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Optimization of Microgrid Dispatch by Using Co-evolutionary Method

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Abstract
The drawbacks of high cost, high pollution and high energy consumption of traditional power system become increasingly apparent, so the energy crisis and energy conservation is an urgent requirement to promote new energy generation and renewable energy generation such distributed generations to become a useful supplement for

main grid. And the Microgrid is an effective way to access grid for the distributed power. Co-evolutionary genetic algorithm has the characteristics of parallel computing, fast convergence and strong optimization ability, which is applied into the optimization of environmental and economic dispatch of Microgrid. By the minimum total costs of power generation and emission as target respectively in isolated mode and grid-connected mode, the optimal scheduling of distributed power contribution is achieved. The experimental results show the method is correct and effective.

Keywords: MICROGRID, CO-EVOLUTIONARY GENETIC ALGORITHM, ISOLATED MODE, GRID-CONNECTED MODE, GENERATION COST, EMISSION COST

1. Introduction

The development of society and advancement of technology make the demands for the quality, safety and reliability of power supply are increasing, which is resulting in the traditional power system facing serious challenges. With the decreasing of the fossil fuel energy resources day by day, the drawbacks of high cost, high pollution and high energy consumption of traditional power system by non-renewable energy mainly become increasingly apparent. So the urgent requirement of energy crisis and energy conservation promotes the power industry to develop new energy constantly and strengthen the utilization of renewable energy while expanding and improving the existing power system. These distributed generations of new energy generation and renewable energy generation will become the useful supplement for main grid, and contribute to human society for the healthy and sustainable development (Zangiabadi, M. et al, 2011).

Distributed generation can be an effective solution to shortage of traditional energy resources and the greenhouse effect caused by carbon dioxide emissions overly. Common Distributed Generation (DG) includes Wind Turbine (WT), Photo Voltaic (PV), Micro Turbine (MT), Fuel Cell (FC) and Gas Turbine (GT) power generation (Cardenas, A. et al, 2012; Brass, J. N. et al, 2012). And Microgrid is a form of power grid combined with distributed generations, power loads, energy storage devices and a variety of controllers (Huang, W. et al, 2009). It is controlled as a single unit to supply electricity and heat to the user by either isolated mode or grid-connected mode in achieving the voltage and frequency stability and power balance in inner. Microgrid not only solved the access problem of large-scale distributed generations, but also could use a variety of distributed generations environmentally friendly and efficiently. It has a high reliability of power supply and is an effective way to access main grid for distributed generations. Many countries have made it as one of the strategic objectives of the future power development. In the research on Microgrid, the study of environmental and economic dispatch is great significant in the development of new energy applications and is an important research aspect of the smart grid (Xue, S. et al, 2012).

The environmental and economic dispatch of Microgrid means that the distributed power outputs are coordinated to make the whole power generation costs and emission costs minimum under the premise of meeting the load demands and operation constraints. So far, some achievements in this area have been achieved, which relates to the Particle Swarm Optimization (PSO) (Saber, A. Y., 2012; Li, R. et al, 2012), Ant Colony Optimization (ACO) (Cai, J. et al, 2012), Genetic Algorithm (GA) (Liao, G. C., 2012; Liao, G. C., 2012) and so on (Coeho, L. S. et al, 2009; Zhong, Q. X. et al, 2013), but there is a certain gap from the actual demands.

The environmental and economic dispatch of Microgrid both in isolated mode and grid-connected mode is further discussed in this paper. The mechanisms and methods are analyzed especially on the combination of Co-evolutionary Genetic Algorithm (CGA) and scheduling of Microgrid. The CGA method has the characteristics of parallel computing, fast convergence and strong optimization ability, which is applied into the optimization of environmental and economic dispatch of Microgrid for the aim of total costs minimum of Microgrid. Simulation results show that the method in this paper is feasible and effective.

2. Mathematical Model of Environmental and Economic Dispatch of Microgrid

Microgrid has two operation modes including of grid-connected mode and isolated mode. In grid-connected mode, the main grid is an important support of Microgrid and can ensure reliable power supply to load; In isolated mode, Microgrid don't absorb power from main grid and is powered independently by internal micro power sources completely. The Microgrid environmental and economic dispatch system is to adjust the DG unit output in the Microgrid so as to make the generation costs and emission costs minimum in satisfying the load demand and power operation constraints. In addition, only the mathematical model in grid-connected mode is described in following text, the model in isolated mode can be easily obtained by not considering the power exchange between Microgrid and main grid.

2.1. Objective Function

$$\min F=\sum_{i=1}^{N}[C_G(P_i)+C_E(P_i)]+C_M(P_M) \quad (1)$$

where F is the total cost (Euro), N is number of DG unit, Pi is generation power of No.i unit of DG (kW·h); PM is the exchange power between Microgrid and main grid (kW·h), and PM < 0 represents to output power to main grid, whereas it represents to input power from main grid; CG(Pi) is generation cost of No.i unit of DG (Euro), CE(Pi) is emission cost of No.i unit of DG (Euro), CM(PM) is the exchange power cost or income between Microgrid and main grid (Euro).

2.1.1. DG parts

(1) Generation cost

The generation cost of DG unit is mainly composed of two parts, namely, fuel cost and operation & maintenance cost. That is,

$$CG(Pi) = \alpha iPi + \beta iPi \quad (2)$$

where αi means the fuel consumption expense for generating 1kW·h of DG unit, namely, the fuel coefficient of No.i unit of DG (Euro/kW·h); βi means the operating and maintenance expense for generating 1kW·h of DG unit, namely, the operating and maintenance coefficient of No.i unit of DG (Euro/kW·h).

(2) Emission cost

The emission cost can be denoted as follows:

$$CE(Pi)=\sum_{j=1}^{W}\eta_j\gamma_{ij}P_i \quad (3)$$

where W represents the number of kinds of emissions such as NOx, SO2 and CO2, etc. γij means the No.j emission greenhouse gas weight for generating 1kW·h electricity every time of No.i unit of DG, namely, the No.j emissions coefficient for No.i unit of DG (kg/kW·h); ηi means the discharge fee which every time emission 1 kg No.j greenhouse gas must pay, namely, the No.j greenhouse gas emissions cost (Euro/kg).

2.1.2. Power exchange part with main grid

$$CM(PM)=\begin{cases} C_B(P_M) & P_M>0 \\ 0 & P_M=0 \\ -C_S(P_M) & P_M<0 \end{cases} \quad (4)$$

where CB(PM) is cost to buy electricity from main grid, CS(PM) is income to sell electricity to main grid.

(1) Cost to buy electricity

In PM > 0, Microgrid inputs power from main grid, which cost to buy electricity includes price cost and emission cost, namely,

$$CB(PM)=c_bP_M+\sum_{j=1}^{W}\eta_j\gamma_{Mj}P_M \quad (5)$$

where cb is price to buy electricity from main grid, γMj means the No.j emission greenhouse gas weight for generating 1kW·h electricity every time of main grid, namely, the No.j emissions coefficient for main grid (kg/kW·h).

(2) Income to sell electricity

In PM < 0, Microgrid outputs power to main grid, which income to sell electricity can be denoted as follows:

$$CS(PM) = cs\,|PM| \quad (6)$$

where cb is price to sell electricity to main grid.

2.2. Constraints

In the environmental and economic dispatch of Microgrid, two kinds of constraints are needed generally, that is equality limiting condition and inequality limiting condition.

(1) Equality limiting condition

The environmental and economic dispatch essentially satisfies condition of the power balance limit which is one of basic criteria in power supply system.

$$\sum_{i=1}^{N}P_i+P_M=PD+PL \quad (7)$$

where PD is the total load demand and PL is the total line loss in power transmission.

(2) Inequality limiting condition

To guarantee steady DG running, each DG must satisfy the capacity limiting condition, which means the DG power generation must satisfy the upper or lower value limit for the output of each unit.

$$P_i^{\min}\le P_i\le P_i^{\max} \quad (8)$$

where $P_i^{\max}$ and $P_i^{\min}$ are respectively the upper and lower limit value of No.i unit of DG.

The exchange power between Microgrid and main grid should satisfy the following:

$$P_M^{\min}\le P_M\le P_M^{\max} \quad (9)$$

where $P_M^{\max}$ and $P_M^{\min}$ are respectively the upper and lower limit value of exchange power between Microgrid and main grid.

3. Analysis of CGA

The CGA method is usually achieved based on multiple populations, which evolve through mutual competition and cooperation. The CGA has the characteristics of high convergence speed, strong robustness and not easy to fall into local trap (Gong, D. W. et al, 2009). In addition to competition, cooperative relationship between species is another very popular relationship. Cooperative Co-evolutionary Genetic Algorithm (CCGA) is presented for mutual adaptation optimization module widely existed in the real world. The flowchart of CCGA is as Figure 1.

In practice, the number of sub-populations can be more or less determined by the problem itself. When each sub-population evolves independently, the evolutionary process of CCGA is more flexible, which not only used the same evolutionary algorithm, but also used various ones. This is consistent with the diverse evolutions of nature. For example, genetic operations can use selection, crossover and mutation, as well as can use the relative operations in evolutionary strategy or evolutionary programming.

4. Simulation and Results

A basic Microgrid experimental system is constructed in this paper. Select typical experimental data and system parameters, do a number of simulation experiments in MATLAB R2010a, then compare and analyze the experimental results.

In the basic structure of Microgrid, there are five DG units, that is PV, WT, MT, FC and GT. These units provide power to the load in together. The entire Microgrid relative to main grid through a Point of Common Coupling (PCC) is a whole. In addition, if the main grid is out of work or the quality of electricity cannot achieve the standard of system, Microgrid can operate under the style of isolated mode to guarantee itself and enhance the reliability and security of power supply. Therefore, isolated operation is the most important ability of Microgrid. Looking from the main grid, the Microgrid is just as the load or generator in the electric grid, that is, a modular of the whole system. As the limitation of paper length, all the reference data are not listed here.

4.1. Studies Case 1

The first experiment aims at verifying the effectiveness of the proposed CGA in the environmental and economic dispatch of Microgrid in grid-connected mode and isolated mode. From Figure 2(a) and (b), because load 1 are all less than load 2 from 1:00 to 17:00, but load 2 are less than load 1 for the rest of period, the minimum total costs of load 1 are just lower than load 2 from 1:00 to 17:00, and the minimum total costs of load 2 are just lower than load 1 for

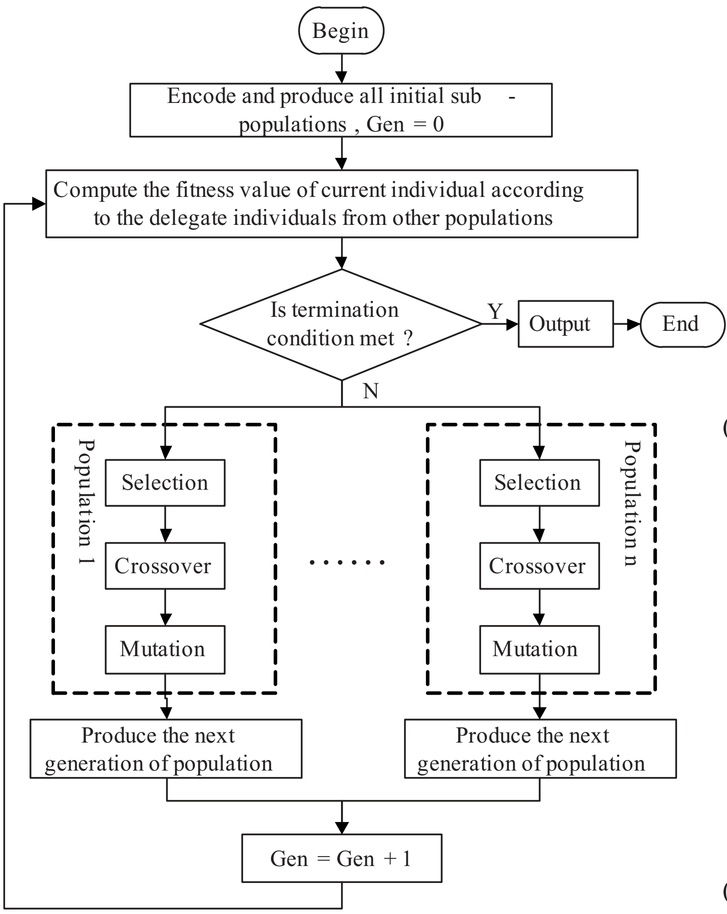
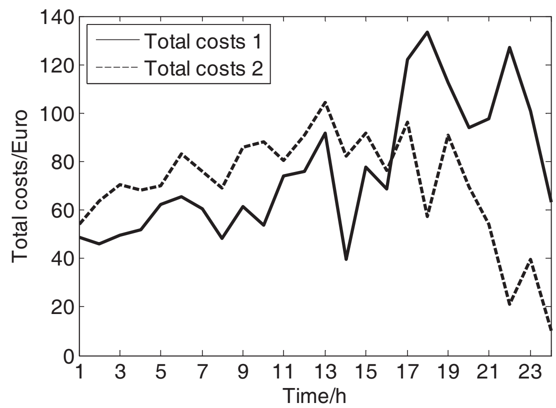
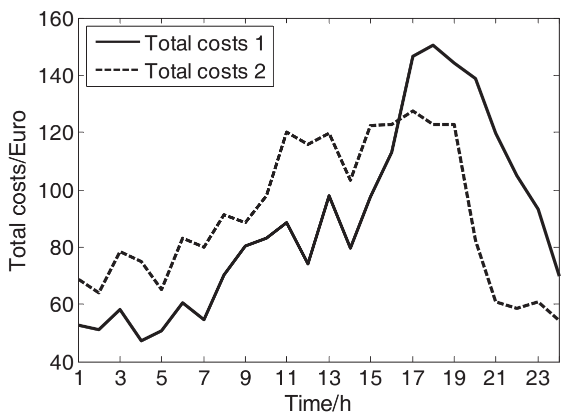


Fig 1.. Flow Chart of CGA



(a) In grid-connected mode



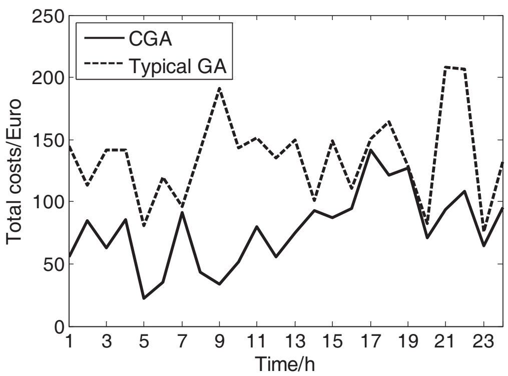
(b) In isolated mode

Fig 2. The minimum total cost for requirements of load 1 and load 2 in different modes the rest of period. This optimization results are consistent with the theoretical analysis. In other words, the lower load demands are, the lower total costs are, thus it demonstrates the correctness of CGA in the environmental and economic dispatch of Microgrid.

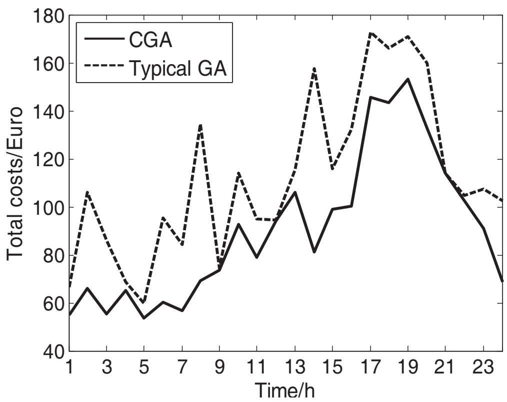
4.2. Studies Case 2

The purpose of the second experiment is to verify the superiority of CGA compared with the ordinary typical GA in environmental and economic dispatch of Microgrid in grid-connected mode and isolated mode. The selected ordinary typical GA is a common algorithm. To improve the credibility of the experimental conclusions, the parameter settings and a variety of genetic manipulations of CGA are consistent with the typical algorithm.

As can be seen from Figure 3(a) and (b), the minimum total costs of load 1 optimized by CGA for each period are all lower than ones by typical GA. This illustrates that the optimization effect of CGA is significantly better than the typical GA in the same conditions, which reflects the superiority of the former. The conclusions about these two methods for the optimization of load 2 are consistent with load1, so they are not repeated here again.



(a) In grid-connected mode



(b) In isolated mode

Fig 3. The minimum total cost of two methods for requirement of load 1 in different mode

4.3. Studies Case 3

The purpose of experiment 3 is to further verify the superiority of CGA from the optimization performance and CPU running time. By the example of load 1, to keep the other parameters of algorithm unchanged and only adjust the population size, 10 times of tests are performed for various population size respectively, then fill the average of results in Table 1.

Tab 1. Performance comparisons of algorithms

Mode	Algorithm	Population size	Total costs average (Euro)	CPU time (s)
Grid-connected mode	CGA	30	74.1639	5.699014
	Typical GA	30	127.7084	2.669091
		60	96.0547	4.780867
		90	84.2412	6.978115
		120	74.7959	9.210788
Isolated mode	CGA	30	88.8617	6.726305
	Typical GA	30	116.3781	2.584372
		60	94.6362	4.338016
		90	91.8535	6.209440
		120	89.5666	8.048473

Experimental results show that the expansion of population size of typical GA does play a catalytic role for the optimization, but the effect isn't obvious again and the running time increase seriously. Therefore, the optimization results can be achieved easily for CGA, but the typical GA will have to pay a heavy price. So, the CGA method has good optimization performance and convergence rate.

5. Conclusions

In this paper, a new optimization method is introduced into the environmental and economic dispatch of Microgrid, which is presented based on co-evolutionary thinking and the CGA method fully demonstrated the feasibility and effectiveness applied to the Microgrid scheduling no matter in grid-connected mode or isolated mode. For this Microgrid distributed architecture itself, the CGA has a good adaptability. In the future, to use the distributed characteristics of CGA and Microgrid, and introduce the distributed parallel computing technology, the optimization capabilities of CGA will be further enhanced in Microgrid scheduling.

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