Tracking Error Fitness Function V/F Control of Micro-Grid Based on Genetic Algorithm

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Abstract. This paper presents a method of V/f control parameters tuning for micro-grid based on genetic algorithm. Firstly, the fitness function which representing the tracking error of V/f control system in micro-grid is established. The solving path of genetic algorithm is optimized by using the offset threshold condition between the output voltage and the instruction voltage of the load side, leading to that the individuals with high priority will tend to the optimal solution in the target solution, obtaining the global optimal V/f control parameters. Secondly, the frequency domain response characteristics of equivalent output impedance of V/f control system are analyzed, and the influence of PI parameters on the whole control system is compared. The results shows that the V/f control parameters tuning based on genetic algorithm with the tracking error fitness function can effectively guarantee a constant output of micro-grid’s voltage and frequency. The effectiveness and the advantages of the method is verified by simulation result, which indicated that the proposed method is easy to implement and has a wide range of applications.

1. Introduction
Electricity, the pillar of national energy and economic lifeline, is particularly important in the rapid development of society. At present, power production mainly relies on non-renewable energy. Correspondingly, power distribution mainly relies on high-voltage long-distance transmission. However, the drawbacks of this mode appear as time goes by, which will not only waste a lot of electric energy, but also lead to resource exhaustion and environmental pollution [1]. By contrast, distributed generation has the advantages of in-situ power output, in-situ consumption, with no need for high-voltage transmission system, which can utilize clean secondary energy such as solar energy, wind energy and so on. Nevertheless, if the distributed power supply is connected to the power grid, it will bring a series of impacts on the distribution network, even impacting the public power grid and causing regional paralysis [2]. Therefore, it is of great significance to study the control method of micro-grid with distributed generation. At present, the control object of micro-grid mainly focuses on inverters, and the control strategies mainly include PQ method, V/f method and Droop method [3]. This paper mainly studies V/f method of micro-grid.

In reference [4], the control strategy of grid-connected inverters based on gain scheduling adaptive is proposed, and the simulation model and experimental platform of three-phase LCL grid-connected inverters are built to explain the feasibility and effectiveness of the adaptive control method. In reference [5], the conditions for maintaining the stable operation of micro-grid and the control strategies of PQ method and V/f method are studied when micro-grid is connected to the grid under
various types of small signal disturbances. In reference [6], the V/f method based on droop characteristics is described comprehensively, and the constant voltage-frequency is achieved when the micro-grid operates on islands. In reference [7], under the effect of master-slave control of inverters, V/f method and PQ method are used to realize seamless switching of DGS, and synchronous phase-locked technology is introduced to prevent oscillation caused by sudden change of phase angle. In reference [8], the pole assignment method based on the transfer function of the control system is used to design the parameters of the micro-grid's PQ method and V/f method models respectively. Finally, the accuracy of the parameters is verified by simulation.

Whether PQ method, V/f method or Droop method are realized by PI regulation, so it is very important to set the parameters of PI regulator accurately. In classical control theory, the methods commonly used in double-loop control system in synchronous coordinate system are classical system tuning method and closed-loop pole placement method. The above methods are based on the transfer function of the double-loop method system. Although the stability of the control can be ensured, the influence of the closed-loop zeros on the response of the control system is neglected. Therefore, necessary adjustments should be made according to the actual dynamic characteristics of the system to meet the requirements of the control performance index [9]. The parameter tuning method of PI controller based on genetic algorithm proposed in this paper does not based on accurate transfer function. It can directly adjust the parameters and realize the stability of the control system.

2. Micro-grid structure
Compared with the general power grid, the structure of micro-grid is more flexible. The internal load of micro-grid is divided into different grades, and different number of distributed generators are equipped according to different load levels. When distributed power generation (DG) operates independently, the voltage and frequency of the whole micro-grid are required to be constant. When DG is connected to the grid, the frequency of the output power voltage should be controlled and maintained in accordance with the large power grid [10]. At present, the output of distributed generation is mostly direct current, which needs to be converted to 50Hz AC power supply or grid-connected through DC/AC inversion. Therefore, power electronics technology, especially inverter technology, plays an unique role in the operation and control of micro-grid [11]. Structure of the general micro-grid shown in figure 1.

![Figure 1. Structure of the typical micro-grid.](image)

3. Design of V/f control method based on genetic algorithm for micro-grid

3.1. V/f control principle of micro-grid
Based on the voltage and current double-loop V/f control strategy, the control structure is shown in figure 2. In outer loop, the voltage control needs to collect the voltage \( U \) on load side. \( U_d \) and \( U_q \) are...
obtained via coordinate transformation and get the differences from the given values \( U_{dref} \) and \( U_{qref} \).

The reference values \( I_{dref} \) and \( I_{qref} \) of current inner loop are obtained by PI compensation. \( i_d \) and \( i_q \) are obtained by collecting the filter inductance current, which are inferior to \( I_{dref} \) and \( I_{qref} \) respectively by coordinate transformation. Through proportional compensation and feed-forward decoupling, the reference voltage \( u_d^* \) and \( u_q^* \) are obtained. Through coordinate inverse transformation and PWM modulation, the switching signal of the inverter can be achieved, ensuring the constant voltage amplitude and frequency [12].

![Figure 2. V/f control strategy.](image)

Based on Kirchhoff's law, the voltage equation of filter inductance and the differential equation of filter capacitance can be obtained from figure 2.

\[
L \frac{di_d}{dt} = U_{dc} - U_{ld}
\]

(1)

\[
C \frac{dU_{ld}}{dt} = L \left( I_d + I_f \right)
\]

(2)

According to equation (1) and equation (2), a double-loop controller can be designed as shown in figure 3. Among them, the current loop is inner loop, the voltage loop is outer loop, and the current loop is proportional controller. The main purpose of the voltage loop is to maintain the load voltage stability, and the purpose of the current loop is to improve the dynamic response of the system.

![Figure 3. Double loop control of V/f.](image)
The equivalent output impedance equation of the corresponding inverters are as follows:

\[
Z(s) = \frac{Ls^2}{LCs^3 + KK_{\text{pwm}}Cs^2 + (1 + KK_{\text{pwm}}K_{vp})s + KK_{\text{pwm}}K_{vi}}
\]  

(3)

Figure 4. Frequency response, \( K_{vp} = 10 \).

Figure 5. Frequency response, \( K_{vi} = 100 \).

By changing \( K_{vp} \) and \( K_{vi} \), the frequency response curve of equivalent output impedance was observed. When \( K_{vp} = 10 \), the frequency response curves of \( K_{vi} \) at 0.1, 1, 10 and 100 are shown in figure 4. When \( K_{vi} = 100 \), the frequency response curves of \( K_{vp} \) at 0.1, 1, 10 and 100 are shown in figure 5. It can be seen from figure 4 that the output impedance has broader inductance frequency band in consistent with the decreasing of \( K_{vi} \). And it can be seen from figure 5 that the output impedance has broader inductance frequency band in consistent with the increasing of \( K_{vp} \). Because of the fact that the high frequency output impedance resistivity will effectively suppress harmonics, the \( K_{vi} \) and \( K_{vp} \) parameter which have too wide inductive frequency band of output impedance can not be selected.

3.2. Design of genetic algorithm controller

(1). Design of fitness function

Generally, the solution corresponding to the individual in the population is directly taken as a component of the fitness function [13]. However, the genetic algorithm in this paper is not used to find the solution of a certain function, but to find the optimal parameters in V/f controller of micro-grid. Therefore, the selection of fitness function should satisfy the control requirement of micro-grid load side output voltage as close as possible to the command output voltage. The fitness function is designed as follows:

\[
\min f = \frac{1}{2} e^2 = \frac{1}{2} [y(t) - y(t)]^2
\]

(4)

In (4), \( y(t) \) is three-phase symmetrical voltage \( u = 311\sin(100\pi) \) V; \( y(t) \) is load side output voltage; \( e \) represents tracking error, and the control effect is mainly indicated by the value of \( e \).

(2). Parametric optimization principle of V/f controller based on genetic algorithm
The V/f control principle based on genetic algorithm is shown in figure 6.

![Diagram showing V/f control structure based on genetic algorithm](image)

**Figure 6.** V/f control structure based on genetic algorithm.

According to figure 2, the V/f control simulation model of micro-grid is built, and the PI parameters of current loop are introduced into genetic algorithm for optimization. The parameters range $K_p$ and $K_i$ of PI regulator are chosen as $[0,100]$. The simulation time of each iteration is 1.5s. The operation parameters of the genetic algorithm are determined as follows: the initial population size is 300, the number of iterations is 9, the crossover probability is 0.4, and the mutation probability is 0.04. According to solution of genetic algorithm, the global optimal solution to ensure the stability of V/f controller is $K_p = 15.9574$ and $K_i = 98.291$. The results are consistent with the previous analysis of equivalent output impedance curve in frequency domain.

4. Simulation

Combining with V/f control structure figure 2, Simulation are carried out for islanding operation of micro-grid. The parameters of control system are set as follows: DC input $U_{dc} = 650V$, $r = 0.01 \Omega$, filter capacitance and inductance $C = 200 \mu F$, $L = 2 mH$, $K = 1$, respectively. The total simulation time is set to 1.5s. Initially, the load power is $P = 100kW$, $Q = 0$, the load is cut into 60KW at 0.5s and the load is cut out 60KW at 1s. At this time, the inverters are controlled by V/f method. The voltage, current and frequency of the load side are shown in figure 7.

![Simulation results](image)

(a). Simulation result of voltage.

(b). Simulation result of current.

(c). Simulation result of frequency.

(d). Simulation result of power.

**Figure 7.** Simulation results of V/f control.
As shown in figure 7, the V/f control of the inverters can ensure that the phase voltage at the load side of the micro-grid is maintained at 311V and the frequency is maintained at 50Hz. At 0.5s, the load side current and frequency both have abrupt changes, which are due to the cut-in load. When the load is cut out at 1s, the load side current and power are back to the initial value. The above results prove the validity of V/f control and the feasibility of applying genetic algorithm to PI parameter adjustment.

5. Conclusion
In this paper, the V/f control of micro-grid under islanded operation mode is established, and the PI parameters of current loop are optimized by genetic algorithm. Based on the established fitness function representing tracking error, the PI parameters are solved by using the threshold condition between the output voltage and the instruction voltage of the load side. The global optimal PI parameters obtained by genetic algorithm are applied to the V/f control simulation model. The simulation results show that the method is effective. At the same time, the optimal value of V/f control parameters is also consistent with the analysis results of frequency domain response characteristics of equivalent output impedance, which can effectively suppress harmonics and improve control accuracy.

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