Microgrid Frequency Control Based on Genetic and Fuzzy Logic Hybrid Optimization

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Abstract. Power system frequency is an important performance index of AC microgrid operation. The power quality and user load, and even the safe and stable operation of microgrid, are affected directly by the frequency. Most modern microgrid contains a large number of intermittent renewable energy generation, this generation units have small capacity, many quantity, larger environmental and user load disturbance, strong nonlinear and unpredictable. The traditional control theory is difficult to effectively solve the problem of the microgrid frequency control. A new combination intelligent control method is presented. Two stage combinatorial optimization techniques of genetic algorithm and fuzzy logic is used. First, genetic algorithm is used to optimize the input and output fuzzy triangular membership function parameters. Second, fuzzy logic is used to optimize PI controller parameter to achieve the optimal control of the microgrid system frequency. The effectiveness of the two stage combination intelligent control algorithm is validated by the MATLAB simulation experiment.

Keywords: Microgrid · Frequency control · Intelligent control · Genetic algorithm optimization · Fuzzy logic

1 Introduction

With the increasing popularity of renewable energy, a large number of nontraditional power is introduced in power system. This promotes further rapid development of new energy as well as efficient use, but also brings a series of problems to power system stability, such as increasing the traditional power system complexity, uncertainty and power quality. The most new energy generation device is distributed at low voltage grid to form a local microgrid, the microgrid is integrated in the large grid by the distributed generation. Typical distributed generation microgrid consists of diesel generator (or micro gas turbine generator), photovoltaic generator, wind turbine, energy storage device. In microgrid system, because of the small inertia characteristics of the generation unit, the generator unit dynamic is impacted greatly by load disturbance. Energy storage unit is very important to improve the power quality and stability of the microgrid system, and the common energy storage device are storage battery and super capacitor.

The main performance index (such as voltage and frequency) of the microgrid system must be controlled by appropriate control strategies to maintain the system's good

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performance and stability. The current control structures are centralized control, single agent control and decentralized control. In the centralized control structure, central control unit controls the load and system parameters, collects all information of the microgrid load and DGS (distribute generations) device, and determines the system load size as well the microsource power supply. In the single agent control structure, local load and system parameters of the microgrid system is controlled by a bigger controllable microsource device, the disadvantage of this method is that the system needs to be assembled with a high cost microsource device. In decentralized control structures, each microsource device is equipped with a local controller to realize the distributed control of the microgrid. For microgrid frequency control, the current method is mostly traditional PI controller. A modified PID control of diesel governor is used to deal with the slow and big net-load fluctuations to achieve the zero steady-state error frequency control of islanded micro-grid [1]. Using traditional proportion integration (PI) block to replace damping block in rotor motion equation, It eliminated frequency deviation in standalone mode in the microgrid system [2]. Because of the bandwidth limitation, the control dynamic performance can not meet the microgrid requirements. Some complex control algorithms are proposed, Such as model predictive control, robust H∞ control [3–6]. However, these control methods are based on exact mathematical models. When the microgrid structure or the nonlinearity is changed, the controller can hardly achieve the desired performance. Intelligent control method, such as H2/H∞ controller based on improved particle swarm optimization, combination of the neural network and fuzzy logic optimization, combination of the fuzzy logic and the particle swarm optimization, is used for the regulation frequency of the micro grid [6–8]. Also some paper present virtual synchronous generator control strategy [9–11], the frequency stability of microgrid is improved by using synchronous generator's rotor motion equation. With the aid of data communication networks, generation unit should be selected reasonably as control leader in secondary frequency control of microgrids [12–14]. For multi-microgrids system, distributed method is applied microgrid frequency control [15, 16].

In order to improve the reliability of microgrid power supply, microgrid can operate at the grid connected mode or island mode. Under the island mode, the voltage and frequency of microgrid need to be regulated independently in order to ensure the quality of power supply. Because the microgrid is placed the low voltage site and medium voltage distribution networks, so it is affected greatly by the load disturbance. What's more, the new energy generation device has intermittent characteristics, these factors will bring some difficulties to the microgrid voltage/frequency control. The traditional PI control method is difficult to achieve satisfactory results. For improving the power quality of microgrid, this paper proposes intelligent method based on Fuzzy logic and genetic algorithm hybrid to achieve microgrid frequency control. In the proposed control strategy, the PI parameters are automatically tuned using fuzzy rules, according to the online measurements. In order to obtain an optimal performance, the GA technique is used online to determine the membership functions parameters.

2 Microgrid Structure and Control Scheme

AC microgrid is a interconnection network system of the distributed load and low voltage distributed energy. It is composed of microsource unit and new energy power generation unit, such as micro diesel generator (DEG), wind turbine generator (WTG), photovoltaic (PV) and energy storage equipment. An example of a microgrid architecture is shown in Fig. 1, the distributed system is consisted of many radial feeders, its load can be divided into sensitive (L1, L2) and non sensitive (L3, L4) in the microgrid, sensitive load can be fed by one or more microsource unit, while the non sensitive load can be closed in case of emergency or severe disturbances. All microsource unit is connected by a circuit breaker and power flow controller which are controlled by the central controller or energy management system. The circuit breaker is disconnected from the feeder when serious disturbance occurs, so that other equipment is not affected by the serious fault. Microgrid is connected to the main grid by a fast switching (SS). The SS is capable to island the MG for maintenance purposes or when faults or a contingency occurs.

Microsource and energy storage devices are connected generally to microgrid via a power electronic circuit, the connection mode depends on the type of device, respectively DC/AC, AC/DC/AC, AC/AC power electronic converter interface, and microgrid control depends on the control of the inverter. The diesel generator and the energy storage system must be sufficient energy compensation to avoid power supply interruption. With the aid of advanced control technology, microgrid central controller can control microgrid operating in stable and economic. The microsource controller controls the microsource and energy storage system, while load controller controls the controllable load in user side. In order to increase the reliability of the traditional power system, the microgrid must maintain good performance both in main grid and island mode. In main grid mode, the main grid is responsible for controlling and maintaining power system in desired conditions, and the MG systems act as real/reactive power injectors. But in island mode, the microsource is responsible for maintaining the local loads and keeping the frequency and voltage indices at specified nominal values.

Control is one of the key problem for the safe and stable operation of AC microgrid. The microgrid has a hierarchical control structure with different layers, which needs advanced control technology to control effectively. As mentioned above, the microgrid can not only run at the island, but also connected with the main grid. In the island mode, microgrid should provide proper control loops to cope to the variations of the load disturbances, and perform active power/frequency and reactive power/voltage regulation. The AC MG operates according to the available standards, and the existing controls must properly work to supply the required active and reactive powers as well as to provide voltage and frequency stability. From Fig. 1, each of microsource has a local controller, each of load controller can control the controllable load, microgrid need central controller to achieve microgrid and the main grid connected control. Similar to the traditional power system, AC microgrid control is divided into different levels of control, which mainly includes the primary local control layer, the secondary level control layer, the central control layer and the emergency control layer. The primary local control layer achieves the current and voltage loop control of the microsource. The secondary level control layer realizes the control of microgrid's frequency and voltage deviation control. The central control layer realizes the microgrid economic optimum operation and scheduling control. The emergency control layer covers all possible emergency control schemes and special protection plans to maintain the system stability and availability in the face of contingencies. The emergency controls identify proper preventive and corrective measures that mitigate the effects of critical contingencies. In contrast to the local control, the primary local control layer does not need communication. The secondary level control layer, the central control layer and the emergency control layer need communication channels. Therefore, the primary local control layer can also be referred to as decentralized control, the secondary level control layer, the central control layer and the emergency control layer are called centralized control. Because of the variety of power generation and load, the AC microgrid has a high nonlinearity, dynamic and uncertainty. It needs an advanced intelligent control strategy to solve complex control problems.

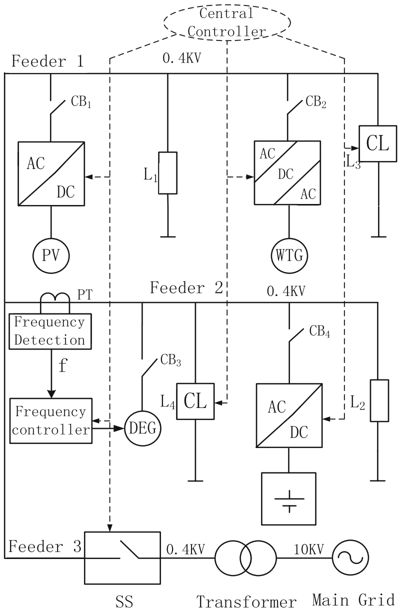

Fig. 1. Example of a microgrid structure.

3 Mathematical Model of Microgrid Frequency Control

Under the island mode, the control of the microgrid system is more important than the connected grid mode. Because the island mode microgrid has not the large grid support, the control is more difficult. Based on Fig. 1 example of microgrid structure, this paper establishes the AC microgrid control model of island mode, as shown in Fig. 2. The diesel generator is only as frequency control, photovoltaic and wind turbine keep always the maximum power output, storage battery is used for compensating diesel oil generator power shortage.

Wind generation and photovoltaic generation are intermittent power source, which its rated power are set respectively to 30 KW and 100 KW, and connected to feeder by power electronic control interface. The inverter control interface is modeled two series inertia model, the inverter switching time constant TIN equals 0.04, and filter time constant TLC equals 0.003. The diesel generator rated power is set to 120 KW, its model is equivalent to two series inertia model, the electromechanical time constant Tg equals 0.09, and inertia time constant Tt equals 0.5. Diesel generator frequency is controlled by the intelligent controller. Storage battery rated power is set to 80 KW, its model is equivalent to a first order inertia, time constant TB equals 0.15. L1 and L2 is the sensitive load, and its load power may not be controlled. L3 and L4 is non sensitive load, its load power can be controlled according to the energy balance need to increase or decrease the load at any time, even to remove the load.

In the microgrid, the new energy generation has the characteristics of large intermittent, fluctuation, nonlinear and non predictability. The advanced intelligent control method is needed to control the system frequency, so as to ensure the stability, reliability and power quality.

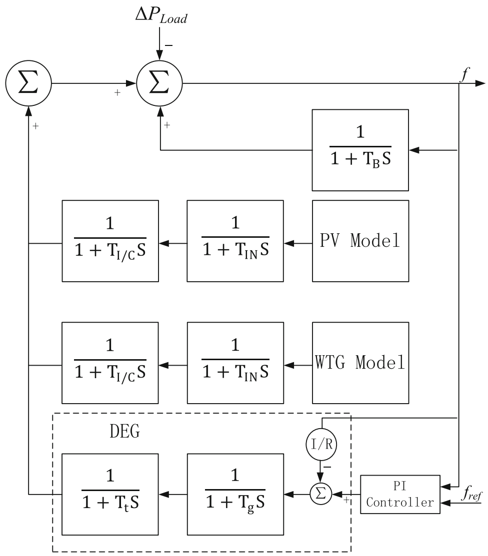

Fig. 2. Model of microgrid frequency control.

4 Genetic-Fuzzy Controller Algorithm Design

A. Theoretical Background

The GA is a popular heuristic optimization technique usually applied when the problem is highly nonlinear and high dimensional order. The idea behind it is based on biological genetics and the concept of "survival-of-the-fittest." Successive generations inherit features from their parents in a random fashion through the crossover of chromosomes. Also, certain changes, called mutations, may occur to the structure of the chromosomes at random. It is thought that through the process of evolution, successive generations will breed "better" populations, since only the fittest will survive. In the frame of optimization, the algorithm is built such that each chromosome is composed of a vector of possible values of the variables to be found. Initially, a number of these chromosomes are initialized at random, and designated as the initial population. Through successive iterations, the fitness of these chromosomes are evaluated, and a certain fraction of the chromosomes having the best fitness are retained in the next generation, which the rest discarded. These are replicated to make up the population number. Then, crossovers and mutations are applied on the chromosomes, and the process is repeated for a given number of iterations. The chromosomes are eventually converged to an optimum. As all other heuristic techniques, however, GA can be susceptible to being stuck in local minima. Fortunately, this effect is less so in GA than other heuristic techniques such as PSO with proper tuning of parameters, particularly the number of mutations, which introduce chromosomes randomly, hence enhance the capability of exiting local minima.

The fuzzy logic is a many-valued logic where the fuzzy logic variables may have truth values ranging in different degrees between 0 and 1, known as their membership grade. Fuzzy logic can deal with the uncertainties in the system through a simple IF-THEN rule based approach, thereby mathematical model is eliminated for the system control. This is especially useful in complex systems for which a complete mathematical model representation may not be possible. However, the fuzzy logic based system complexity increases rapidly with more number of inputs and outputs. A fuzzy logic control system consists of four principal components, respectively as fuzzification, fuzzy rule base, inference system, and defuzzification. The fuzzification converts the binary logic inputs into fuzzy variables, while the defuzzification converts the fuzzy variables into binary logic outputs. This conversion is achieved by means of a membership function. The rule base is a collection of IF-THEN rules that describe the control strategy. The output of each rule is deduced by the inference logic to arrive at a value for each output membership function. The "fuzzy centroid" of the composite area of the output membership function is then computed in order to obtain a binary output value.

B. **Conventional fuzzy PI controller**

In the traditional power system, the secondary frequency regulation is controlled by the conventional PI controller that is usually tuned based on preset operating points. When the operating condition is changed, the PI controller will not meet the desirable performance requirements. While, if the PI controller can be continuously able to track the changes occurred in the power system, the optimum performance will be always achieved. Fuzzy logic can be used as an suitable intelligent method for online tuning of PI controller parameters.

Fuzzy PI controller is composed of two parts, respectively a traditional PI controller and fuzzy logic unit. The input variables of the Fuzzy logic units are the Δf (microgrid frequency deviation) and ΔPL (load disturbance). The output variable of the fuzzy PI controller parameter are KP (the proportional gain) and Ki (the integral gain). Fuzzy rule base consists of a group of 18 rule, as shown in Table 1. The input variable Δf fuzzy subsets T(Δf) equals {Negative Large (NL), Medium (NM), Negative Small (NS), Positive Small (PS), Positive Medium (PM), and Positive Large (PL)}. The input variable ΔPL fuzzy subsets T(ΔPL) equals {Positive Small (PS), Positive Medium (PM), and Positive

Large (PL)}. The output variable fuzzy subset T(KP, Ki) equals {Negative Large (NL), Medium (NM), Negative Small (NS), Positive Small (PS), Positive Medium (PM), and Positive Large (PL)}. They have been arranged based on triangular membership function which is the most popular one. The antecedent parts of each rule are composed by using AND function (with interpretation of minimum). Here, Mamdani fuzzy inference system is also used.

Fuzzy PI controller has better performance than the traditional control method, but its control performance is highly dependent on the membership function. If there is no precise information of the microgrid system, the membership function will not be accurately selected. And the designed fuzzy PI controller will not achieve the optimal performance under the large range of operating conditions.

Table 1. The fuzzy inference rules.

ΔPL	Δf					
	NL	NM	NS	PS	PM	PL
S	NL	NM	NS	PS	PS	PM
M	NL	NL	NM	PS	PM	PM
L	NL	NL	NL	PM	PM	PM

C. **Genetic algorithm to optimize membership function parameters**

Genetic algorithm is an efficient global optimization search algorithm, which simulates biological evolution process. The algorithm has simple structure, it can be processed in parallel, and get the global optimal solution or sub optimal solution without any initial information. The optimization design frame is shown in Fig. 3, the optimization target is the minimum frequency deviation Δf.

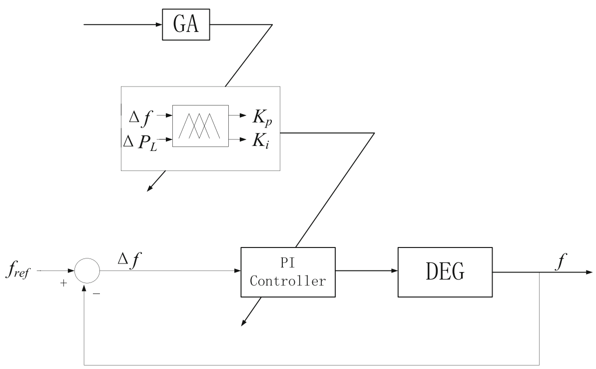

Fig. 3. GA-Fuzzy PI frequency controller

The membership function of the input and output variable is isosceles triangle function. The Parodi and Bonelli coding method is adopted. Real number coding parameters (c, w) are expressed respectively the position and width of the single membership degree function. R_{jk} is expressed as the *j-th* linguistic variables of the *k-th* membership degree function, C_{jk} is expressed as fuzzy domain position of the R_{jk}, and W_{jk} is expressed as fuzzy domain width of the R_{jk}. Thus membership function MF_j of the fuzzy linguistic variable set I_j can be expressed as string encoding (c_{j1}, $\mathrm{w}_{\mathrm{j}1}$) … (c_{jk}, w_{jk}) (where k is fuzzy set number). The string encoding is expressed as a gene in the genetic algorithm. The individual's chromosome is composed of a number of such genes. The chromosome length depends on the number of input and output variable number.

Genetic operations include selection, crossover and mutation. The best individual preservation method is adopted for Genetic selection, that is, a number of individuals with the lowest fitness value of the population are copied. A special crossover and mutation method is introduced for real number encoding, that is the max-min-arithmetical crossover method and one-point mutation method. The mutation operation has been achieved to result in a new individual by adding random number e ($-w_{jk} \leq \mathrm{e} \leq w_{jk}$) to the any value ($c_{jk}$, w_{jk}). If the mutation operation aims at the position of the membership function. After the mutation, the C must be reordered to ensure that the membership function is ordered on the domain by this value. According to the mutation rate, many gene (c, w) of the same chromosome may be selected.

The calculation formula of the optimal algorithm index is as follows

$$J = \int_0^\infty \Big(\omega_1 |\Delta f(t)| + \omega_2 u^2(t)\Big) dt + \omega_3 t_u \tag{1}$$

where $\Delta f(t)$ is for microgrid frequency error, $u(t)$ is the controller output, t_u is rise time, ω is weights, and $\omega_1 + \omega_2 + \omega_3 = 1$. The smaller J value is, the better performance of the system is. In the Genetic algorithm, the bigger individual fitness value is, the better chromosome is. The fitness function is defined as follows.

$$F(x) = \frac{1}{1 + \alpha J} \tag{2}$$

where α is sensitive parameter. The J value of range [0, $+\infty$] is transformed into $F(x)$ value of range [0, 1] by the formula, meanwhile genetic optimization is transformed into solving the problem of the maximum fitness value in the range [0, 1] (Fig. 4).

The wheel game is used as selection method, and the crossover probability P_c is set to 0.6, and the mutation probability P_m is set to 0.01, and the initial population is set to 50, and the largest evolutionary G is set to 100 as the termination condition.

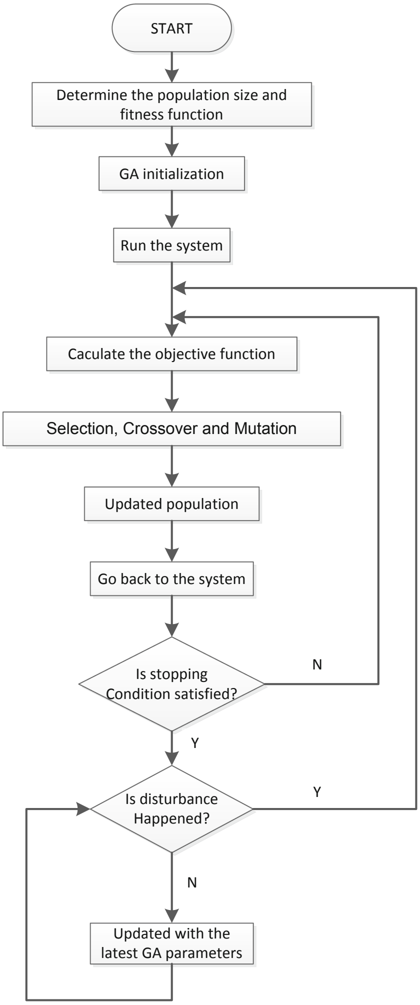

Fig. 4. Flowchat of GA-Fuzzy PI control

5 Simulation Analysis

In order to compare the performance of the traditional PI, the classical fuzzy PI and GA-Fuzzy PI controller, the three control schemes are modeled and simulated using MATLAB programming. The Fig. 5 shows the dynamic response of the microgrid frequency control when multiple step disturbance is inputted three controller respectively. From Fig. 5, the performance index of the GA-Fuzzy PI controller is superior to the classical fuzzy PI controller and the conventional PI controller.

Figure 5 shows that the proposed GA-Fuzzy PI control method has better performance, and the new control algorithm quickly eliminates the frequency deviation before the secondary load step disturbance starts. For more severe disturbances, such as 0.084 pu

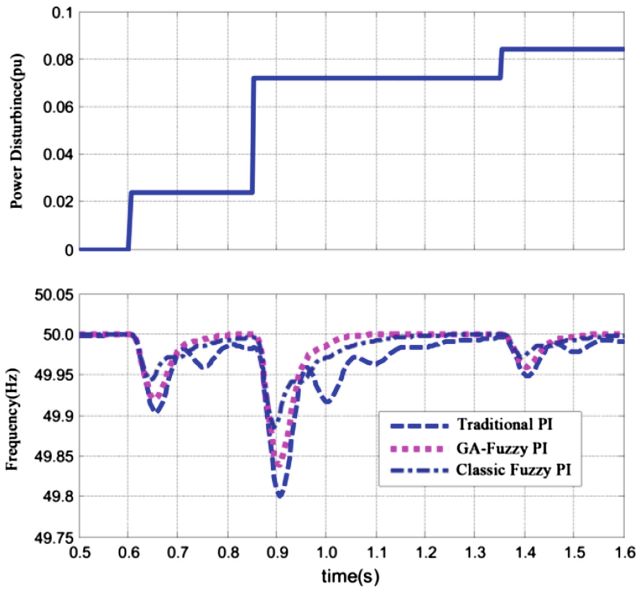

Fig. 5. Multiple step disturbance response

perturbance amplitude, the performance of GA-Fuzzy PI controller is better than the fuzzy PI and the traditional PI controller.

In practical application, the characteristics parameter of the new energy generation device can be affected and changed randomly by nature condition. The performance of the closed-loop control system is greatly reduced. The main advantage of the intelligent control method is that it can resist the disturbance.

When the characteristics parameter of the microsource is changed, the control performance of the system is shown in Figs. 6 and 7, the GA-Fuzzy PI controller has good adaptive performance. when the parameters are reduced 30% in the Fig. 6 (the turbine time constant T_g is set to 0.063, the generator time constant T_t is set to 0.35, and the time constant T_B of the energy storage battery is set to 0.105), the conventional PI controller is unable to adapt to the parameter perturbation. In the Fig. 7, when the parameters are increased 30% (the turbine time constant T_g is set to 0.117, the generator time constant T_t is set to 0.65, and the time constant T_B of the energy storage battery is set to 0.195), the GA-Fuzzy PI controller has more advantages than the other two controllers.

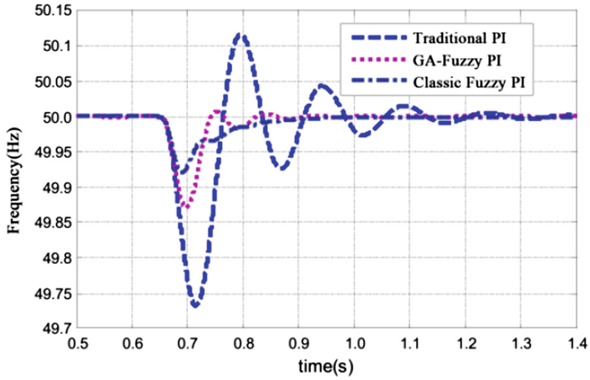

Fig. 6. Multiple step disturbance response

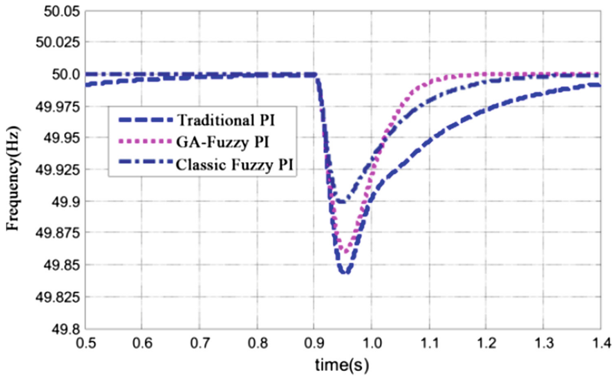

Fig. 7. Multiple step disturbance response

6 Conclusions

For AC microgrid island operation, the grid frequency is supported by the microsouce in the microgrid, the microgrid frequency control is more important, especially in the face of large disturbances, uncertainties and load changes. Traditional frequency control method is difficult to meet the required performance index. A new adaptive intelligent control method is proposed for the microgrid. Fuzzy membership function parameters are optimized by genetic algorithm. It has better effect than the classical fuzzy PI frequency controller. Based on GA-Fuzzy PI control method applied to the microgrid, the simulation result shows good response characteristics, and has fast response and small overshoot. Especially when the microsource parameters are changed largely, the controller still has strong robustness.

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