatch model of a Micro-grid. Taking the characteristics of mixed integer programming and nonlinear in model into account, a two-stage optimization was proposed in this paper. For the first stage, SA is used to find the optimal operating strategy, while the pattern-search is used to solve the optimal power in the second stage.

So far, simulated annealing (SA) algorithms are widely used in energy management [10-11], machine learning [12-13], path planning, image processing and other fields. The SA algorithm is based on the simulation of physical phenomena that occurs during the solidification of some types of fluids. Its main advantage is the possibility to find a new optimal point after a local optimum to the evaluation function has been found, it has poor time performance for little information to the entire search space. In order to improve the performance of traditional simulated annealing algorithm, various improved simulated annealing algorithms are proposed. A hybrid genetic simulated annealing algorithm to solve the job shop scheduling problem was proposed in [14], it combines genetic algorithm's high convergence speed and SA's strong exploration ability. In [15], a heuristic criterion for determining the temperature updating function of simulated annealing algorithm was proposed, the improvement increase significantly the computational efficiency for solving the global optimization problems. While in this paper, to improve the time performance of SA, the pattern search combined with SA algorithm was implemented to solve the Micro-grid dispatch problem, it can take advantage of the SA's large exploration ability and overcome pattern-search's difficulty on integer optimization.

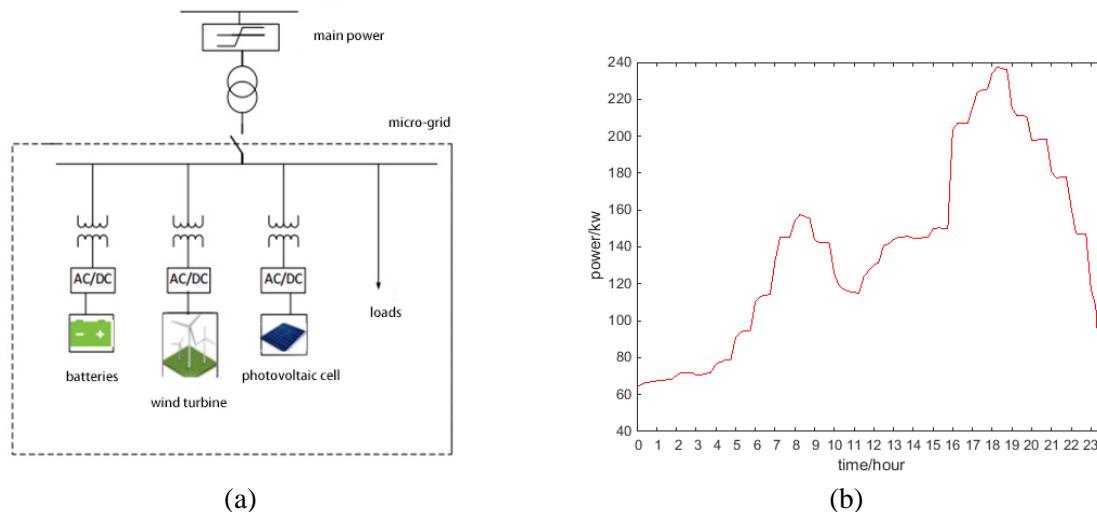


Figure 1. Micro-grid system. (a) System architecture. (b) The total load for one day.

2. Model Building

2.1. Model Hypothesis

To simplify the problem, here's a series of assumptions about the model:

- (1) Ignore the network loss and line loss.
- (2) The power generation equipment is independent, there is no interference with each other.
- (3) Ignore the battery from the power generation.
- (4) Ignore the battery charge and discharge conversion loss.

2.2. Battery Model

For batteries, the main solution for the charge state (SOC, State-of-Charge, that is, battery remaining capacity and battery capacity ratio), is setting the unit time interval Δt , the battery charge and discharge power are constant, SOC value changes from the following formula.

$$S_t = S_0 + \frac{\sum_{t=1}^n P_{cha,t} * X_t * \Delta t - \sum_{t=1}^n P_{dis,t} * Y_t * \Delta t}{E_b} \quad (1)$$

Where S_0 is the initial SOC state of the battery. $P_{cha,t}$ and $P_{dis,t}$ are respectively for the battery in the first t period of charging and discharging power. X_t and Y_t ($X_t, Y_t \in \{0,1\}$) are battery charge status and discharge status respectively. And Δt is unit time interval, n is the total number of hours. S_t is SOC state of the battery during the time period of t .

Considering that the battery can't be in the same state of charge and discharge at the same time interval, the states of the battery needs to satisfy the constraint $X_t * Y_t = 0$.

In order to prevent the battery overcharge and over discharge occurs, the battery charge state SOC should meet the upper and lower limit constraints $S_{\min} \leq S_t \leq S_{\max}$. S_t , S_{\min} , S_{\max} are SOC states of battery and its Upper and lower limits during t . When SOC reaches the maximum value, the battery stops charging. While SOC reaches the Minimum value, the battery stops discharging.

In the process of optimizing the operation of the system, the energy state of the battery needs to satisfy the same constraint $S_0 = S_T$, at the beginning and end of the scheduling cycle.

At the same time, taking into account the size of the battery charge and discharge power and battery life, the general unit time charge and discharge maximum power for the battery rated capacity of 20%.

$$0 \leq P_{cha,t} \leq 0.2E_b X_t, \quad 0 \leq P_{dis,t} \leq 0.2E_b Y_t \quad (2)$$

Where E_b the battery is rated capacity. $P_{dis,t}$, $P_{cha,t}$ are discharge power and charge power per unit time.

In a scheduling cycle, the battery charge, discharge times and the depth of discharge will have an impact on battery life, the charge and discharge depth can be constrained as following.

$$\sum_{t=1}^n |X_{t+1} - X_t| \leq N_1, \quad \sum_{t=1}^n |Y_{t+1} - Y_t| \leq N_2 \quad (3)$$

Where N_1 , N_2 are the number of times the battery is charged and discharged.

2.3. Renewable Energy Model

In order to simplify the problem, it is concluded that the cost of renewable energy can be considered to be proportional to the time. So define the cost of photovoltaic power generation A_1 , the cost of wind turbine A_2 , Q_t is the power of photovoltaic power generation per unit time period. P_t is power of wind turbines per unit time period, t is time of a single time period, n is the total number of time periods. In order to minimize the cost, here allow the abandoned wind and photovoltaic, that is, the cost of the fan and the cost of photovoltaic power generation are defined 0 or 1 by the coefficient λ_{wt} , λ_{pv} . So the renewable energy cost J_r is

$$J_r = \sum_{t=1}^n [\lambda_{pv} * Q_t * A_1 + \lambda_{wt} * P_t * A_2] \quad (4)$$

2.4. Power Grid Model

Power grid and micro-network are connected. When the micro-network needs electricity, you can buy electricity to the grid, while the micro-network power is left, you can sell electricity to the grid. Here, refer to the actual situation, defined sale price to Micro-grid in different time a_t , purchase electricity price from Micro-grid in different time b_t . W_t provides power for grid at different time periods. $W_t > 0$ means that Micro-grid buys electricity from power grid and $W_t < 0$ means that Micro-grid sells electricity to power grid. So the cost of the grid J_g is

$$J_g = \sum_{t=1}^n [W_{t(W_t > 0)} * a_t - W_{t(W_t < 0)} * b_t] \quad (5)$$

Micro-grid and network need to sign a power transmission agreement with the national grid, Micro-grid and large power grid interaction power can't exceed the maximum limit W_m . The load for each period is P_{loadt} . The constraint of can be described as follows

$$W_t = P_t + Q_t - P_{loadt} + P_{dis,t} * Y_t - P_{cha,t} * X_t, |W_t| \leq W_m \quad (6)$$

3. Optimized Scheduling Model

3.1. Objective Function

In this paper, the average power supply price of loads is regarded as the objective function, the rest are constraints. If power requirement for each time period is S_{loadt} , the objective function can be written

$$\min C_2 = \frac{1 / \Delta t * \sum_{t=1}^n [\lambda_{pv} * Q_t * A_1 + \lambda_{wt} * P_t * A_2 + W_{t(W_t > 0)} * a_t - W_{t(W_t < 0)} * b_t]}{1 / \Delta t * \sum_{t=1}^n S_{loadt}} \quad (7)$$

The goal is to make the average power supply unit price minimal. Compared to the battery, the photovoltaic cell life are much larger than the battery life. Thus, this article only considers the cost of battery life constraints.

3.2. Restrictions

$$s.t \left\{ \begin{array}{l} \sum_{t=1}^n |X_{t+1} - X_t| \leq N_1, \quad \sum_{t=1}^n |Y_{t+1} - Y_t| \leq N_2 \\ \lambda_1, \lambda_2 \in \{0,1\} \\ S_{\min} \leq S_t \leq S_{\max}, \quad S_0 = S_T \\ X_t * Y_t = 0, \quad 0 \leq P_{cha,t} \leq 0.2E_b X_t, \quad 0 \leq P_{dis,t} \leq 0.2E_b Y_t \\ W_t = P_t + Q_t - P_{load,t} + P_{dis,t} * Y_t - P_{cha,t} * X_t, \quad |W_t| < W_m \\ S_t = S_0 + \frac{\sum_{t=1}^n P_{cha,t} X_t * \Delta t - \sum_{t=1}^n P_{dis,t} Y_t * \Delta t}{E_b} \end{array} \right.$$

4. Model Solving

4.1. Determine the Value of the Parameters

For the convenience of comparison and solution, through access to information and the actual provisions of some assigned parameters.

- (1) The total length is defined as 24 hours a day, the time interval of 15min.
- (2) The total installed capacity of fan is fixed as 250Kw, and power generation cost is 0.52RMB/kwh.
- (3) PV installed capacity of the total is fixed as 150Kw, and power generation costs 0.75RMB/kwh.
- (4) If the battery loss, battery rated capacity is defined as 300kWh, battery SOC operating range is [0.3, 0.95], the initial SOC value is 0.4, the number of daily charge and discharge limit is 8 times
- (5) Assume that load forecasting, fan and PV future output are entirely accurate, seen in the Figure1. (b).
- (6) Sale prices of different time are considered as follows

Table 1. Sale prices of different time.

time	00:00-7:00	07:00-10:00	10:00-15:00	15:00-18:00	18:00-21:00	21:00-0:00
Sale price(RMB/kwh)	0.22	0.42	0.65	0.42	0.65	0.42
Purchase price(RMB/kwh)	0.25	0.53	0.82	0.53	0.82	0.53

4.2. Optimize Variables

In the day, the photovoltaic and wind power generation capacity can be predicted under the conditions. At each moment, the new energy state can choose or abandon. Defined as 0 or 1. $\lambda_{wt}, \lambda_{pv}$ express the wind and the photovoltaic use states, respectively. Thus the states of the fan in 96 periods is $\lambda_{wt-1} * P_{wt-1}, \lambda_{wt-2} * P_{wt-2}, \dots, \lambda_{wt-96} * P_{wt-96}$, photovoltaic states is $\lambda_{pv-1} * P_{pv-1}, \lambda_{pv-2} * P_{pv-2}, \dots, \lambda_{pv-96} * P_{pv-96}$

Under the condition that the scenery is determined, the power exchanged with the grid can be calculated according to the formula (x), and the power of the battery can be used for scheduling. The charging and discharging strategy are described as X_t, Y_t , Thus the status of the battery in 96 times is $X_1, X_2, \dots, X_{96}, Y_1, Y_2, \dots, Y_{96}$. Then on the basis of the above status, the charge and discharge power P_{Bat-t} can be solved for each time period.

4.3. Algorithm Flow and Solving Steps

The implementation of the algorithm can be shown in Figure 2. Then main steps include as follow.

Firstly, initialize the simulated annealing parameters. Set the initial temperature as 90, the end temperature as 6, the cooling coefficient as 0.9, and Markov chain length as 300. Import the predicted wind turbine, photovoltaic, load demand power and the time period of the battery. Then set the initial states of the battery and the parameters of battery capacity.

Then, generate the initial fan, including $\lambda_{wt}, \lambda_{pv}$, and X_t, Y_t . Due to the limitation of the maximum power of the grid exchange and the number of charge and discharge cycles, it is necessary to adjust X_t, Y_t to satisfy the above constraints.

Finally, produce disturbance and generate new solutions $(\lambda_{wt}^*, \lambda_{pv}^*)$. Update the battery strategy (X_t^*, Y_t^*) and the constraint. When the grid switching power is greater than 150, $X_t = 1$ means batteries charge. Otherwise, $Y_t = 1$ means that batteries discharge. Disturb the points other than the power constraint until the charge and discharge limits are met.

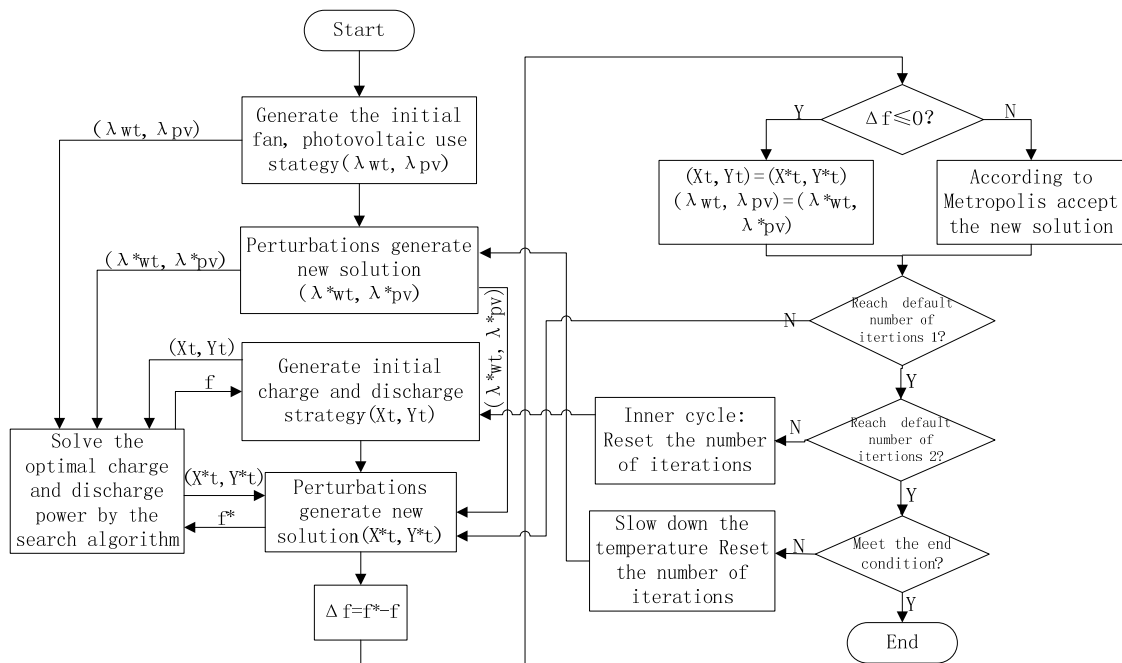


Figure 2. Algorithm flowchart.

5. Result Analysis

5.1. Power Distribution without Optimal Scheduling

5.1.1. Consider the Situation of No Renewable Energy. When the micro-network doesn't use the battery energy storage, only consider the non-renewable energy, which means that it completely relies on the grid to micro-network power supply, the power of total load is shown in Figure 1. (b). In this case, the price only includes the sold price of the grid electricity. The average price of the day is 0.4773 RMB/ Kwh, and the total price is 1578.7 RMB.

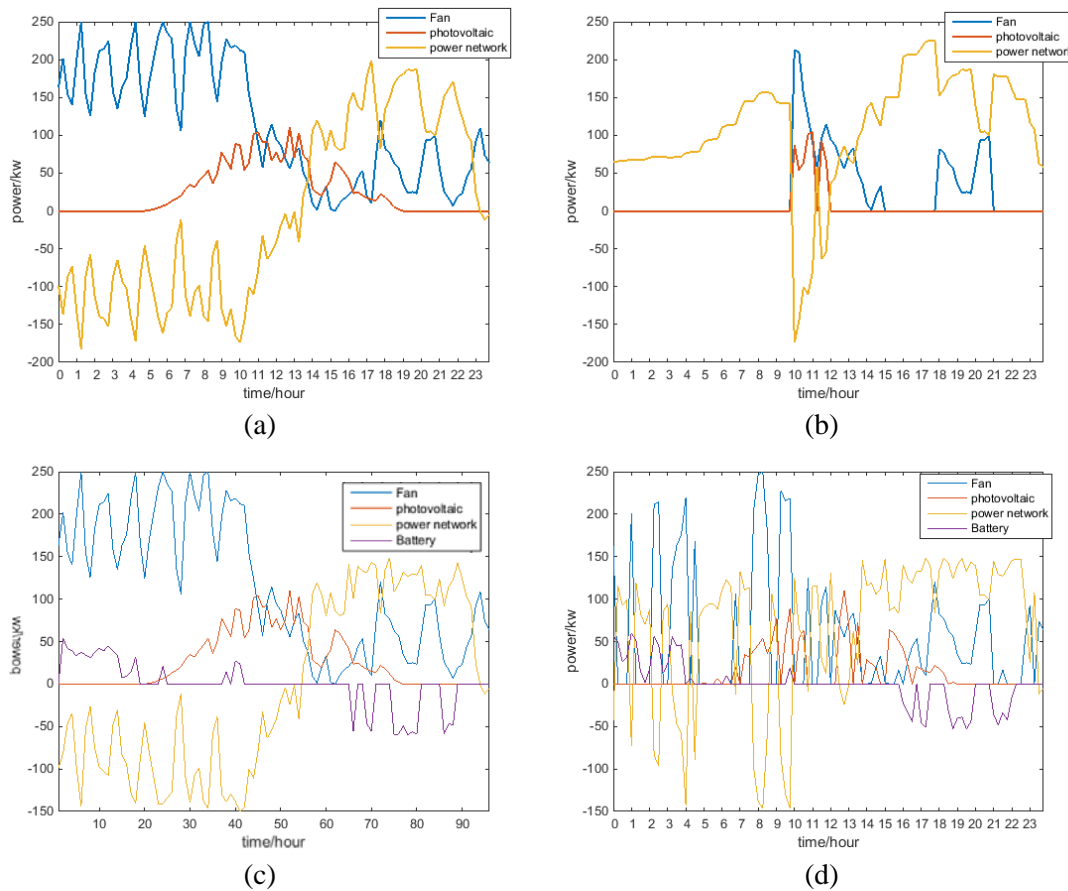


Figure 3. The load composition in different cases. (a). Full use of renewable energy. (b). Optimized scheduling of renewable energy. (c). Optimized scheduling of batteries. (d). Co-optimal scheduling of Wind, light and renewable energy.

5.1.2. Full Use of Renewable Energy. When renewable energy is unpredictable, the renewable energy generation capacity is full used as long price of the day the lowest. The load composition under full use of renewable energy can be shown in Figure 3. (a). In this case, the average price is 0.6065 RMB/Kwh, and the day total price is 5,500 RMB.

5.2. Optimize Dispatch of Renewable Energy

Under the case that renewable energy can be predicted, renewable energy can be optimally dispatched. Scheduling wind and light at different times without any constraints results in the lowest average power price for the entire day. The load composition can be seen in Figure 3. (b). the average price of the day is 0.4486 RMB / Kwh, and the total price is 1483.8 RMB a day.

5.2.1. Introduce the Battery for Optimal Scheduling. In the case of full use of wind and light, batteries are used to optimize the dispatch of the grid power. Taking into account the many constraints of the battery, the states of charge and discharge of the battery are determined first, and then the power of the battery is optimized. The load composition can be seen in Figure 3. (c). the average price of the day is 0.5940 RMB / Kwh, iterative convergence process of which can be seen in Figure 4. (a) and total price is 1964.6 RMB a day.

5.2.2. Consider the Renewable Energy and the Battery to Optimize the Scheduling. When the wind and light can be selected, wind, light, and storage batteries are used to optimally schedule the grid

power. Taking into account the many constraints of the battery, the factors of wind and light are firstly determined. And then the state of charge and discharge of the battery is performed. Finally, the exchange power of batteries is determined. The load composition is shown in Figure 3. (d). the average price is 0.4221 RMB / Kwh, iterative convergence process of which can be seen in Figure 4. (b). and the total price of 1396.1 RMB a day.

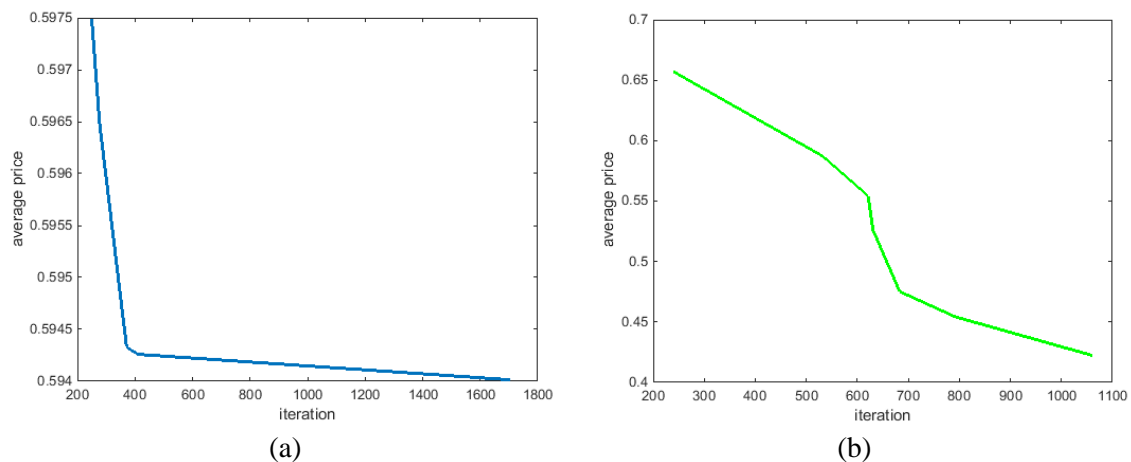


Figure 4. Iterative convergence process. (a). Optimized scheduling of batteries.
(b). Co-optimal scheduling of Wind, light and renewable energy.

6. Conclusion

This paper takes the micro-grid model combined with wind, light and storage as an example to consider making full use of the scheduling functions of renewable energy and storage batteries so as to optimize the economic benefits, and to formulate a micro-grid optimization and adjustment strategy. The multiple search algorithm is used to solve the model and find the global optimal solution that meets the conditions. This strategy is superior to the simple micro-grid model strategy and has a guiding role in the dispatch of the micro-grid.

Acknowledgements

This paper was supported in part by the Nature Science Foundation of Shenzhen City, China under Grant JCYJ20160530173515852 and in part by the Nature Science Foundation of China under Grant 51707168. Thanks for the data provided by Chinese Society for Electrical Engineering (CSEE).

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