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Active and Frequency Control Strategy of Improved Droop Control in Islanded Micro-grid

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***Abstract*—The traditional droop control will reduce the frequency of the system, and will seriously affect the power quality in an independent micro-grid consisting of a variety of distributed power sources. However, if the frequency recovery time is too long, the frequency does not return to the power frequency and will drop seriously and deviate from the rated value when the next load disturbance occurs. In order to solve these problems, this paper proposes a fuzzy PI active and frequency control strategy based on the traditional droop control. The degree of frequency offset is taken as the reference amount, and its control parameters are dynamically adjusted to quickly restore the frequency to the stable value. In addition, the first function term of the power and droop coefficient is established to replace the fixed droop coefficient to prevent the frequency from crossing the boundary. Finally, the effectiveness of the proposed strategy is verified by Matlab/Simulink simulation. The improved control strategy can make the system frequency stable in power frequency and improve the dynamic performance of the system.**

Key words—microgrid; active and frequency; frequency deviation; fuzzy PI control;

I. INTRODUCTION

After several years of development, it has been able to achieve "plug and play" of distributed power through microgrid, while maximizing the use of renewable energy and clean energy [1-2]. In the case of isolated islands, the frequency support of the large power grid has been lost. How to ensure the frequency stability of multiple inverters in parallel has become a research hotspot. In this regard, Liang Haifeng et al [3] introduced the "anti-S" droop control strategy of "replace the line with a curve" to effectively solve the problem of frequency crossing. However, the method is complicated and does not give a method of frequency recovery; Li Yanqing et al [4] achieve frequency recovery in island operation by adjusting the value of power P_0 corresponding to the nominal frequency w_0 in the droop curve. However, this method does not discuss in detail the specific value of the scale factor K that affects the frequency adjustment speed, which is crucial for the dynamic performance of the system. In order to solve the problem of active frequency control of traditional droop control in island microgrid, this paper proposes improved droop control, introduces fuzzy PI control to adjust the frequency recovery speed, and establishes a function term of power and droop coefficient to prevent frequency from crossing the boundary [5-6], better guarantee the quality of power. The rationality of this strategy is verified by simulation experiments, which can effectively make the system work at the power frequency and improve the stability of the system.

II. TRADITIONAL DROOP CONTROL

In the micro-grid operated by the isolated island, multiple distributed generation (DG) are connected in parallel to supply power to the load system. Each DG is converted into three-phase alternating current with voltage source inverter as interface, and is connected to the common bus through the transmission line after high-order harmonics are eliminated by low-pass filter.

The traditional droop control mainly controls the inverter by simulating the primary frequency drooping characteristic of the traditional generator [7]. The principle is to adjust the output frequency and voltage of each inverter according to the active and reactive power output by each DG. The droop equation can be expressed as:

$$\omega_i = \omega_0 - m_i P_i \tag{1}$$

$$U_i = U_0 - n_i Q_i \tag{2}$$

Where, U_0 and ω_0 are the output voltage amplitude and frequency of DG unit respectively; U and ω are rated amplitude and frequency ratings of output voltage of DG unit respectively; Q_i and P_i are respectively reactive power with active power output. The letters m and n are the droop coefficients of frequency and voltage amplitude of microgrid respectively.

The conventional droop structure obtained by the above two equations is shown in Fig. 1. The instantaneous voltage u_0 and the instantaneous current i_0 are the output of the DG unit, and then the average power is obtained after passing through the power calculation module. The voltage U and the frequency ω obtained by the droop control serve as reference inputs for the inverter voltage and current double loop. Therefore, appropriate frequency and voltage offset can be obtained through droop characteristics, and the primary control can respond quickly so that the system output and load changes can always be balanced.

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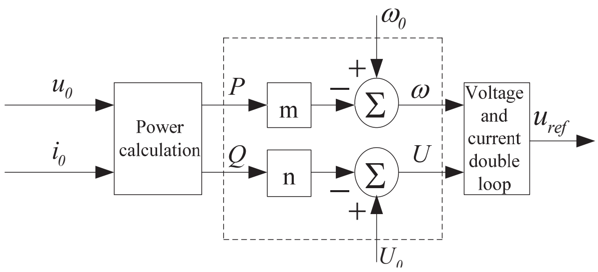

Fig.1 Structure of conventional droop control

Fig. 2 and Fig. 3 are *P-f* and *Q-U* droop characteristic curves. When the above traditional droop control method is adopted, it is assumed that the reactive power output by the inverter at t_1 is Q_1, and when the droop coefficient is n_1, the corresponding voltage amplitude is U_1.At time t_2, the reactive power output by the inverter becomes Q_2 due to the change of load's reactive power. Since the sag coefficient n_1 is fixed, the output voltage amplitude of the inverter becomes U_2, which deviates from the set value of the output voltage amplitude of the inverter. Similarly, when the output active power fluctuates, it will also cause the fluctuation of the output frequency. If the fluctuation is large, it will cause the unstable operation of the micro grid.

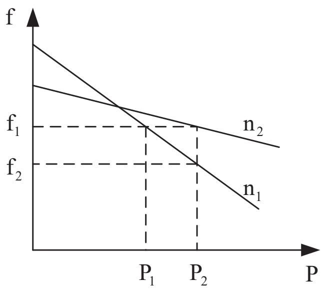

Fig.2 *P-f* droop characteristic curve

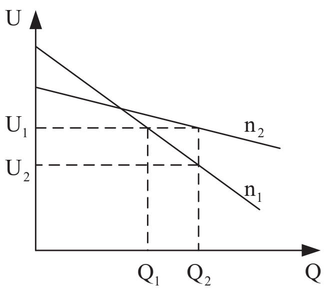

Fig.3 *Q-U* droop characteristic curve

A large number of simulation studies have proved the effectiveness of active frequency control [8-9], but with the deepening of research, the drawbacks of active frequency control are gradually revealed:

1) The increase of the active load in the microgrid will cause the frequency offset. If the load disturbance occurs and the frequency has not recovered to the power frequency, the frequency offset will be deepened, which greatly affects the power quality.

2) The microgrid frequency is a global variable. If a large load occurs, the frequency may cross the boundary when switching, which affects the safe operation of the entire system.

III. DYNAMIC RECOVERY OF FREQUENCY

Fuzzy control simulates people's thinking, reasoning and judgment, which can avoid the specific mathematical model of the controlled object and overcome the influence of the system nonlinear factors. PI controller is simple and accurate, and its integral adjustment can theoretically make the steady-state error of the system zero. The combination of fuzzy control and PI control not only has the advantages of strong adaptability and high flexibility of fuzzy control, but also has the characteristics of high precision of PI control [12]. In the microgrid, the PI controller can stabilize the system at the power frequency due to the frequency shift caused by the increase of the active load. Therefore, this paper adopts fuzzy control to adjust the corresponding parameters to achieve the purpose of stabilizing the voltage amplitude and frequency. The improved frequency droop control equation added the PI regulator can be expressed as:

$$f = f_0 - m_i P_i + (k_p + \frac{k_i}{s})(f_0 - f) \tag{3}$$

$$f = f_0 - \frac{m_i}{1 + k_p + \frac{k_i}{s}} P_i \tag{4}$$

It can be concluded that although the PI regulator can restore the frequency to the power frequency, the unreasonable parameters will cause the droop coefficient to become smaller, and the dynamic performance of the system will be affected. In the face of load disturbance, the fixed PI regulator coefficient will not only affect the recovery speed of the frequency, but also affect the sagging coefficient of the system and even affect the dynamic performance of the system.

The most important thing about fuzzy control is to reflect people's experience and people's common sense inference rules. The algorithm can adjust the controlled parameter system according to fuzzy reasoning without knowing the precise mathematical model of the controlled object to achieve the desired effect [10-11]. In this paper, the fuzzy PI controller is used to adjust the parameter K_p, K_i of the controller by fuzzy control.

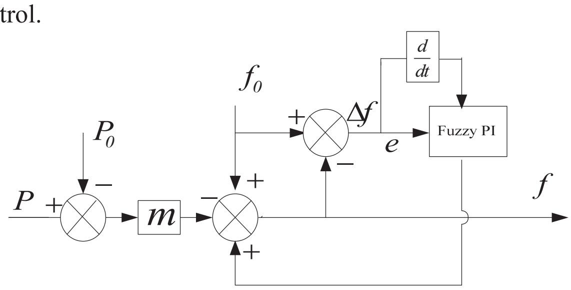

Fig.4 Improved active frequency control

As shown in Fig. 4, this paper selects the two-dimensional fuzzy controller. The frequency error signal *e* and differential error signal *ec* are taken as input, and the parameter changes obtained by fuzzy algorithm and fuzzy rule table are taken as output[12]. In order to facilitate control, the basic theoretical fields of input and output of *d* axis and *q* axis are set as [-6,6]. The quantization factor and scale factor input in d axis e were 0.018 and 0.5, respectively; the quantification factor and scale factor input in *ec* were 2.4×10^{-8} and 1, respectively. The quantization factor and scale factor of *q* axis *e* input were 0.03 and 0.5, respectively, and the quantification factor and scale factor of *ec* input were 7.5 × 10-10 and 1, respectively. After quantization and scale factor quantization, both fall within the range of fuzzy set {-6, -4, -2, 0, 2, 4, 6} [13]. The set of corresponding language variables is {NB, NM, NS, ZO, PS, PM, PB}[14]. Fig. 5 shows the triangle membership function curve of input and output.

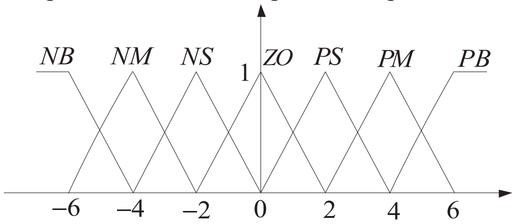

Fig.5 Membership function of fuzzy controller

Fuzzy rules are the premise of fuzzy reasoning. The rationality of fuzzy rules is directly related to the performance of the controller. According to engineering technicians and practical control experience, The fuzzy control rules of proportional coefficient and integral coefficient formulated in this paper are shown in table I and table II, and the fuzzy control rules of "if e and *ec* then *Kp* and if *e* and *ec* then *Ki*" are adopted. Mamdani fuzzy reasoning method is adopted to obtain the fuzzy value of the output variable through the input variable fuzzy reasoning. Through Centroid method, the fuzzy value can be obtained to obtain the accurate number.

TABLE I
THE FUZZY RULE TABLE OF KI

ec	*e*						
	NB	*NM*	*NS*	*ZO*	*PS*	*PM*	*PM*
NB	*PB*	*PB*	*PM*	*PM*	*PS*	*ZO*	*ZO*
NM	*PB*	*PB*	*PM*	*PM*	*PS*	*ZO*	*ZO*
NS	*PM*	*PM*	*PM*	*PS*	*ZO*	*NS*	*NS*
ZO	*PM*	*PM*	*PS*	*ZO*	*NS*	*NM*	*NM*
PS	*PS*	*PS*	*ZO*	*NS*	*NS*	*NM*	*NM*
PM	*ZO*	*ZO*	*NS*	*NM*	*NM*	*NB*	*NB*
PB	*ZO*	*ZO*	*NS*	*NM*	*NM*	*NB*	*NB*

TABLE II
THE FUZZY RULE TABLE OF KP

ec	*e*						
	NB	*NM*	*NS*	*ZO*	*PS*	*PM*	*PM*
NB	*NB*	*NB*	*NB*	*NB*	*NM*	*NS*	*ZO*
NM	*NB*	*NB*	*NB*	*PM*	*NS*	*ZO*	*PS*
NS	*NB*	*NB*	*NM*	*NS*	*ZO*	*PS*	*PM*
ZO	*NB*	*NM*	*NS*	*ZO*	*PS*	*PM*	*PB*
PS	*NM*	*NS*	*ZO*	*PS*	*PM*	*PB*	*PB*
PM	*NS*	*ZO*	*PS*	*PM*	*PB*	*PB*	*PB*
PB	*ZO*	*PS*	*PM*	*PB*	*PB*	*PB*	*PB*

IV. CONTROL STRATEGY TO PREVENT FREQUENCY FROM CROSSING THE BOUNDARY

In the island mode, if the switching is performed under a large load, since the coefficient *m* of the droop control is fixed, the frequency is likely to cross the boundary. In the microgrid safe operation standard, the fluctuation of the frequency value should be between 49.5Hz and 50.5Hz. In the "anti-S" type droop control, the parameters are not easy to set, and the calculation process is cumbersome. Therefore, this paper adds a primary function term related to active power to replace the fixed droop coefficient in the traditional droop control equation [15]. This method is relatively easy to implement and the parameters are easy to set. Due to the role of frequency recovery control, its expression is as follows:

$$f = f_0 - m(P - P_0), P_0 \le P \le P_1 \tag{5}$$

$$f = f_0 - [m - m_1(P - P_1)](P - P_1), P_1 \le P \le P_{\max} \tag{6}$$

When the frequency is small, the power adjustment follows the linear droop characteristic when the power is at P_0 and P_1. When the load is cut at a large load, the proposed method can adaptively change the droop coefficient, and can effectively prevent the frequency from crossing the boundary compared with the conventional droop characteristic and destabilizes the system. The active droop curve when m1 takes different values is shown in Fig. 6. In order to ensure that the system has certain droop characteristics in the operating range, m-$m_1(P$-$P_1)>0$ must be satisfied, so m_1 is between $0.3m/P_1$ and $0.6m/P_1$. In order to better suppress the drop of the frequency, $0.6m/P_1$ is selected as the value of m_1.

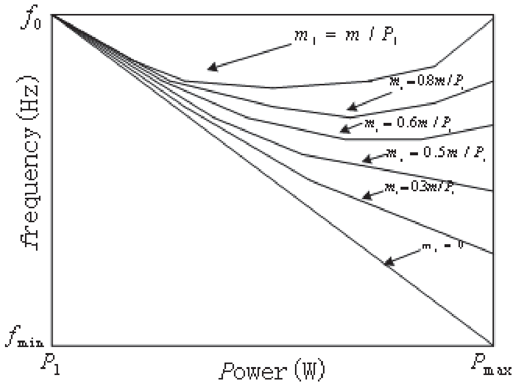

Fig. 6 Droop curves with different value of m1

V. SIMULATION

In order to verify the effectiveness of the above strategy, the MATLAB/Simulink simulation software was used to construct the microgrid system as shown in Fig. 7. The main simulation coefficients are shown in table III. The simulation model adopts the parallel system of two generators, it is assumed that the two inverters have the same capacity. In 0~0.2s, the active load of the two inverters is 10kW. At this time, the active power is evenly distributed and both frequency and voltage can be stabilized. After 0.2s, the switch S1 was closed and input load 1 was put into use. and after another 0.2s, the switch S2 was closed and input load 2 was put into use. Fig. 8 is the active power output value of each micro-source.

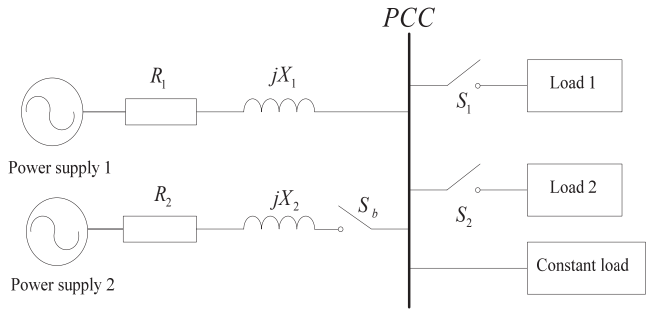

Fig.7 Model of microgrid in island model

TABLE III
SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
U_{dc} (V)	800	m	1×10^{-4}
f_0 (Hz)	50	n	2×10^{-4}
f_s (kHz)	10	R_{line} (Ω)	0.642
L_f (mH)	4×10^{-3}	L_{line} (mH)	2.64×10^{-4}
C_f (μF)	1500	P_{ref}	5×10^{3}
R_f (Ω)	0.1	Q_{ref}	5×10^{2}
k_{vp}	10	k_{fp}	0.4
k_{vi}	100	k_{fi}	10
k_{ip}	5	P_1 (kW)	5
k_{iv}	20	P_2 (kW)	20

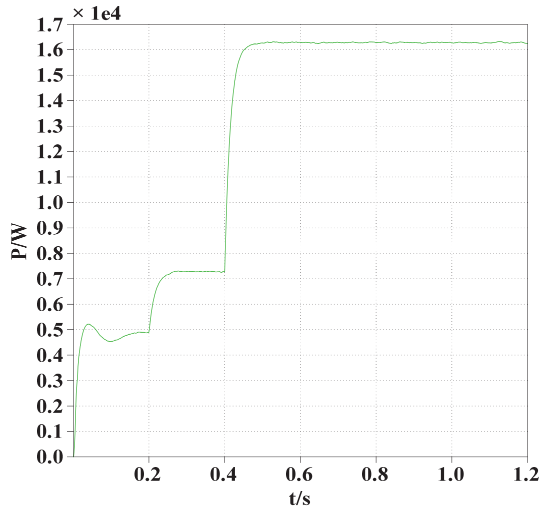

Fig.8 The active power value of the micro source

Fig. 9 shows the system frequency values for conventional droop control. As can be seen from the figure, the switching of the load 1 and the increase of the active power of the system cause the system frequency value to decrease. At 0.4s, the heavy load is cut, the frequency drop is very obvious, and obviously exceeds the safe operation standard of the microgrid. It can be seen from the above that the traditional control strategy does not have a frequency recovery system, and it cannot meet the requirements under the condition of heavy load switching.

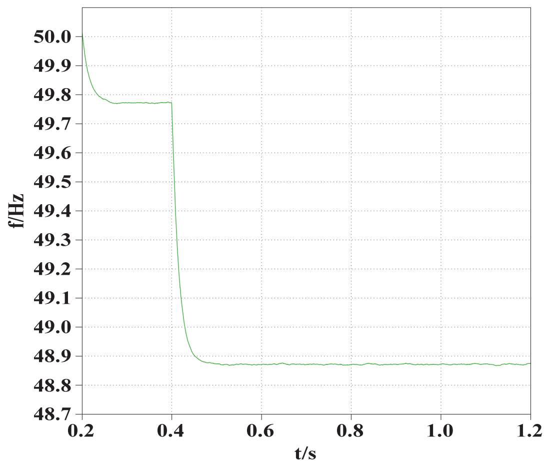

Fig.9 The frequency of the traditional droop control

Fig. 10 is a simulation result of the fuzzy PI regulator proposed herein. From 0.2s to 0.4s, the frequency did not stabilize at the decreasing value, but gradually recovered to the power frequency within 0.1 seconds. At 0.4s, the load is cut and the frequency drops sharply. Compared with the traditional control strategy, since the frequency is dropped from the recovery point, the drop value is not conventionally low, but it is still beyond 49.5 Hz. And the recovery rate is faster. The advantages of this control strategy over traditional droop control are verified.

Fig. 11 is a simulation result of adding a primary function term related to active power to replace the fixed droop coefficient after 0.4 s. By using the improved active frequency control strategy proposed in this paper, take frequency skewness as reference, dynamically adjust its control parameters, and quickly restore the frequency to a stable value, the frequency drop can be reduced by dynamically adjusting the frequency drop coefficient of the inverter. After the improvement, the frequency drops to 49.77Hz, which fully meets the safe operation standard of the microgrid. To sum up, the traditional control effect is not good, and the improved fuzzy PI control can not only achieve stability quickly, but also has the advantages of smaller fluctuation range, stronger anti-interference ability, strong robustness and good dynamic performance, so the control effect is relatively ideal.

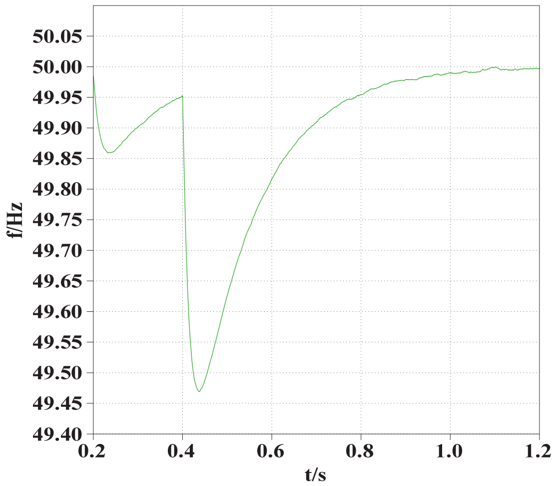

Fig. 10 Frequency recovery of fuzzy PI control

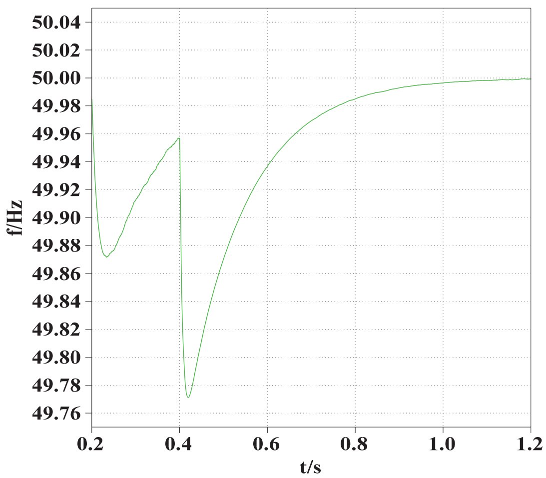

Fig.11 The frequency of the improved droop control

VI. CONCLUSION

In this paper, the improved active frequency control is proposed, and the fuzzy PI control is introduced to adjust the frequency recovery speed, so as to prevent the frequency from crossing the boundary, overcome the problem that the frequency cannot be maintained at the power frequency in the traditional control strategy, and better guarantee the quality of power. The simulation results show that the fuzzy control adjustment can quickly restore the frequency to the power frequency, the frequency range is small, avoiding the serious frequency drop when the load is disturbed. A one-time function term is added to replace the fixed droop coefficient, which avoids the frequency crossing of the boundary during large load disturbance. The simulation results show that the improved active frequency control strategy can meet the microgrid safe operation standard and prove the feasibility and effectiveness of the proposed control strategy.

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