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The Optimal Economic Dispatch of Smart Microgrid Including Distributed Generation

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Abstract

With the decreasing of the fossil energy source and the increasing of load demand, making full use of clean and renewable energy, Distributed Generation (DG) technologies gain more and more attentions. Microgrid (MG) integrates the advantages of power generation from new energy and renewable energy power generation systems connected to the grid. MG can not only enhance the comprehensively cascaded utilization of energy, but also can be used as an effective complementary network of the utility in order to improve the power supply reliability and power quality. Based on the analysis of the structure of Microgrid, an optimization model of economic dispatch Microgrid system is established. By integrating these problems, such as the scheduling of generators, intelligent management of energy storage units and optimization of operated efficiency of the network, into a uniform optimization problem, the complexity of application optimization algorithm is reduced.

In this plan, use the Isolation Niche Immune Genetic Algorithm (INIGA) to confirm the accuracy and validity of the mathematic model through some actual examples, and then used this method to compare with some other optimization approaches that usually be used to solve the Energy Management and Optimization Operation problem to show the superiority and usability of the approach mentioned here.

Keywords: Microgrid, Renewable Energy, Distributed Generation, Photovoltaic, Wind Power, Isolation Niche, Immune Genetic Algorithm, Energy Management, Optimization Operation.

1. Introduction

With national economic development, social demand for electricity is increasing. Electrical energy is clean and highly efficient. It is suitable for mass production, centralized management, long-distance transmission and flexible distribution. Thus, the power ministry focuses investment on thermal power generation, hydropower, nuclear power generation and centralized power supply and super-voltage and long-distance power transmission. However, large-scale electric power system has become increasingly problematic with continuous expansion of the power grid. It has high costs, and big difficulty in operation, and cannot meet higher and higher safety, reliability and diversity requirements of users. Especially, widespread power outages occurred several times in the world in recent years. Vulnerability of a large power grid has been exposed fully. Besides, reserves of primary resource for power generation (such as coal and petroleum) are limited. CO_2 and sulfide from burning directly cause greenhouse effect and acid rain. This is one of the main reasons of human survival environment aggravation. Distributed power generation has high reliability, high efficiency of resources utilization, and flexible installation locations. It can solve potential problems of large and middle centralized power grids. Development of wind energy, solar energy and renewable green energy, and research of wind energy power generation, solar power generation, waste power generation, fuel cells and other environment friendly distributed power generation technologies are the scientific approach of sustainable economic and social development. Some scholars have predicted that distributed power generation will become a powerful supplement to the future large power grid and an effective support, an important part of the future intelligent power grid, and one of the development trends of the power system.

Optimal operation of microgrid [1]-[4] means reasonable and effective arrangement of output power of each micro power supply units at full load. It can minimize power generation costs, emission costs or total costs of microgrid. In the past, many methods were used to solve microgrid operation optimization and power energy management, such as: Dynamic Programming (DP) [5], [6]; it has an advantage that cost function can be either discontinuous or non-monotonic increasing. Its disadvantage is that its computer memory and needed calculation time is increased with increase of number of units. In addition, there are several local minimum values, and only suboptimal solution can be found. On the other side, optimization methods have been developed in artificial intelligence field. Thus, some scholars used random optimization method to solve microgrid operation optimization and power energy management, such as Simulated Annealing (SA) [7]-[10], Genetic Algorithm (GA) [11]-[16], Evolutionary Programming (EP) [17], [18] and Evolutionary Strategy (ES) [19]. These are excellent optimization technologies which can find the global optimal solution. In determination of optimal solution, SA uses a probability method to receive candidate solutions to avoid the local optimal solution. However, its parameters are difficult to set, and the calculation time is longer. For a large grid system, it is not easy to operate. GA method has been applied to solving operation optimization and electrical energy management of microgrid but the calculation is time consuming. It cannot ensure global optimal solution. Similarly, EP is also used to solve operation optimization and electrical energy management of microgrid. For large power system, the long calculation time is the main shortcoming.

In this plan, immune genetic algorithm based on habitat isolation technology is proposed to solve operation optimization and electrical energy management of microgrid [20]-[22]. Habitat isolation technology is an excellent

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optimization method. We use the habitat isolation technology-based immune genetic algorithm. The algorithm can also use antibody affinity and concentration judgment. It can make optimization method get rid of local solution and keep diversity of clusters. Premature will not occur in solving process. Thus, we combine the two methods, and make use of their advantages to develop an excellent method for optimizing operation.

2. Mircogrid structure and electric energy management system

Figure 1 shows basic microgrid structure. For a large power grid, microgrid is a whole body. It is connected by using static switch and super-grid. In the microgrid, distributed power supply can use different kinds of energy to generate power, including renewable resources (such as wind power generation, solar photovoltaic power generation, and water turbine) and non-renewable power generation (micro gas turbine, fuel cells, etc). The system can supply heat to load users through combined heat and power generation to improve efficiency of multi-stage energy utilization.

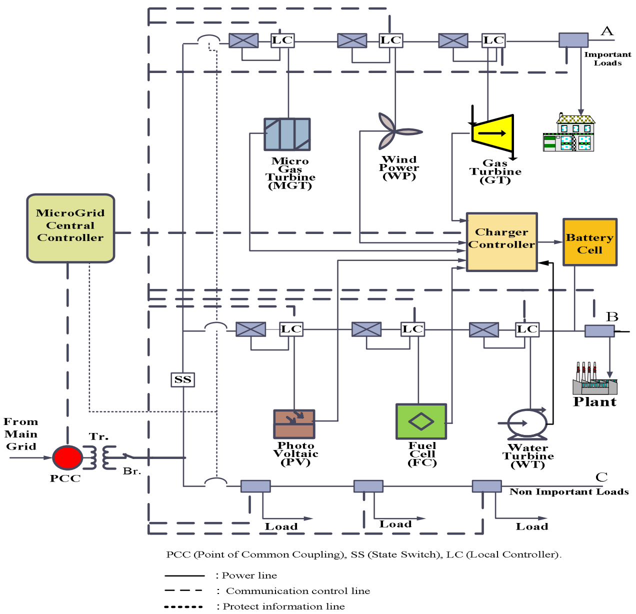

Figure 1. The basic construction of MicroGrid

As shown in Figure 1, microgrid contain A, B and C feeder lines. The entire network is radial pattern. Feeder lines are connected to the super power distribution system through microgrid main isolation device (static switch SS) to achieve transfer from microgrid connection and isolation. Feeder lines A and B are connected to sensitive load (important load). Many distributed power supplies are installed. Feeder A is connected to micro gas turbine of cogeneration to supply heat and power: Feeder line C is non-sensitive load. In isolated network, if microgrid be operated at overload, load of feeder C can be cut selectively. In normal case, microgrid and external large-scale power grid are connected for operation. Distributed power supply and external power grid can satisfy demand for load in microgrids. For power failure or abnormal operation of external large-scale power grid, connection of microgrids with the external power grid can be cut by the main circuit breaker, and the microgrids operate in the way of isolation. At this time, microgrids load demand is provided by the power supply in the microgrids. After troubleshooting, the main breaker is reclosed. Mcirogrids and the external large-scale grid operate synchronously anew, and steady transition to grid-connection operation should be ensured.

3. Mathematical model of microgrid operation optimization

3.1 Grid-connected operation mode

For microgrid system in grid-connected operation, not only unit scheduling and power dispatch between the power supplies in the system but also transaction with external power grid should be considered. According to the load demand and electricity price, the mircogrid energy management system economically dispatches output if distributed power supplies and energy storage units in the microgrid and transacted electricity between the microgrid and external power grid. Economic dispatch strategy: the power generation cost of the power generation unit and price of electricity purchased from the external power grid are compared. If the power generation cost is higher than the purchase price, power generation unit should be closed. The load demand can be satisfied by purchase of electricity from the external power grid. If the power generation unit cost is lower than the electricity purchase price, the power generation unit can normally operate. At this time, if the power generation unit can meet the load demand without maximum output, the power generation cost will be compared with the electricity price of the external power grid. If the power generation cost is lower than the sales price, the power from the unit can be sold, otherwise, the power generation unit will not generate additional power. From the above, the economic grid-connected operation strategy of microgrid with small CCHP system is as follows: (1) WT (wind power generation) and PV (photovoltaic power generation) are not controlled. As renewable energy, wind and PV do not directly consume fuel, and have small environment pollution and quick start-up, and the load can be increased and reduced quickly. Thus, their unit output is preferred; (2) when WT, PV and MT (micro gas turbine) units cannot meet all load demand, a battery storage device discharges electricity and meanwhile supervise battery discharge and charge state. When the battery has not reached maximum discharge limit, it can sell electricity to the external power grid; (3) if the battery is still unable to meet load demand within the allowable discharge range, we can economically dispatch output of power supply units and energy storage unit or purchase electricity from the external power grid according to the total generating cost of the distributed power supply to meet demand for the rest of load.

Microgrid economic operation optimization in grid-connected operation can minimize system operation cost and pollution discharge when the system load demand and reliability are satisfied. Meanwhile, the system can sell electricity to external power grid, and optimization should ensure maximum system efficiency.

3.2 Objective functions

For the microgrid in grid-connected operation, economic operation optimization cost function involves technical performance of distributed power supply, local available energy resources, load demand, environment protection expenses, and operation and maintenance expenses of microgrid power supply. Besides, electricity transaction between the microgrid and external power grids should be considered, namely, system electricity purchase and sales. Thus, total cost function of grid connection is as follows:

$$C_T(P)=\sum_{t=1}^{T}\left[\sum_{i=1}^{N}\left[F_i(P(t))+COM_i(P(t))+\sum_{k=1}^{M}C_k\times\eta_k^i(P(t))\right]+ C_b(t)\times P_{buy}(t)-C_s(t)\times P_{sell}\right] \quad (1)$$

In Eq.(1), *P(t)* denotes output power of distributed power supply *i* in a time interval *t*; *Fi(p(t))* denotes fuel cost function of distributed power supply, *COMi* denotes operation and maintenance cost function of distributed power supply *i*, as shown in Equ.(1). In the equation, $K_{COM\,i}$ denotes proportional constant of distributed power supply, *Ck* is external cost of emission type *k*, η_k^i is emission factor when the emission type of distributed power supply *i* is *k*. *Cb(t)* and *Cs(t)* denote electricity purchase price and sales price in a time interval t respectively, $\sum_t P_{buy}(t)$ is purchased electricity, $\sum_t P_{sell}(t)$ is sold electricity, *N* is total distributed power supply, *M* is emission type (NOx, SO2 or CO2), and *T* is total time interval of optimal cycle.

$$COM_i=\sum_{t=1}^{T}COM_i(P(t))=\sum_{t=1}^{T}k_{COMi}\bullet P(t) \quad (2)$$

MT and FC (fuel cells) power generation needs to burn fossil fuel, and causes NOX, SO2, CO2 and solid smoke dust and particles. Treatment expenses of discharged gas can be calculated by cost of external discount multiplied by total power output of micro power supply

3.2 Constraint conditions

1). Power balance constraint

Sum of load difference between unit output power and purchased and sold electricity must satisfy total load demand.

$$\sum_{i=1}^{N}P_i=P_L-P_{PV}-P_{WT}-P_{batt}+P_{buy}-P_{sell} \quad (3)$$

$\sum P_i$ is total output power of FC and MT, kw, *PL* is load power demand, kw; *PPV* is PV cell output power, kw; *PWT* is wind unit output power, kw: *Pbatt* is battery output power, kw, *Pbuy* is battery output power, kw, *Pbuy is* purchased electricity. kw, *Psell* is sold electricity, kw.

2). Power generation constraints

To ensure operation stability, actual output power of each power generation unit has strict upper and lower limits

$$P_i^{\min}\le P_i\le P_i^{\max} \qquad \forall i=1,\ 2,...,N \quad (4)$$

where, $P_i^{\min}$ is minimum output power of unit *i*, and $P_i^{\max}$ is maximum output power of unit *i*. <0}

3.3 Isolated-grid operation

For microgrid in isolated grid operation, electricity transaction with external grid will not be considered. Load should be supplied by the micro power supply in the system and energy storage device. Micro power supply management system is responsible for real-time management and maintenance of safe and reliable operation of the system, and optimization of microgrid distributed power supply through dispatch of centralized microgrid power.

Thus, optimal operation strategies of microgrid with small CCHP system are as follows:

1). WT and PV unit output is preferred.

2). When WT, PV and MT units cannot meet all load demand, first consider discharge of battery storage device, and monitor discharge and charge states of battery.

3).If the battery is still unable to meet load demand within the allowable discharge range, we can economically dispatch output of power supply units and energy storage unit or purchase electricity from the external power grid according to the total generating cost of micro power supply to meet demand for the rest of load.

4). If power generation of units at full load, and full discharge of battery are still unable to meet the load demand, we can first consider cut of non-critical load, and ensure power supply for critical load; when the load demand cannot be met, cut some load according to importance.

Microgrid economic operation optimization in grid-connected operation can minimize system operation cost and pollution discharge when the system load demand and reliability are satisfied. In the optimization mathematical model, micro power supply technical performance, local available resources, load demand, operation and maintenance costs of micro power supply and environment protection expenses should be considered

3.4.1 Objective function

In isolated grid operation, objective function (cost function) of microgrid optimal operation is as follows:

$$C_{TS}(P)=\sum_{t=1}^{T}\sum_{i=1}^{N}\left[F_i(P(t))+COM_i(P(t))+\sum_{k=1}^{M}C_k\times\eta_k^i(P(t))\right] \quad (5)$$

Meaning of each coefficient is shown in Eq.(1).

3.4.2 Constraint functions

1). Power balance constraint

$$\sum_{i=1}^{N}P_i = P_L - P_{PV} - P_{WT} - P_{batt} \quad (6)$$

Meaning of each coefficient is shown in Eq.(3)

2). Power generation constraint

To ensure operation stability, actual output power of each power generation unit has strict upper and lower limits.

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad \forall i = 1,\ 2,\ldots,N \quad (7)$$

where, $P_i^{\min}$ is minimum output power of unit i, and $P_i^{\max}$ is maximum output power of unit i.

4. Habitat isolation niche immune genetic algorithm

Eleven steps for implementation of Habitat isolation based immune genetic algorithm are as follows, and the flow chart is shown in Figure 2:

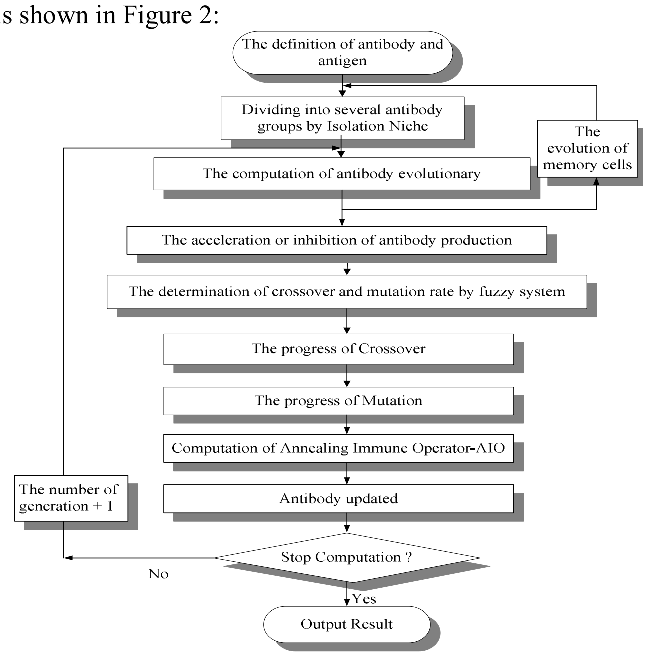

Figure 2 The flow chart of isolation niche immune genetic method

5. Actual operation results and comparison

There is one wind power plant and other five different power generation sources (shown in Figure 1). For the six different power generation sources, the total load demand of 24 hours in the D day of summer is listed in Table 1. Wind power plant includes parallel operation of 20 wind power generation units. The rated effective output power is 100MW. Wind power generation curve in 24 hours of the D day in summer is shown in Figure 3. The wind quantity per hour is estimated through neural network, and converted to power. Maximum effective power of total output of the wind power plant is 100MW, and minimum value is 15MW. Figure 4 shows output power of solar power generation in 24 hours of the D day of summer. Table 3 shows comparison between generating costs and CUP convergence time in 24 hours of D day in different methods. From Table 3, the generating costs using the proposed methods are reduced by USD$ 7,972, USD$ 11,156 and USD$ 18,289 as compared to EP, GA and DP.

Table 1 Total load demand of 24 hours in the D day of summer for the six different power generation sources

Time (hr)	Loads (MW)	Time (hr)	Loads (MW)
1	233	13	643
2	228	14	637
3	221	15	687
4	186	16	732
5	256	17	654
6	224	18	565
7	337	19	554
8	467	20	529
9	532	21	455
10	633	22	443
11	712	23	372
12	758	24	338

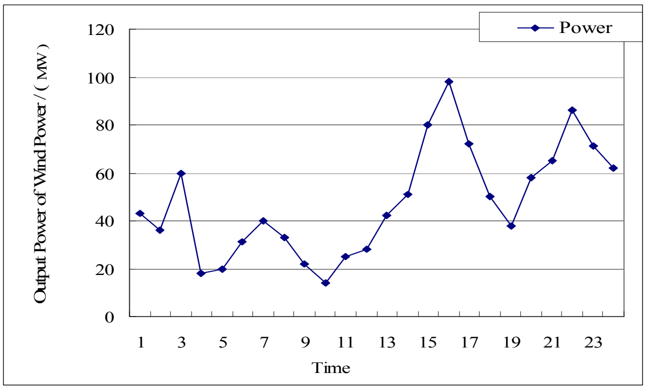

Figure 3 Wind power generation curve in 24 hours of the D day in summer

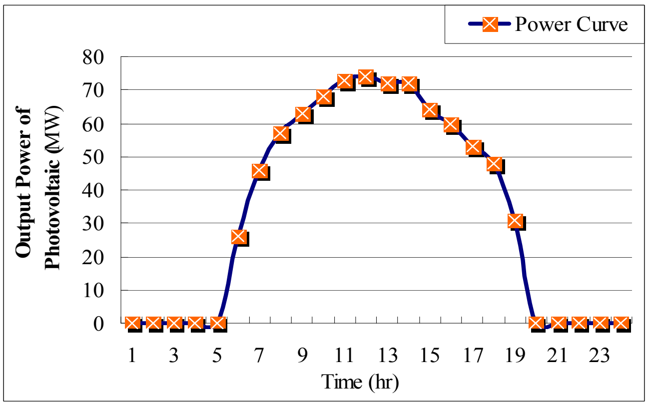

Figure 4 Solar generation power output in 24 hours of the D day in summer

Table 3 Comparison between generating costs and CUP convergence time in 24 hours of D day in different methods

Different Method	Generation Cost (U.S.$)			CPU (s)		
	Min.	Max.	Ave.	Min.	Max.	Ave.
DP	142,734	148,315	145,525	8.54	9.73	9.13
GA	137,223	139,561	138,392	5.56	7.82	6.69
EP	133,524	136,892	135,208	4.67	5.89	5.28
In Here	124,332	130,139	127,236	2.67	3.24	2.96

6. Conclusions

In this paper, habitat immune genetic algorithm is used. It can diversify clusters. Thus, it can prevent earlier convergence in algorithm. Besides, the immune genetic algorithm can prevent local solution in search of optimal solution. The two methods are combined to increase accuracy of optimization method and convergence speed. As compared to the results of other common optimization methods, this method can meet accuracy and promptness requirements.

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